Fall 12-2017

Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults

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Recommended Citation

Torre, Dennis, "Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults" (2017). *Seton Hall University Dissertations and Theses (ETDs)*. 2445.
https://scholarship.shu.edu/dissertations/2445

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Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Health Sciences
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ACKNOWLEDGEMENTS

There are so many individuals both on a personal & professional level who have contributed in various ways to the emergence of this document, and for upon whom I ask Almighty God’s blessings: my beloved-departed Mom & Dad, Jennie & Anthony Torre, for their countless sacrifices which can never be repaid; Dr Genevieve Zipp, committee chairperson, for her inspiring mentorship, steadfast-of-purpose to keep me focused & great gift of wisdom; Dr Raju Parasher who conceived the study’s original theme & Dr Preeti Nair, both committee members, for their depth of knowledge, sound critical scholarship, & collaboration despite different time-zones; Dr Wendiann Sethi for her invaluable statistical counsel; my brother Charles Torre, PE for engineering & building the “PhD Box” to control switch-mats & signal-lights; Dr Terrence Cahill, Dr Lee Cabell, Dr Deborah DeLuca & Ms Joanne DeBerto for partaking & aiding in my scholarly formation; my research assistants Mr Kweku Agyeman, Dr Gerard Fiordalisi, & Mr Anthony Porcelli for their logistical & essential support; my dear girlfriend Sonia Rivera, sisters Mary Jane Catalanotti & Fran Torone, & late brothers Anthony & Frank Torre for their love, comfort & prayers; all the dedicated Sisters, Priests, & Brothers who instilled in me a passion for learning & faith at an early-age; and all the considerate study participants who gave of their valuable time & effort.

DEDICATION

All to the Glory of God the Father, God the Son, and God the Holy Spirit

Amen.

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ABSTRACT

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Hip fractures can be life-threatening, debilitating, and costly. The odds for hip fracture increases from impact of sideways falls. While turning has been strongly associated with hip fracture & sideways falls, the distinction between the risks for walking-turns as opposed to low-velocity in-place turning is not clear. The present study sought to fill a gap as previous research had not compared walking-turn performance in young & healthy older adults at low-fall risk within the same study and response-conditions of speed interacting with direction-cue time constraints. Spatial-temporal variables representative of AP braking/propulsion (i.e. stride-length & speed) & ML stability (left/right H-H BOS) were collected with the Gaitrite upon approach of a turning zone whose entrance width was just 73 cm; and turn-strategy categorical data for stable wide-BOS step-turns, biomechanically challenging narrow-BOS spin-turns, and combined subtypes of mixed-turns either of the “extra-step” variety representative of an AP stability/braking issue or “small-amplitude” variety representative of a ML stability/balance issue were captured on video. Mixed-ANOVA of gait measures for AP propulsion/braking revealed no age-group differences in speed despite a trend for less of a fast-pace increase in elderly stride-length, yet similar anticipatory slowing and shorter strides approaching

turns. Measures of ML stability revealed similar anticipatory widening of right BOS approaching turns, and a three-way interaction showed both had similar anticipatory narrowing of left BOS when approaching turns at fast-pace and similar reactive narrowing of left BOS following an unexpected turn-cue at preferred pace. Loglinear analysis of turn-strategies revealed no age-related associations as both preferred mixed-turns the least. At fast speeds preference for spin-turns decreased, yet when late-cued preference for both step-turns and spin-turns decreased 5.5-fold & 4.0-fold, respectively, indicating other factors besides biomechanical. Furthermore, the standardized residual reached significance for the elderly mixed-turns cell at the most constrained fast-speed*late-cue response-condition, with the “extra-step” sub-type contributing greatest possibly implying an AP rather than ML stability issue. The findings suggest that when approaching turns across an interaction of response-time conditions, healthy older adults show similar anticipatory/reactive gait adaptations and turn-strategy preferences with regards to AP propulsion/deceleration and ML stability/balance. In conclusion, within study limits, fall-prevention gait-training for healthy elderly with low-fall-risk and no age-related speed declines, in addition to addressing important ML stability issues of turn execution, are best served by not losing sight of the fundamental prerequisite to arrest forward momentum upon approach, and being inclusive of spin-turns for their ML space-efficiency.

Chapter I

INTRODUCTION

Relationship between Elderly Falls, Hurrying, Turns and Hip Fracture

The annual fall incidence in those 65 years and older is believed to be between 28-35% (Tinetti, Speechley and Ginter, 1988; Masud and Morris, 2001). Relative to young adults, same-level falls (i.e. slips, trips, transfers, etc.) in the elderly result in more frequent serious injury, with death 10 times more prevalent (Sterling, O’Connor and Bonadies, 2001). In 2000, for those 65 years and older, 10,300 fatal falls occurred at an estimated annual cost of $0.2 billion dollars, while 2.6 million non-fatal falls cost $19 billion with injuries to the lower extremities accounting for nearly 48% of the direct medical expenses (Stevens, Corso, Finkelstein and Miller, 2006). Fall-related injury of elderly community dwellers is among the twenty most costly medical conditions in the United States and highlights the necessity for research directed at minimizing its occurrence (Carroll, Slattium, and Cox, 2005).

While the percentage of elderly falls that result in hip fracture has been reported to be only between1- 2% (Berg, Alessio, Mills, and Tong, 1997; Tinetti, Speechley and Ginter, 1988; Masud and Morris, 2001), hip fracture alone has been estimated to account for 4.4% of the annual fall-injury-related medical expenditure (Carroll, Slattium, and Cox, 2005), and 52% of the total first-year fracture costs (Shi, Foley, Lenhart, and Badmgarav, 2009). Moreover, in elderly individuals suffering hip fracture, the mortality-rate at six-months is 11-23%, and after one-year 22-29% (Marottoli, Berkman, Leo-Summers, and Cooney,1994; Haleem, Lutchman, Mayahi, Grice, and Parker ,2008); while in survivors who were previously independent, the institutionalization rate at six-months is 23% (Marottoli, Berkman, Leo-Summers, and Cooney,1994) and only 45% are able to walk 1 block on their own following one year post-fracture (Magaziner, Hawkes, Hebel, Zimmerman, Fox, Dolan, Felsenthal, and Kenzora, 2000).

A primary reason attributed to falls in the elderly is too much hurrying. Berg, Alessio, Mills, and Tong (1997) performed a one year prospective accidental fall survey on independent walking elderly community-dwelling volunteers (n=96, mean age 71.9, range 60-88 years, all residing in Ohio, USA) using bi-weekly report cards and follow-up fall event phone calls. Berg et al noted that 52% of the elderly subjects (n=50) reported a fall over the one year period which resulted in a total of 91 falls. When asked to choose as many causes as were relevant, from a list of 16 potential reasons for why a fall took place, the most common reason selected was excessive hurrying at 31%. Rounding out the top-five reasons cited for falling, beginning with the second, was not-watching where one was going at 21%, followed by slipping on a slick surface or rug at 19%; tripping over an object such as a curb or cord also at 19%; and directing ones gaze ahead rather than at the ground where stepping 14%. It is worth noting that while not in the top-five, Berg et al. reported the sixth most frequent reason surrounding a fall was tripping-over-ones-own-feet/for-no-apparent-reason at 10%.

Similar to the way excessive hurrying is the most common reason cited for a fall, a sideways fall-direction is believed to make turning the primary activity linked with hip fracture. Nevitt and Cummings (1993) performed a prospective study on 9,704 women who were at least 65 years of age. Over the course of a 4.1 year follow-up period between1986-1990, 130 hip fractures were self-reported (non-proxy) in a fall history questionnaire. Based upon interviews within three months of the most recent fall, Nevitt and Cummings (1993) found that 18% of the subjects who suffered a hip fracture reported a turning-around or back-up activity at the time of their fall, second only to forward walking at 40%. However, although a higher percentage of hip fractures occurred during the activity of forward walking, the primary direction of fall in those who fractured their hip was sideways onto the hip/buttock or leg at 56%, with much lower percentages reported for falls in either the forward or backward directions at 14% and 17%, respectively. Nevitt and Cummings (1993) calculated that relative to falling without suffering a hip fracture, when falling sideways or straight down the odds-ratio of fracturing the hip was 3.3 times greater. It is worth noting that Nevitt and Cummings (1993) found no relationship between a 1 SD reduction in walking speed of 1SD and hip fracture [mean gait speed 1.1 (-0.23) m/s)].

In a related study examining fall-directionality and non-linear gait, Cumming and Klineberg (1994) performed a case-controlled investigation of the fall characteristics associated with hip fracture. Data was collected using an interviewer-administered questionnaire of 209 cognitively intact subjects aged 65-100 who had a minimum of one fall over the past three years, of whom 125 subjects suffered hip fracture and 84 did not and served as controls. Cumming and Klineberg (1994) noted that although the highest percentage of hip fractures falls occurred when walking straight at 45%, the highest percentage of non-hip fracture falls likewise happened when walking straight at 35%; however, despite the turning task accounting for a smaller percentage of hip fracture falls at 14%, the percentage of non-hip fracture falls when turning was smaller yet at just 2%. Accordingly, Cumming and Klineberg (1994) calculated that relative to a fall during straight walking, when adjusting for age and gender, the odds of a hip fracture from a fall during turning was 7.9 times greater. Furthermore, even when excluding for Parkinson disease, stroke and other medical conditions, the odds ratio of sustaining a hip fracture from a fall when turning was 5.4 relative to a fall when walking straight**.** In fact, relative to a fall when walking straight in one-direction, falls when turning had the highest odds-ratio and posed the greatest risk for hip fracture than all other activities which were assessed including:

falls when negotiating stairs (3.79), falls when sitting-down (2.50), falls when getting-up (2.22), and falls when bending-over (1.03). Cumming and Klineberg (1994) postulated that non-linear walking makes impact on the side of the hip more likely, and concluded that direction of the fall, especially as it relates to turning, is the primary difference between falls that result in hip fracture and falls which do not.

Age-Related Differences in Turning & Related Behaviors: What is Known?

Elderly Use of partial pivots & extra step mixed-turns during the TUGS

In light of death or serious injury falls being more prevalent in the elderly (Sterling, O’Connor and Bonadies, 2001), and a fall while turning being the most likely activity to result in hip fracture (Cumming and Klineberg, 1994), comparing young v. elderly turn performance across identical conditions within the same study is of interest to researchers. Thigpen, Light, Creel, and Flynn (2000) used video analysis to compare young adults (n=20, mean age 24.3 years) and community dwelling elderly subjects with (n=15, mean 80.1 years) and without (n=15, mean 74.9 years) self-reported turning difficulties as they performed 180^0 turns during the Timed “Up & Go” Test. Thigpen et al. (2000) reported that, relative to young adults, across trials healthy elderly participants less frequently completed the 180^0 turn in 2 steps or less (100% v. 51%); and less frequently used just 2 discreet pivots or less (100% v.

58%), but in 42% of trials displayed a “mixed-strategy” described as a series of steps & small-amplitude pivots ≤ 45^0. As a mixed-strategy was most prevalent in a third group of elderly who reported turning-difficulty, Thigpen et al. suggested use of a mixed strategy may be an early marker of a decline in turn performance.

Elderly preference to step-wide when circumventing

Similar to turning except for the direction change being transient, researchers have compared young [n = 12, 72.5(4.5) years] v. elderly [n = 12, 23.2(1.1) years] performance when avoiding obstacles while walking along a straight path. Hackney & Cinelli (2013) had young and elderly adults choose their own direction when avoiding two (2.45 x 0.17 m) vertical obstacles whose separation distance varied between 0.6-1.8 m. Participants were free to walk either straight between the obstacles or to the right/left in which the minimum clearance was at least 2m on either side. The percentage of stepping strategy preference (i.e. a step-wide strategy which increased the BOS similar to a step-turn v. a step-narrow strategy which decreased the BOS similar to a spin-turn) was included in the assessment of personal space during avoidance. Hackney & Cinelli (2013) reported the elderly showed a greater preference for using a step-wide strategy relative to young adults when choosing to change travel path to bypass the two obstacles instead of continue straight through the aperture between them (step-wide strategy: elderly 81% v. young 63%).

Elderly more proactive adjusting speed, step-length but similar step-width change when response time to turn is not constrained

Besides strategy preferences in terms of number of steps & pivots needed to complete a turn and preference for stepping-wide v. stepping-narrow, researchers have also compared young v. elderly spatial-temporal gait adaptations across the last couple of steps preceding a direction-change when right v. left direction was known in advance. Paquette, Fuller, Adkin and Vallis (2008) used motion analysis to compare anticipatory spatial-temporal gait changes in the three approach steps leading up to preferred speed 40^0 turns in young (n=6, mean age 20.7 years) and community dwelling older adults (n=6, mean 83.5 years). The participants were cued-early for right v. left turn direction prior to the start of each trial with no mention of environmental-spatial-constraints, and were asked to execute the turn by either enlarging the base-of-support (BOS) by stepping- out away from the pivot foot planted contra-lateral to the cued turn direction (i.e. perform a step-turn strategy), or reducing the BOS by crossing-over the pivot foot planted ipsilateral to the cued turn direction (i.e. perform a spin-turn strategy). By controlling the leading foot and starting location, both age-groups performed an equal number of random early-cued step-turns and spin-turns to both the right and left direction. Paquette et al. (2008) found no difference in either step-velocity or step length upon approach when comparing step-turns v. spin-turns in either age group; and not surprisingly across both straight control & turn trials, the elderly walked slower & took shorter steps. However, most important, Paquette et al. (2008) noted that regardless of strategy, across the final three turn approach steps terminating in placement of the ultimate pivot footfall (FF), only the elderly decreased step-velocity (i.e. the step ending in ultimate FF was slower than the previous two approach steps) & only the elderly decreased step-length (i.e. step ending in ultimate FF shorter than the step ending in the ante-penultimate FF). However, with regards to step-width both age-groups showed a similar increase when approaching spin-turns [i.e. the step ending in the penultimate (0.100 m) & ultimate FF (0.120 m) were both wider than the step ending in the antepenultimate FF (0.079 m)], and both age-groups showed a similar decrease when approaching step-turns [i.e. the step ending in the penultimate (0.074 m) & ultimate FF (0.078 m) were both narrower than the step ending in the antepenultimate FF (0.096 m)]. Paquette et al., (2008) suggested these anticipatory approach step-width changes enhanced stability and facilitated center of mass (COM) acceleration by altering the center of pressure (COP)-COM distance. Given only the elderly adapted step-length & step-velocity when cued-early, Paquette e al. (2008) proposed the elderly were more cautious when approaching turns. Relating the findings of Paquette et al (2008) to the present study in which only two H-H BOS measures were taken (one right and one left), changes in the lateral distance between heel markers (i.e. step-width) for the step ending in penultimate FF placement would affect the final H-H BOS measure corresponding to the antepenultimate footfall but not the initial H-H BOS measure corresponding to the ante-antepenultimate FF.

Elderly difficulty with deceleration when response time to turn is constrained

Despite excessive hurrying being attributed the main reason for elderly falls, research employing temporal constraints (i.e. a sudden late direction cue coming to one’s attention) to assess age-related differences within the same study for a turning-task has primarily looked at turn success-rates and associated changes at the biomechanical level, rather than spatial-temporal level of gait. Cao, Ashton-Miller, Schultz, & Alexander (1997) used motion analysis to compare turn-failure rates in young (n=20, mean 21.8 years) and elderly community dwellers (n=20, mean 73.8 years) walking at preferred speed (within 10% of 1.3 m/s) along an 8m long x 1m wide path who were visually cued-late for direction & location for 90^0 turns using available response times ranging between 375-750 ms prior to crossing one-of-eight (4 on right, 4 on left) randomly designated turning gate locations marked by ten poles (five each side) spaced 1 m apart. Turn failure was defined either as the COM passing beyond the cued turning gate which was spatially constrained to a width of 0.8m (although no specific regard to the taking of extra-footfalls), making contact with one of the poles separating adjoining turning gaits, foot placement lateral to the 0.8m wide turning path, or turning at a speed 30% slower than that used when direction & location were both known in advance. [It is worth mentioning the available response time range of 375-750 ms was selected based upon a small pre-test/pilot of the first five study participants (4 young adults and 1 elderly female) all of whom performed 20 trials apiece, in which Cao et al (1997) noted that none were able to successfully turn when the available response time was just 300 ms, but all were able to successfully turn when the available response time was 900 ms. Thus, based upon the 375-750 available response time range used during testing,] Cao et al. (1997) found both age groups had a turn success rate greater than 95% when the response time was 750 ms, but less than 50% when the response time was 350 ms. However, younger subjects had significantly greater success rates at response times between 375-600 ms although no difference was seen at 750 ms. More specifically, the success rate for young verse older subjects was approximately 36 v. 6% at 375 ms, 68 v. 27% at 450 ms, 95 v. 78% at 600 ms & about 99 v. 97% at 750 ms (with no right v. left difference in success rates noted). Additionally, using an average preferred walking speed of 1.3 m/s, Cao et al (1997) calculated that when unexpectedly cued-late to turn, to achieve the same 50% turn-success-rate, older adults required both a longer response time (523 v. 408 ms) and distance (68 v. 53 cm) prior to reaching the turn gate. Moreover, across all subjects & late-cue conditions, of the 3,300 attempted trials, failure was scored in 1,174 trials (about 36%), and of these turning failures, 99% were attributed to an inability to arrest the forward momentum of the COM within the available response time. Cao et al (1997) concluded that turning is a time-critical task, and elderly subjects have diminished performance capability.

In a second study by the same authors, whose purpose was to biomechanically quantify what may have contributed to the prolonged elderly response time & distance, Cao, Schultz, Ashton-Miller, and Alexander (1998) used motion analysis to assess forward momentum changes in young (n=40, mean 21.8 years) and elderly (n=40, mean 73.8) healthy adults who were visually late-cued for direction at the point in the gait cycle where the cyclical forward velocity pattern was close to its minimum and set to increase (i.e. late-cued at right mid-stance/left mid-swing) to either turn right or left, 375, 450 or 600 ms prior to reaching a virtual wall while walking at a comfortable pace. Cao et al. (1998) found that after being cued-late to turn, older adults took longer to reach peak forward velocity (elderly 241 v. young 198 ms; note: time to peak velocity for control-no-cue trials was approx. 300 ms); had greater average forward acceleration during post-late cue stance foot push-off (elderly 1.11 v. young 0.83 m/s^2; note: average forward acceleration during push-off for control-no-cue trials was approx. 1.3 m/ s^2); and required a longer total distance to arrest forward momentum (706 v. 593 mm). Moreover, Cao et al. (1998) calculated that the total needed response time to arrest forward momentum was 84.5 ms greater in older subjects, with time to peak velocity being the greatest contributor to the age related increase in the required response time. Cao et al (1998) noted that a delay in reaching peak velocity permitted a further build-up of forward momentum which would eventually have to be arrested (“braked”) when turning. Although not directly assessed, Cao et al. (1998) suggested the possibility of a prolonged calf muscle contraction process, less rapid development of ankle/lower extremity joint torques, or lower plantarflexor “braking” energy absorption as potential reasons for the longer time to peak velocity noted in the immediate post late-cue period of elderly subjects. Cao et al. (1998) concluded older adults require more time to decelerate their forward momentum during unexpected turning, mainly due to less of a reduction in time to achieve peak velocity following cuing (i.e. less of a reduction in the duration of stance-limb push-off once cued).

Although research using temporal constraints to compare strategy preferences and gait adaptations in both young and older adults within the same study has not been carried out for a turning task requiring a permanent direction change, age-related preferences when performing a rapid lane shift and differences in spatial-temporal gait adaptations for a circumvention task when cued-late has been done within the same study

Elderly avoidance of limb cross-over when response time to lane shift is constrained

Gilchrist (1998) late-cued young (n=16, 27(6) years) & healthy elderly (n=16, 70(3) years) females 100 ms post penultimate (prior step) footfall contact for random right v. left rapid lane change responses while walking straight along a center lane at a preferred speed. Glichrist (1998) reported that relative to young adults, the elderly were less capable of a rapid lane shift after just 1 post-cue center lane footfall (elderly 26% v. young 58% of trials), especially when the lane-shift necessitated a "cross-over" spin-turn maneuver as opposed to "side-step" step-turn maneuver (frequency of 1 post-cue center lane footfall: spin-turn maneuvers: elderly 1.5% v. young 31.2% of trials; step-turn maneuvers: elderly 51.6% v. young 84.9% of trials). Gilchrist (1998) suggested the greater threat to balance imposed by the crossing of limbs during the cross-over maneuver likely accounted for it not being the preferred first option strategy when needing to execute a rapid lane shift within just 1 post-cue center lane footfall. Gilchrist (1998) proposed the greater overall frequency of the elderly needing to take more than 1 post-cue center lane footfall when cued-late to shift lanes likely permitted a more incremental ML displacement of the COM; however, the prolonged distance of forward progression brought-about by the taking of an extra footfall could increase the risk of contact with nearby objects.

Elderly less proactive adjusting step-width when response time to circumvent is constrained

Paquette & Vallis (2010) late-cued young (n=6, mean 20.3 years) and elderly (n=6, mean 74.5 years) subjects to circumvent either right or left around an obstacle. By controlling the leading foot and starting location, both age-groups performed an equal number of random late-cued step-out and cross-over maneuvers to both the right and left direction. It is important to again note that unlike turning, circumvention involves a transient direction change as once the object has been cleared, subjects once again resume their original straight trajectory. Paquette & Vallis (2010) noted that overall the elderly walked slower (0.91 v. 1.02 m/s), and for the final step terminating with ultimate pivot footfall placement, relative to straight unobstructed walking, an age-related difference was seen when circumventing as the elderly had a greater reduction in both step length (21 v. 16%) and step velocity (step length/step time) (24 v. 16%). The final approach step was shorter for both the cross-over (.51 v .60 m) and step-out (.38 v .53 m) maneuvers. Paquette and Vallis (2010) proposed the slower stepping velocity may afford additional time to plan and execute the direction change. Interestingly, although both age groups increased step width in the final step ending in ultimate pivot footfall placement, the increase in step-width was smaller in the elderly for both the step-out (.38 v .50 m) and cross-over (.21 v .31m) circumvent maneuvers. Similar to Paquette et al. (2008), Paquette and Vallis (2010) believed adaptations in step-width facilitated medial-lateral (ML) COM acceleration to clear the obstacle.

A gap in the literature: need to compare turn strategies & gait changes in both age-groups under the same conditions of one study when time is constrained

In summary of the background leading up to what remains unknown, about 1/3 of those over 65 fall each year (Masud and Morris, 2001; Tinetti, Speechley and Ginter ,1988); the elderly are more prone to serious fall-related consequences as compared to young adults (Sterling, O'Connor and Bonadies, 2001); fall-related medical care is a financial burden to society (Stevens, Corso, Finkelstein and Miller, 2006; Carroll, Slattium, and Cox, 2005), with the majority of first-year fracture care costs being hip in nature (Shi, Foley, Lenhart, and Badmgarav, 2009); not only is hip fracture costly but its six-month mortality (Marottoli, Berkman, Leo-Summers, and Cooney, 1994; Haleem, Lutchman, Mayahi, Grice, and Parker, 2008) and institutionalization (Marottoli, Berkman, Leo-Summers, and Cooney, 1994; Magaziner, Hawkes, Hebel, Zimmerman, Fox, Dolan, Felsenthal, and Kenzora, 2000) rates are in the range of 20%; too much hurrying is the main reason attributed by elderly fallers (Berg, Alessio, Mills, and Tong, 1997); and the odds for hip fracture are greatest when the fall direction is sideways (Nevitt and Cummings,1993) and the task involves turning (Cumming and Klineberg, 1994). Yet despite the linkage of excessive hurrying (i.e. available time response limitations) with elderly-falls, and turning with elderly hip fractures, gait-related research comparing young v. elderly ability to change-direction while walking across identical conditions within the same study has not included a temporally constrained condition (i.e. late-direction-cue) when assessing either turn strategies (Thigpen, Light, Creel, and Flynn, 2000) or accompanying spatial-temporal gait adaptations; Paquette, Fuller, Adkin and Vallis, 2008); and notwithstanding, even when response time has been constrained with a late-direction-cue for both age-groups in the same study, such research has either reported solely on the turn-success/failure rates with adaptations examined at the biomechanical rather-than spatial-temporal gait level or turn strategy preference level (Cao, Ashton-Miller, Schultz, & Alexander, 1997; Cao, Schultz, Ashton-Miller, and Alexander, 1998), or the spatial temporal gait adaptations assessed were recorded when approaching for a transient direction change when circumventing (Paquette and Vallis, 2010). Moreover, at this time, the principal investigator of the present work is unaware of any studies comparing the two age-groups when the response time to turn is constrained from the interaction of both a late-direction-cue and a fast walking speed. Based upon the above, there is a need for research comparing spatial-temporal gait adaptations and turn strategy preferences in young & older participants hastened to respond to a sudden cue for a permanent direction change within the same study conditions.

Purpose of the Study and Rational

Thus, the purpose of this study is to assess: a) whether there is a relationship between age, walking speed, direction-cue time constraint, and turn strategy preference; and b) whether age-related differences exists in the spatial-temporal gait adaptations based upon the interaction between walking speed, direction-cue time constraint, and direction.

By learning about elderly turning behavior when there is less time to prepare a response, either because awareness of direction is delayed and/or walking speed is hurried, will build-upon our understanding of elderly proactive v. reactive motor control issues, add to the normative data to help screen for turn performance issues in elderly community dwellers, and aid in the design and documentation of effective gait training programs to improve function/prevent falls in otherwise healthy elderly individuals.

Research Questions

Two research questions are being asked:

RQ1. Is there a relationship between the factors age-group, speed, cue-time constraint, & turn strategy preference (step-turn, spin-turn, mixed-turn) when turning right?

If not are there lower–order_interactions between these variables?

Is there a relationship between age-group (young, elderly) & turn strategy preference (step-turn, spin-turn, mixed-turn)?

Is there a relationship between speed (preferred, fast) and turn strategy preference?

Is there a relationship between direction cue time constraint (early, late) and turn strategy preference?

RQ2. Do young v. older adults demonstrate different spatial-temporal gait modifications (Speed, Combined Right/Left Stride-Length, Right H-H BOS, Left H-H BOS) across the final-four recorded approach footfalls based upon the interaction of walking test speed (preferred v. fastest-comfortable), cue constraint (early v. late cuing), and direction (straight v. right-turns)?

Research Hypotheses

Two research hypotheses are being offered:

HA1. There will be a relationship between the factors of age-group (young v. elderly), walking speed (preferred v. fast), direction cue time constraint (early v. late) and turn strategy preference (step-turn, spin-turn, and multi-step mixed strategy).

HA2. Spatial-temporal gait adaptations (speed, cadence, right-stride-length, right DLST, right H-H BOS, left H-H BOS) will be different in elderly as compared to younger participants based upon the interaction between walking speed (preferred v. fastest comfortable walking speed), visual cue time constraints (early v. late cuing) and direction (straight-walks v. right-turns).

Theoretical Framework(s)

The motor control conceptual frameworks which will be used to better understand the propensity for elderly falls when hurrying too much, and hip fractures when turning, within the context of proactive and reactive spatial-temporal gait adaptations and turn strategy preferences brought about by constraining the available response time with a late direction-cue and fast walking speed include: motor program theory, dynamic systems theory, attention limitation theories, and ecological visual perception theory.

Motor program theory: central pattern generators (CPGs)

The neural circuits thought to generate rhythmical limb movements during gait are termed central pattern generators (CPGs) (Liebermann, Buchman, and Franks, 2006; Mackay-Lyons, 2002). CPGs are believed to reside at the spinal level and are considered the basic unit of motor control responsible for locomotor motor programs. CPGs provide spatial-temporal motor commands in a feedforward manner. According to Mackay-Lyons (2002) decerebrate cats have been found to progressively walk, trot and gallop when electrical stimulation was applied to their brain stem at increasing intensities. Thus, it is likely the same CPG programs used to walk straight are also used to generate most gait related subtask including the medial-lateral weight shifts required when turning. Although the mechanism by which CPGs generate rhythmical movement patterns is not well understood, one hypothesis termed the “half center” hypothesis suggest reciprocal inhibition between an extensor center on one side of the spinal cord, and flexor center on the other side of the spinal cord (Mackay-Lyons, 2002). Although regulation of CPGs is not well understood, it is believed that both descending and ascending influence modulates the CPG output. Mackay-Lyons (2002) reports the supraspinal centers (sensori-motor cortex, cerebellum, and basal ganglia) perform five CPG control functions: activation of CPGs, regulating CPG intensity, preserving locomotor equilibrium, coordination of locomotion with other tasks, and modifying limb movement to external demands. Additionally, sensory feedback (visual, vestibular, proprioceptive, tactile) is believed to be important in augmenting CPG generated motor programs to support ongoing adaptation to the environment. Afferent input likely has three functions: reinforce load tolerance in limbs; reinforce timing with regards to position, direction of movement and force; and facilitate phase transitions. Moreover, according to Mackay-Lyons (2002), CPGs interact to bring about coordinated limb movement. The shared CPGs hypothesis views the locomotor network as being made up of distinct spinal CPGs (i.e. hip, knee, and ankle CPGs) with coordination brought about through phase-dependent interactions between the various CPGs. Thus motor learning may entail identifying which grouping and sequence of CGPs are required to generate the desired motor result. Another hypothesis reported by Mackay-Lyons (2002) termed the shared interneurons hypothesis suggest that CPG networks are not anatomical entities but behaviors configured by the vast number of multi-potent interneurons. For example, common interneurons are utilized to generate the rhythmic movements of scratching and locomotion in cats. Thus, sensory feedback, supraspinal higher centers and neuromodulators have been suggested as driving these circuit-switching mechanisms. Finally, Courtine & Schieppati (2003) collected motion analysis and EMG data on young-middle aged adults (n=6, mean age 35 years with range 20-54) who after initially walking straight 3m then negotiated 2-3 gait cycles along a 4.6 m right continuous curve in performing a 220^0 turning task at preferred speed. Based upon two-three gait cycles of right curved path walking, relative to straight gait, Courtine & Schieppati (2003) reported a phase shift between alternate limb movements amounting to a 7% gait cycle duration delay in outer-left foot relative to inner-right foot heel strike when transitioning from straight to continuous turning; however, as no change in both stepping frequency and double limb (gait cycle) stance duration, stability in the rhythmic structure and temporal coupling across trajectories during bipedal gait was suggested. Moreover, although small significant spatial (amplitude) and temporal EMG changes were noted in the lower extremities relative to straight walking, no drastic changes were seen in the organization of the muscle activation patterns. Based upon these findings, Courtine and Schieppati (2003) proposed that during curved path walking, asymmetric sensory feedback especially from cervical & lower extremity proprioceptors, and vestibular system (both known to alter extensor tone) likely modulate the motor commands issued by the CPG's thus adjusting the relative coupling between CPG centers located on either side, which during straight gait are otherwise driven 180^0 out-of-phase by descending tonic supra-spinal influence.

Dynamic systems theory

According to Shumway-Cook and Woollacott, (2012), at the core to understanding dynamic system theory is the basic concept of self-organizing belief in that a system made-up of separate parts coalesces, its many components function in a cooperative and organized manner. Thus, coordinated patterns of movement can emerge without the necessity of directives from a higher center. Shumway-Cook and Woollacott, (2012) note that dynamic systems theory expanded from the original work of Bernstein in the 1960's who viewed the body from a mechanical perspective in considering its mass, external forces such as gravity, and internal forces such as inertia and inter-segmental torques. From Bernstein's perspective, complex movement was regulated from the shared interaction of several collectively working systems. Beginning in the mid 1980's, Shumway-Cook and Woollacott, (2012) acknowledge contributions to dynamic systems theory from several researchers including: Kelso & Tuller, Kugler & Turvey, Thelen and colleagues, Kamm and colleagues, Perry, and Harbourne & Stergiou. Dynamic systems theory proposes nonlinear behavior in that, should the value of a single key control parameter (i.e. speed) reach a critical-level, that one parameter alone can alter the entire pattern and expression of behavior in the organism. Thus, with regards to the present study, should either walking speed or direction-cue-time- constraint affect turn strategy preference, a dynamic system framework can be used to interpret the finding. Moreover, within dynamic systems theory, variability in behavior is not immediately looked upon as error, but instead as a sign of flexibility and adaptation to change in conditions (Shumway-Cook and Woollacott, 2012). Additionally, behaviors which show little variability are considered to be highly stable or preferred patterns of movement (Shumway-Cook and Woollacott, 2012). Preferred movement patterns that show resistance to change are said to have deep attractor wells, and an increase in variability is thought to precede a change in a preferred movement pattern, as when learning a new movement skill (Shumway-Cook and Woollacott, 2012). From a dynamic systems framework, when examining motor control issues, the interaction of multiple systems including the muscular-skeletal, various sensory systems and central nervous system must be considered, in addition to the environment and task constraints. Thus, adaptations to preferred movement patterns (i.e. a preference in strategy) may be explained using physical principles (i.e. speed interacting with mass to build momentum), and not simply with CPGs (Shumway-Cook and Woollacott, 2012). Finally, Lenoir, Overschelde, De Rucke, and Musch (2006) had young participants (82% right-handed, 64% right-footed) perform stationary, walking and slow running 180^0 turns, and reported a left direction turn bias which was significantly higher when running as opposed to walking (left turn bias: running 71.4% v. walk 59.3%). Hemispheric dopamine asymmetries has been suggested as a possible factor in the emergence of opposing turn direction preference and handedness (Mohr, Bracha, Landis & Brugger, 2003; Mohr & Bracha, 2004; Taylor, Strike, & Dabnichki, 2006; Taylor & Strike, 2016). Although Lenoir et al (2006) did not explicitly use step-turn v. spin-turn terminology, the preferred turning foot was described as being forward and pushing off in the opposite direction. Thus it can be inferred a left turn bias consisted of both a preference for left direction turning, and a preference for turning left with a step-turn rather than a left spin-turn (Taylor et al., 2006). Interestingly, Lenoir et al. (2006) noted the left direction turn bias was reduced when initiating the turn from stationary standing with asymmetric limb positioning of the left foot forward, implying a mechanical advantage for preference of a right direction step-turn rather than a left direction spin-turn (left turn bias: left foot forward 9.9% v. feet together 59.7%). However, preference for a left turn bias remained high when running & cued with asymmetric limb positioning suggesting that when necessary (i.e. when cued with right foot forward while running) participants took an extra step to persist in their preferred left step-turn pattern (left bias: right foot forward at whistle 70.8% v. left foot forward at whistle 69.4%). Lenoir et al. (2006) suggested the mechanical advantage afforded for non-preferred right-direction turning when standing with the left limb forward indicates the left turn bias can be superseded by task or environmental constraints. Moreover, the increase in the left direction turn bias (i.e. left step-turn preference) when running, and its persistence regardless of whether the right or left foot was forward at the time of cuing, suggests the preferred pattern of turning may have become even more entrenched, possibly due to either gait being less variable at high speeds, not having to overcome inertia of a stationary COM, greater task complexity/metabolic demand necessitating a more efficient-comfortable strategy, or possibly enhanced vestibular stimulation.

Attention limitation theories

As the walk-turn task in the present study will not only require the use of a ML stepping strategy superimposed on gait (Patla et al., 1999: Hollands et al., 2001; Winter, 1995), but simultaneously will necessitate attentional resources for visual scanning/visual-motor “feed forward” preplanning when cued-early (Patla et al., 2003; Lythgo et al., 2007; Paquette & Vallis, 2010) or visual-spatial attention to a late-direction-cue signal (Chen et al., 1996; Patla et al.,1999; Lo et al., 2015) possibly combined with either online feedback visual-control or retrieval of stored visual-spatial information used to guide foot placement (Yamada et al., 2010), an attention-limitation theoretical framework will be necessary when interpreting findings. To that end, according to Magill (2007) two major branches of attention theories exist including filter theory and central-resource theories, with the latter being subdivided into single-resource and multiple-resource theories. Magill (2007) credits the filter theory of attention (also known as bottle neck theory) to researchers from the 1950's and 1960's including Welford, Broadbent, and Norman. The filter theory proposes that dual/multi-tasking is problematic due to the serial processing of information. Moreover, at some stages the brain can only process singular bits of information at a time & the rest is filtered-out (Magill, 2007).

While the filter theory of attention was prominent for a period, Magill (2007) notes that an alternative view emerged which while proposing parallel processing of information, interpreted a decline in performance under dual-task conditions as a consequence of the attentional single-resource capacity being exceeded. Magill (2007) acknowledges contributions to the central single-resource theories beginning in the 1970's with Kahneman, and extending into the 1990's and 2000's with Neumann, Tombu & Jolicoeur, Pashler & Harris, and Cole and colleagues. Kahneman's flexible central-capacity theory has served as the basic template for interpreting the performance cost of dual-tasking, as it proposes a single-resource with varying capacity depending upon both internal and external conditions i.e. one's arousal level, task demands, task constraints (Magill, 2007). This single attentional resource can be shared amongst several tasks. The allocation policy for distributing attention between different tasks is based upon: (a) how much resource is available given one's arousal level; (b) an assessment of the attentional demands or costs of each task i.e. "is dual-tasking possible"; and (c) three rules which influence attention allocation policy:

1. Ensure completion of at least one of the tasks.
2. Enduring or involuntary disposition: our attention is drawn to novel, unexpected, and meaningful events
3. Momentary intentions: attention is self-directed through one's will or desire, or externally-directed upon being instructed to do so (Magill, 2007).

It is worth noting here these last two rules which sway the attention allocation policy are meaningful for the present study as the sudden appearance of a visual direction cue signal while walking can be considered both as an enduring disposition and a momentary intention since participants were instructed to base their motor action upon the visual signal received.

In addition to a single attention pool or resource, others have advocated for the existence of several-information processing attentional resources, with each geared towards a particular information-processing function while having its own attentional limit. Magill (2007) credits the multiple-resource theories to the work of Navon & Gopher in the 1970's, and Wickens and

Allport in the 1980’s and 1990’s. The multiple-resource theory of Wickens (2002, 2008), considered to be the most widely held, proposes dichotomous dimensions of information processing that supports time-sharing of available attentional resources between concurrent tasks, and aid when interpreting & predicting the potential for a dual-task performance decline i.e. dual task costs (DTC): (a) dimension one: a dichotomy for stage of information processing having separate resources for working memory (i.e. perception, cognition, encoding) & response selection/execution (i.e. manual-spatial, vocal-verbal); (b) dimension two: a dichotomy for perceptual modality having separate resources for a visual channel & an auditory channel; (c) dimension three: a dichotomy for code of information active applicable across both stages of processing (i.e. working memory & responding) having separate resources for analogue-spatial/manual processes and categorical-symbolic linguistic/verbal processes (Magill, 2007). Additionally, bundled within the visual channel is dimension four: a dichotomy for separate resources for focal-mainly-central vision (mediated by the ventral visual pathways used) used for object/text/symbol recognition & ambient-peripheral-proficient-vision (mediated by the dorsal visual pathways) used for perceiving orientation, speed, direction & displacement during gait (ego motion). Wickens (2008) proposed that dual/multi-tasks capacity in-part depends on whether tasks feed from the same or different dichotomous level across each of the four dimensions. Hence, the benefit of the multiple-resource theory is that by having specific dimensions & levels for attentional resources, a tally can be kept to anticipate whether dual-task costs are likely to diminish performance. Thus, when considering multiple-resource theory from the simple perspective of just this one component of resource-competition, less of a decline in performance can be anticipated from a dual-task necessitating both one visual and one lower-extremity response, as opposed to two different visual responses (Magill, 2007). However, in addition to this issue of resource-competition, the multiple-resource model proposed by Wickens (2008) also includes two other components when interpreting DTC, namely, task difficulty as to whether the tasks exceed the available resources (i.e. are residual resource capacities still available for unanticipated events), and also the resource allocation policy with regards to how available resources are distributed between dueling tasks (i.e. which task is given priority-over-the-other and shielded from interference, with the decision believed to be a central-executive-function). Given the present study may require dual-tasking attentional resources from a source supplying two limb responses for both gait (Al-Yahya et al., 2011; Hollands et al., 2014; Simoni et al., 2013) & a ML stepping strategy (Brown et al., 1999), and a source supplying at times two vision (visual-spatial attention) responses for both processing a late-cue, and/or feedback or feed forward visual-motor control (Lo et al., 2015; Chen et al., 1996; Patla & Vickers, 2003; Brown et al., 2005; Yamada et al., 2010; Patla et al, 1999; Hollands et al, 2001), depending upon the allocation policy

& perceived task-demands, there is a possibility attentional resources spent on vision could affect either gait or turn-strategy performance. Finally, in interpreting any findings within the present study from the standpoint of DTC incurred from visual-spatial processing, the 4th dimension proposed by Wickens (2008) is of particular interest in regards to the possibility of competition for focal vision in the vicinity of the late-cue or a decline in capacity to use ambient/peripheral vision when spatial separation between direction lanes is large (Horrey & Wickens, 2004) i.e. a large turn-angle.

Ecological visual perception theory

In light of the bilateral cones placed at the entrance to the turning zone spatially confining its width to approximately 73 cm, the influence of perception of the environment on both turn strategy preferences and spatial-temporal gait adaptations, in particular preservation of a consistent ML (and AP) safety margin envelop, is a potential factor that has to be considered (Hackney & Cinelli, 2013; Hackney and Cinelli, 2011; Gerin-Lajoie et al., 2008; Gerin-Lajoie et al., 2006). According to Shumway-Cook and Woollacott (2012), ecological theory considers how perception of environmental features, relevant to an intended goal, can be used to organize and regulate the motor-output action needed to achieve the desired objective. From this standpoint, the organization of the motor response is task & environmental specific. Shumway-Cook and Woollacott (2012) credit ecological theory to the original work of Gibson in the 1960's, while acknowledging the contributions of other researchers in the 1980’s including Lee & Young, and Reed. What is unique about ecological theory is that it goes beyond acknowledging the importance of sensation in augmenting a motor response, to instead emphasizing the role of perception of facets within the environmental which are needed to adapt locomotion so as to achieve the task goal (Shumway-Cook and Woollacott, 2012). Within an ecological framework, the individual is engaged with task and environmental constraints while actively searching for multiple strategies to safely and effectively execute a desired goal (Shumway-Cook and Woollacott, 2012). Finally, according to Warren (2007), information derived from the optic flow of field of expansion, when converted to units of eye height (tau rate of change of object image/visual angle expansion on the retina i.e. tau time to contact) can be used by the visual system to compute the distance a person is from a target location or the target’s dimensions (i.e. distance from the turn-zone or its width & depth). Moreover, Warren (2007) states the visual system can calibrate further to either “body-scale” this information by proportioning relative to a body segment unit (leg-length or shoulder-width), or “action-scale” this information by proportioning into units of current stride-length or stride-time, thereby enabling the visual-system to regulate obstacle negotiation at the step level.

Chapter II

REVIEW OF LITERATURE

Turn Behavior during a Typical Day

The number of turn-related steps take during a typical day accounts for greater than one-third of the total with the percentage being higher in spatially constrained environments (Glaister, Bernatz, and Klute, 2007), with the average turn-angle thought to be about 60^0 (Leach, Mellone, Palumbo, Coni, Bandinelli, & Chari, 2016). In young adults two primary turn strategies have been identified in the literature, with turn strategy preference affected by direction-cue-time constraints. (Patla et al.,1991; Hase and Stein, 1999).

Prevalence of turn steps, and influence of the environment and task

Given the association between turning and fall-related hip fracture, the frequency with which turning steps are taken when negotiating throughout everyday environments and tasks are of interest. Glaister, Bernatz, and Klute (2007) used video analysis to measure the amount of turning that young adults (n=11, mean age 30.7 years) typically perform in various settings of activities of daily living (ADL) including walking through a convenience store, a cafeteria, from one office room to another, and from an office to a car in the parking lot. Glaister et al. (2007) reported that although straight gait encompassed the majority of steps taken, turning steps comprised a sizeable percentage in most ADL settings (i.e. the percentages of turning steps: cafeteria 50%, office to office 45%, convenience store 35%, and office to car in parking lot 8%). Glaister et al. noted that the percentage of turn steps taken was greatest when space in the environment was confined or cluttered as in a cafeteria. Additionally, greater use of two-step-turning (i.e. one turn-initiation-step and one turn-termination-step) as opposed to multiple-step-turning was seen when a series of tasks were performed one after another [i.e. turn-initiation-step, turn-continuation step(s), turn-termination-step]. Glaister et al. (2007) concluded that non-linear turning steps encompass about 35-45% of the total steps taken during an average day, although the total percentage of non-linear steps and number of steps used per turn were dependent upon both spatial and task constraints, respectively.

Average angle of a typical turn

The average turn angle taken over the course of a day by older adults is believed to be about 65^0. Leach, Mellon, Palumbo, Coni, Bandinelli and Chiari (2016) used a body sensor to do in-home continuous monitoring of elderly community-dwellers [n=171, 79.9 (6.6)] across a 6-day period, and also performed a 12 month retrospective & prospective survey of fall history. The criteria used to classify a direction change as a turn was an angle between 45^0-200^0 and duration between 0.5-10 sec. Leach et al reported that relative to retrospective / prospective non-fallers & single-fallers, retrospective recurrent fallers turned using smaller mean angles [60.07^0 (SE $2.51)^0$ v. 65.85^0 (SE 0.49^0)], whereas prospective-recurrent fallers turned less often (436.41 v.766.12 turns/hour), took longer to complete the turn (1.75 v. 1.61 s) and had more variability in turn velocity (0.34 v. 0.32 COV). Leach et al. (2016) suggested the smaller turn angles in retrospective recurrent fallers may indicate a narrower window of stability when changing direction.

While the recent work of Leach et al. (2006) indicates elderly non-fallers turn on average about 65^0, prior turn-related research has often used larger turn angles including 90^0 (Taylor, Dabnichki, & Strike, 2005; Strike & Taylor, 2009) as the present study . In supporting the decision to assess 90^0 turning, Taylor et al. (2005) cited previous research by Sedgman, Goldie, & Iansek (1994) purporting to have shown that during everyday tasks, turns within the range of $76\text{-}120^0$ account for the greatest percentage (49.6%). However, the principal investigator of the present study could not locate a copy of the work by Sedgman et al. (1994) to ascertain the methods used including the age range of the sample (young v. elderly). Interestingly, based upon COM computations, Strike & Taylor (2009) noted that despite instructing young adults [n = 7, 22.3 (6.7) years] to turn at a right-angle and placing line markings on the floor, when early-cued at preferred walking speed, young adults nonetheless turned less than 90^0 for both right & left step-turns with the angle of left step-turns slightly higher [land right turn left $82.8(5.3)^0$; land left, turn right $80.2(5.5)^0$].

Turn strategies used by young adults and preferences when response time is constrained

The two major turning strategies used by young adults were first identified as preferred and non-preferred direction turns when response time was temporally constrained. Patla, Prentice, Robinson and Neufield (1991) assessed turn success rates, direction preference, and ground reaction force data in young adults as they walked at preferred speed and were visually cued to continue straight or turn 60^0 turns, either one step prior to force plate pivot foot contact or upon force plate pivot foot contact, although they were free to choose to turn either right or left. Turn success was success was defined as placing the ultimate pivot foot within 7.5 cm of a 15 cm wide mat located atop the force plate, followed by doing the same with the subsequent turn executing foot on a similar mat located one step into the right/left 60^0 direction change. Patla et al. (1991) found that subjects were unable to perform the 60^0 turn when cued upon pivot foot contact with the turning point, but had high success ($\geq$ 70%) when cued-late one step prior to the turning point (i.e. allowed 1 step to respond). Based upon this finding, Patla et al. (1991) believed that planning in the previous step was required for successful turning (i.e. cuing one step prior to the turning point which is known as the approach step or as the primary investigator of the present study refers to the penultimate footfall). Furthermore, Patla et al. (1991) reported that the direction in which the subjects preferred to turn was not dependent on hand or leg dominance but instead upon which foot landed on the force plate turning point**.** Using 60% of trials as a “majority” cut-off to show direction preference, Patla et al. (1991) observed that when cued-late upon contact of the penultimate footfall and allowed 1 step to respond, 8 of 10 young adults preferred to turn right if their left foot landed on the turning point and vice-versa. Patla et al. (1991) termed this the “preferred direction strategy” as opposed to the less often chosen “non-preferred direction strategy” whereby participants turned left if their left foot landed on the turning point and vice-versa. Interestingly, when Patla et al. constrained the cue-response-time to just half-a-step by subtracting 300 ms, only one of ten subjects was able to successfully respond, although the “non-preferred direction strategy” was no longer an option, as the participant could only utilize the “preferred direction strategy”. Moreover, Patla et al. (1991) reported the non-preferred turn direction strategy required greater absolute medio-lateral (ML) ground reaction force (GRF) magnitude with a change in sign (direction) relative to straight gait. Patla et al. (1991) proposed that pre-planning in the prior step (i.e. the final approach step) was needed to ML decelerate the center of mass (COM) to zero in the direction opposite the turn prior to ultimate pivot foot heel strike, and the reason for the preferred direction strategy when late-cued was biomechanical given its wider base of support (BOS) and similar ML GRF sign & amplitude.

Shortly after the work of Patla et al. (1991), the “preferred-direction and “non-preferred direction” turn strategies would soon become synonymous with step-turn and spin-turn strategies, respectively. Hase and Stein (1999) used descriptive video analysis, electro-goniometers, vertical force sensors beneath the heel, first & fifth metatarsal heads, and right lower extremity electromyography (EMG) recordings to investigate turn strategies in middle-aged adults (26-57 years) who were unexpectedly randomly cued with a non-noxious electrical stimulus over the right ankle to perform a sudden 180^0 direction change walking at a preferred speed. The gait cycle was divided into 16 parts, with parts 8 & 16 representing the initiation of force registration at left & right heel-contact, respectively. Although participants were free to choose direction (i.e. turn right or left), to facilitate interpretation of the data, only right turns were analyzed. Based upon descriptive video analysis, Hase & Stein (1999) reported 7 of 10 young participants were able to complete the 180^0 direction change by using just 2 steps (i.e. within 2 footfalls) of being cued, and showed flexibility in being able to execute two different strategies. The first strategy termed a spin-turn, was observed to the right when the late-cue was temporally delivered in proximity of left heel strike (i.e. one step prior), and involved rotating to the right with the ball of the right (forward) foot producing the braking force and acting as the turn axis. The second strategy termed a step-turn, was noted when the late-cue was temporally delivered in proximity of right heel strike (i.e. also 1 step prior), involved rotating to the right with the ball of the left (forward) foot producing the necessary braking force and serving as the main axis for direction change. Both the spin turn and step-turn as noted here by Hase & Stein (1999) are comparable to the non-preferred direction & preferred direction strategies, respectively, previously described by Patla et al. (1991). Moreover, while a significant difference in the preference of each strategy was noted dependent upon which part of the gait cycle the cue was delivered (i.e. as mentioned preference for right step-turns when cued in proximity of right heel contact during parts 13-16 & 1-4, whereas preference for right spin-turns when cued in proximity of left heel-contact during parts 6-11, preference for step-turns covered cuing across a larger period of the gait cycle (step-turns 8 parts v. spin-turns 6 parts) and step-turns were exclusively used when temporal-proximity window to right heel contact was further narrowed (i.e. when cued during parts 13-16, 1-3). In contrast, there was no part in the gait cycle upon which a cue was delivered that participants exclusively chose a spin-turn. Furthermore, in the 3 of 10 young participants who failed to use both strategies, it was a spin-turn that was avoided across all 16 parts of the gait cycle, as one extra footfall was taken to instead choose a step-turn despite the longer response distance & time (i.e. were unable to complete the turn within just 2 footfalls after being cued). In agreement with Patla et al. (1991) who also cued-late one step prior, Hase and Stein (1999) suggested a step-turn preference in young adults for the biomechanical reason of a more stable wider base of support. Finally, based upon EMG analysis, Hase & Stein (1999) found no increase in hip abductor muscle activity in the ultimate pivot limb during step-turns, yet an additional large second burst from the hip abductors in the ultimate pivot limb was seen during spin-turns, which may have helped hike the contra-lateral (left) pelvis to facilitate shifting the COM into the right turn. Interestingly, all 3 of the 10 participants who bypassed spin-turns with extra footfall step-turns lacked this second bursts from the gluteus medius in the ultimate pivot limb.

Bias to turn in direction opposite the stability limb equates with a step-turn preference and its modulation across speeds and conditions

In young/middle-aged adults a left direction turn bias has been reported in right-handers and a weak right direction bias in non-right-handers, with the suggestion of its linkage with dopamine hemispheric asymmetry. Mohr, Bracha, Landis & Brugger (2003) using a belt secured device which summed partial direction changes to tally the frequency of right v. left 360^0 turns naturally occurring in young-to middle-aged healthy adults over a 3-day period, found a significant left turn bias in right-handers and a significant right turn bias in non-right-handers. Mohr et al. (2003) suggested that outside of fine motor ability, turn direction preference is the only other dichotomous task shown to be linked to handedness. Classifying turning as a bimanual tasks, and citing research supporting a link between right caudate dominance and bimanual proficiency, Mohr et al. (2003) proposed hemispheric dopamine asymmetries as a possible factor in the emergence of opposing turn direction preference and handedness. Mohr & Bracha (2004) went-on to replicate their earlier results of Mohr et al. (2003) on a prior data set of 121 individuals by once again showing a left turn direction bias in right-handers, and right turn direction bias in non-right-handers. Mohr & Bracha (2004) believed this bolstered their proposal that handedness and turn direction preference may both be linked with dopamine hemispheric asymmetry. Yazgan, Leckman, and Wexler (1996) after a direct observation of 41 participants also reported a turn direction bias but only in right-handers with no effect for gender, and that the bias was leftward and “robust”, with test-retest reliability being high.

The left direction bias opposite the dominant stability foot of healthy right-handers/right-footers has been equated with a step-turn bias with the biomechanical intent of maintaining the COM within the BOS; however, given the bias is absent (only a trend) in right-handed amputees, suggest biomechanics alone can’t explain the bias “equated” with step-turns as hierarchal priority of control variables appears to emerge from the interaction of the individual, task & environment. Noting that a handedness turn bias had previously been established in the literature, Taylor, Strike, and Dabnichki (2006) used video analysis to compare left turn preference in right-handed healthy & amputee participants [92 healthy and 27 amputees (16 right tibial, 11 left tibial)]. Taylor et al. (2006) found a leftward turn bias of 66.8% in the healthy group; and while no left turn bias was observed in the amputee group

(47.4%), only a non-significant trend of 59% was seen for a preference of turning towards the side of amputation. Moreover, in those healthy right-handed individuals who were also right footed, chi square analysis likewise revealed a significant left direction bias. Accordingly, based upon the gait asymmetry theory of Sadeghi et al.(1997) suggesting right-footed individuals use the right limb more for push-off & the left-limb more for stability during gait, Taylor et al (2006) proposed that given push-off is required in the pivot foot, it is understandable that right-footers would show a left turn bias, and believed their findings supported a turn bias in the direction opposite the dominant foot. Taylor et al. (2006) went on to propose that turning opposite the stance foot as when performing a step-turn, facilitates maintenance of the COM within the base of support (BOS), as opposed to turning towards the stance foot as during a spin-turn were the COM lies lateral to the BOS. However, as the amputee group showed no such preference for turning away from the dominant hand or foot, Taylor et al. (2006) suggested anthropometric asymmetry precipitated a change in turn biomechanics, possibly in part related to the absence of an ankle strategy. Taylor, et al. (2006) went on to suggest that biomechanics alone cannot explain the presence or absence of a turn bias as evidenced by the lack of uniformity in the preference for turning towards the prosthetic limb. Thus, based upon their findings of a leftward turn bias present in healthy right side dominant (young) individuals but not in trans-tibial amputees, Taylor et al. (2006) concluded that the ultimate choice of turn bias (away or towards the dominant limb (i.e. step-turn v. spin-turn) is influenced by a multitude of intrinsic factors which may oppose each other [among them visuo-spatial, age-related sensory-vestibular, dopamine system , hormonal (ovarian/ menstrual), pathology, biomechanics] with hierarchal priority likely establishing by the central nervous system based upon such extrinsic factors as environmental conditions and task constraints/complexity.

Notwithstanding, other researchers have reported a left bias regardless of handedness or footedness with the bias increasing at fast speeds yet decreasing when initiated from certain static asymmetric postures. As reported in the introduction of this present study, Lenoir, Overschelde, De Rucke, & Musch (2006) had young participants (82% right-handed, 64% right-footed) perform stationary, walking and slow running 180^0 turns, and reported a left direction turn bias which was significantly higher when running as opposed to walking (left turn bias: running 71.4% v. walk 59.3%), reduced when initiating the turn from stationary asymmetric standing with the left foot forward as opposed to feet together (left turn bias: left foot forward 9.9% v. feet together 59.7%); however, preference for the left turn bias remained high when combining running & cuing at the instant of asymmetric limb positioning (regardless of which limb was forward), suggesting that when necessary participants took an extra step to persist in their preferred left step-turn pattern so as to simultaneously avoid both a right step-turn and left spin-turn on the subsequent footfall (left bias: right foot forward at whistle 70.8% v. left foot forward at whistle 69.4%). Lenoir et al. (2006) suggested the mechanical advantage afforded for non-preferred right-direction turning when standing with the left limb forward indicates the left turn bias can be superseded by task or environmental constraints. Moreover, the increase in the left direction turn bias (i.e. left step-turn preference) when running, and its persistence regardless of whether the right or left foot was forward at the time of cuing, suggests the preferred pattern of turning may have become even more entrenched, possibly due to either gait being less variable at high speeds, greater task complexity/metabolic demand necessitating a more efficient-comfortable strategy, enhanced vestibular stimulation, or was a consequence of not having to overcome the inertia of a stationary COM.

In a study circumvention study with apparent low task complexity & constraints, there may be a suggestion of a linkage between direction & turn-strategy preference but this linkage shows inter-subject variability. Vallis & McFadyen (2003) had young adults perform right & left circumvent maneuvers around a 2m high x 0.23 diameter obstacle placed 3m directly in front. Although no speed, response-time, spatial, lead-foot, or pivot foot (i.e. asymmetrical forward limb positioning) constraints were in place, after completing 5 trials in one direction, participants were required to reverse direction to perform 5 trials in the opposite direction. Vallis & McFadyen (2003) observed two circumvent strategies across participants including a lead-out strategy (i.e. execution limb away from obstacle, similar to a step-turn) used 48.3% of the time, and a lead-in strategy (execution limb close to obstacle similar to a spin-turn) used 51.7%. Interestingly, among the 6 young subjects, 5 of the 6 consistently displayed a particular “lead-in” v. “lead-out” strategy preference for each direction; however, inter-subject variability existed across participants, as different lead-in v. lead-out strategy preferences were seen for each direction. While not discussed by Vallis & McFadyen (2003), given the very low task-complexity combined with the lack of control of right v. left initiating & pivot foot, it is possible that although each separate participant may have been consistent with regards to pivot foot across his or her own two blocks (right & left direction) of 5 trials, differences in asymmetrical forward limb positioning in immediate proximity to the circumvention point before the obstacle, may explain the inter-subject variability in the linkage reported between direction & turn-strategy preference. Thus, as a preferred lower-limb to manipulate objects (i.e. “lead-out” as when kicking or stepping) has been identified in adults (Gentry & Gabbard, 1995) (although it may not necessarily coincide with the dominant lower-limb when a compensatory step is needed from a forward lean i.e. dominant limb used 64%, *p*=0.32, Lakhani et al.2011), and as the coefficient of variability for stride-length and step-length has been reported to be small (Hollman et al., 2011; Collins & Kuo, 2013), given the lack of randomization in the testing protocol, each participant may have unwittingly self-imposed a gait constraint by being consistent in the use of not only a gait initiating foot but also a pivoting foot across all of his or her own trials.

Finally, although a left direction bias may exist, poor limits of intra-subject agreement across conditions has also been reported in young participants which again bolsters the belief that gait constraints can modify a turn direction bias. Taylor & Strike (2016) had young adults (90 right-handers, 10 left-handers) walk back-and-forth 10x across a 12m distance and perform a180^0 turn at each end-zone (which had a depth of 1.5 m) with & without a prior pause with feet shoulder-width apart. Although Taylor et al (2016) reported a left direction bias regardless of whether or not participants paused with parallel feet prior to turning [pause: 67.5(38.6) %, no-pause: 62.8(38.0%)]; poor limits of agreement was found between the pause & no-pause condition as a change in the percentage of the right v. left direction turning was noted in 43% of participants, with 22% of participants actually switching their bias when omitting the pause. Moreover, video analysis revealed three different strategies during the no-pause condition: a two-footfall 180^0 step-turn or spin-turn pivot (44% of participants); an oval-loop (41% of participants) in which the 180^0 direction change was spread across three consecutive footfalls in an “arcing” pattern, with the same direction bias used in both end-zones); and a “figure-of-8” strategy (15% of participants) in which a subtle diagonal veering away from the corner of the turn direction with continued use of a footfall “arcing” pattern, and an opposing direction bias in each end-zone. Based upon the finding of little direction preference agreement between conditions when not pausing, and that use of a “figure-of-eight” strategy facilitated a bias-reversal at either end of the walkway, Taylor and Strike (2016) proposed that neurochemical influences on direction preference may be modified by the mechanics of gait upon turn approach.

Biomechanical Principles of Turning while Walking

Closer examination of step-turns and spin-turns

When cuing is delivered late in the turning cycle (such as one step prior) a preference for step-turns has been demonstrated in young adults and attributed to greater kinematic and kinetic spin-turn demands (Patla, Prentice, Robinson and Neufield, 1991; Hase and Stein, 1999). Motion and GRF analysis of both turn strategies appear to be in agreement that relative to straight gait, there is an increase in the plantarflexor braking moment, possibly more so for step-turns; a decrease in the hip abductor moment in step-turns, yet possibly an increase in spin-turns; changes in transverse moments; preservation of medial placement of the COM to the pivot foot during step-turns, as opposed to lateral placement during spin-turns; and a reversal in the ML GRF & invertor/evertor moment during spin-turns which appear to suggest spin-turns present a greater ML biomechanical challenge; however, there are some discrepancies within the literature which may be methods-related.

Taylor, Dabnichki & Strike (2005) used motion & force plate analysis of the ultimate pivot foot along with descriptive analysis on young adults (n=10, mean age 22.8 years) to compare early-cued yet abrupt 90^0 right step-turns and left spin-turns. In analyzing the force plate data, the medial-lateral & A-P forces were interchanged as the 90^0 turn took place. Taylor et al. (2005) reported a consistent right step-turn pattern in 8 of the 10 subjects as the left stance ultimate pivot footfall was displaced slightly medial and in front of the penultimate right footfall with toe-in positioning. However, for the left spin turn, two distinct sub-strategies were seen. As Taylor et al. (2005) classified a spin turn as a turn in the direction of the ipsilateral limb (i.e. land left turn left), the two spin-turn sub strategies were defined either as an ipsilateral pivot (seen in 4 subjects) or ipsilateral crossover (seen in 6 subjects). In the ipsilateral pivot spin-turn to the left, the subject landed toe-down with toe-out position and rotated on the toes; whereas in the ipsilateral crossover spin-turn to the left, the left foot remained planted during the major part of stance as the contra-lateral right foot swung around. Taylor et al. (2005) reported that relative to straight gait, A-P braking GRF was larger in all turn strategies but greatest for step turns, A-P propulsion GRF larger in the step-turns & ipsilateral pivot turns but decreased for the ipsilateral crossover turn; both step-turns & spin-turns required a larger mid-stance plantarflexion moment (especially the ipsilateral pivot which exhibited a large power generation at mid-stance -A0), yet no increase in the push-off plantarflexor moment or power generation (A2) was seen and was actually reduced for cross-over spin-turn. Taylor et al added that relative to straight gait, while no increase in hip abductor moments were reported in spin-turns, hip & knee abductor moments were reduced in step-turns towards terminal stance, suggesting the power to actuate step-turns was derived from a redirection of momentum (i.e. a “fall” of COM) rather than active propulsion given the COG was situated medial to (within) the base of support and in the direction of the turn. When comparing strategies, 68% of lower limb joint moments & powers had greater peaks in spin-turns, most notably for the ipsilateral-pivot which also displayed two additional sagittal plane powers (A0-ankle prior to pivot & HMS-hip during the mid-stance pivot). However, Taylor et al. (2005) reported spin-turn required: greater ankle displacement in each of the three planes; greater transverse plane external rotator moments at the hip, knee, and ankle; greater pelvic & thoracic rotation angular velocities (especially for ipsilateral pivot); necessitated rotating the COG 270^0 (as opposed to the 90^0 requirement for step-turns); displacement of the COG lateral (outside) the base of support complicating balance (ipsilateral pivot 84%, ipsilateral cross-over 55% of stance phase) ; smaller toe-to-toe minimal distance increasing the risk of tripping (step turn 298 mm, straight gait 157 mm, ipsilateral pivot turn 136 mm / ipislateral crossover 100mm); and persistence of lateral GRFs as opposed to the medial GRFs of straight gait & step-turns, with reversal in sign of frontal plane ankle moments as well. In simplifying the findings, Taylor et al. (2005) suggested that with the exceptions of a sign reversal for ML GRF & ankle invertor/evertor moments, and greater transverse plane displacements & external rotator moments, sagittal and frontal plane displacements & moments for spin-turns and step-turns were not too dissimilar. In discussing the findings of a lack of an increase in ankle push-off power generation in step-turns & decrease in cross-over spin-turns; and also a lack of an increase in hip abductor moments in cross-over spin-turn & decrease in step-turns, Taylor et al (2005) suggested both strategies were not entirely driven through active propulsion but facilitated through toppling of the COM. Namely, step-turns were facilitated through redirection of momentum & falling of the COM into the turn direction given its placement medial to (within) the base of support; and similarly, given the cross-over spin-turn lacked the additional mid-stance sagittal plane ankle & hip powers of the ipsilateral pivot, in addition to the cross-over spin-turn harnessing some rotational momentum from the pelvis & thorax, it was likewise facilitated through redirection of momentum & falling of the COM into the turn direction given its placement lateral (outside) the base of support. Taylor et al. (2005) considered the possibility that active propulsion for step-turns and spin-turns is derived from the ankle invertors and evertors, respectively. Taylor et al. (2005) suggested a simplification strategy distinguishes the two strategies as step-turns offer greater stability at a lower cost of transverse plane angular displacement & external rotator moments. Taylor et al. (2005) concluded spin turns were more biomechanically challenging, while step turns more closely resemble straight gait.

Xu, Chow and Wang, 2006 used motion analysis, forces plates to compute internal joint moments in young adults who were early-cued for 45 & 90^0 right step-turns (land left turn right) & right spin-turns (land right, turn right) while walking at preferred speed. In agreement with Taylor et al. (2009), relative to straight gait Xu et al. (2006) reported a lower hip abductor moment during step-turns, although higher than straight gait during spin-turns; movement of the body medial (inside) the pivot (BOS) foot during step-turns, whereas lateral (outside) the pivot (BOS) foot during spin-turns; and a reversal in sign of the ML GRF & invertor / evertor moment during the propelling phase of spin-turns although reported it as an invertor moment . In agreement with Taylor et al (2005), Xu et al. (2006) reported that relative to straight gait, the plantarflexor braking moment was larger, and also noted an increase with turn-angle for both strategies, as did transverse moments. As smaller changes were seen in sagittal plane hip & knee extensor moments (actually a decrease in knee extensors), Xu et al. (2006) proposed the ankle plantarflexors were most crucial in decelerating the body prior to turning. Xu et al. (2006) suggested spin turns were more taxing than step turns, especially for those with weak or poorly coordinated ankle musculature. In contrast to Taylor et al. (2005) who noted an increase in ankle & hip external rotator moments during spin-turns, Xu et al. (2006) reported greater ankle &

hip propulsion external rotator moments during step-turns opposite the internal moments of straight gait, yet greater internal rotator moments during spin-turns. Furthermore, in contrasts to Taylor et al. (2005) who noted an evertor moment during propulsion during spin-turns (most notably for the crossover spin-turn), Xu et al (2006) reported an invertor moment during prolusion of spin-turns. In interpreting the conflicting findings between Xu et al. (2006) and Taylor et al. (2005), especially during the propulsion phase, it is worth noting that unlike Taylor et al., Xu et al. made no mention of: interchanging the medial-lateral & A-P forces as the 90^0 turn took place, distinguishing between two types of spin-turns (cross-over v. pivot); requesting turns be performed abruptly; provided no magnitude for the actual turn angle achieved; and performed step-turns & spin-turns to the same right direction.

Medial/lateral COM acceleration and balance control strategies during relaxed standing & straight gait

Within the present study, the footfalls recoded when approaching turns represent linear straight gait. But more important, in order to appreciate the ML control mechanisms needed when turning, it is first helpful to examine the strategies used to accelerate the COM into the turn direction in both relaxed standing and straight walking. From this review use of a frontal plane trunk/hip and to a lesser extent ankle strategy emerges; however, depending upon the model, other muscles typically associated with vertical support &

forward progression and may also substantially contribute to ML regulation of balance when walking.

Winter (1995) reported that ML acceleration of the COM was proportional to the distance (cm) separating center of pressure and the vertical projection of the COM onto the ground. Winter (1995) defined the center of pressure (COP_{NET}) as the point location of the vector corresponding to the vertical ground reaction force; and that In order for the COP_{NET} to regulate the COM, it must oscillate side to side with greater amplitude and frequency, beyond the outside boundary of the COM. According to Winter (1995), similar to that seen in the anterior-poster (AP) direction, a double inverted pendulum model of ankle & hip predicts a strong negative relationship between the COP_{NET} - COM difference and the horizontal acceleration of the COM in the ML direction. Thus, the further leftward COP_{NET} is to the COM, the greater rightward acceleration of the COM (and vice versa). Winter (1995) reported that in relaxed stance with feet side-by-side pelvic width apart, COP_{NET} is regulated by four time-varying factors with two being the right & left ankle invertors / evertors (in my view the ML equivalent of an “in-place” ankle strategy), and the other two being fluctuations in the right v. left hip abductors / adductors (in my view the ML equivalent of an “in-place” hip strategy) altering the distribution of body weight (i.e. sharing of the vertical GRF load between limbs). According to Winter (1995), when in double-limb-support, an increase in right hip abductor or/and left hip adductor muscle activity will produce greater right limb & lesser left limb vertical GRF loading. Moreover, Winter (1995) notes that when using two force-plates, unlike in the AP where the COP_R & COP_L ankle PF/DF muscle contributions are in-phase with each other and correspond to $COP_{NET,}$ in the ML direction the COP_R & COP_L ankle invertor / evertor muscle contributions are out-of-phase and essentially cancel each other with no correlation to COP_{NET}. Additionally, Winter (1995) also reported the narrow width of the foot would restrict ankle moments to about 10 Nm before tilting-over the medial/lateral border would ensue. Based upon these observations, Winter (1995) concluded that in relaxed stance activation of the hip abductors/adductors were primarily responsible for regulating ML balance in modulating COP_{NET} - COM distance, with much less contribution coming from the ankle invertors/evertors. Finally, while the above review of the work of Winter (1995) minimizes the role of the weaker ankle invertor / evertor strategy in controlling ML balance whether walking straight or in relaxed stance with feet side-by-side, Winter (1995) reported a role-reversal for tandem stance. Namely, in more intermediate standing positions such as tandem, ML balance is supported primarily through the use of an ankle strategy (invertors / evertors), whereas AP balance is mainly the responsibility of a hip strategy of loading & unloading.

In relating a single inverted pendulum model of static stance to straight gait, Winter (1995) reported that during single-limb-support, the model predicts the COM to track along the inside border of the weight-bearing foot as it progresses (falls) forward to the anticipated planted location of the swing foot. As the COP located beneath each foot tracks lateral to the COM progression, the COP accelerates the COM away from the stance foot and towards the anticipated upcoming location of the swing foot during each single limb support phase. Moreover, given the COP located beneath the foot during single limb stance of gait is able to regulate COM acceleration / displacement, and as the lateral distance separating the foot and COM also determines the total-body frontal plane gravitational moment acting about the sub-talar joint, Winter (1995) was in agreement with earlier research by MacKinnon & Winter (1993) in suggesting that swing-limb ML foot displacement, relative to the total body COM, at initiation of single-limb-support (i.e. initial contact) was the single-most important factor in both generating medial COM acceleration and controlling frontal plane total-body balance about the support foot. Similar to relaxed stance, Winter (1995) believed that for ML balance during straight gait, the invertors/evertors played a negligible role, whereas the hip abductors / adductors once again were of primary importance with the added key function of adjusting ML foot placement of the swing-limb (i.e. in my view the ML equivalent of a step strategy) to regulate COM acceleration through both the COP and sub-talar joint (STJ) gravitational moment-arm.

The interplay between the ML regulation of both the COP & STJ gravitational moment-arm (during single-limb support of straight gait) to either decrease or increase frontal plane COM acceleration had been earlier described [through the interaction of what the principal investigator would liken to an “in-place” ankle strategy (i.e. STJ eversion/inversion) & and an “in-place” hip strategy (contra-lateral pelvic hike/drop)]. Mackinnon & Winter (1993) used a single inverted pendulum model along with kinematic & force plate data from 4 young adults (mean age 26.3) to investigate the destabilizing and stabilizing frontal plane moments about the hip and supporting foot (i.e. subtalar joint) which regulate total body balance during single-limb stance of preferred speed walking. Citing previous studies showing a hierarchy of balance strategies during stationary standing, MacKinnon &Winter (1993) suggested a hierarchy of balance strategies may also be operant during gait, in that use of a distal STJ “rocking” strategy may suffice when only small changes in frontal plane COM acceleration are needed, whereas greater changes would necessitate a more proximal hip strategy. Hence, MacKinnon & Winter (1993) suggested that to correct for excessive medial COM acceleration, as would be caused by exaggerated lateral foot placement, a) a STJ evertor moment could assist in displacing the STJ center medially, so as to not only reduce the total body gravitational moment, but also cause a medial shift in the COP beneath the stance foot to lessen the medial directed GRF; and b) an increased hip abductor moment would also be needed to elevate the contra-lateral side of the pelvis to laterally shift the HAT COM closer to the stance foot, in order to further reduce the total body gravitational moment. On the flip-side, to correct for insufficient medial COM acceleration, as would be caused by exaggerated medial foot placement, a) a STJ evertor moment could assist in displacing the STJ center laterally, so as to not only increase the total body gravitational moment, but also cause a lateral shift in the COP beneath the stance foot to heighten the medial directed GRF; and b) a decreased hip abductor moment would also be needed to drop the contra-lateral side of the pelvis to medially shift the HAT COM a greater distance from the stance foot, in order to further increase the total body gravitational moment.

While the use of a hip and ankle strategy within the frontal plane provides a much needed foundation to understand frontal plane balance, other research has suggested significant contributions to ML COM acceleration from AP progression & vertical support muscles as well. Pandy, Lin, & Kim (2010) performed biomechanical modeling derived from kinematic, force plate, EMG data to determine hip, knee and muscle contributions to frontal plane COM acceleration during stance as 5 young adults (mean age 26.4) walked at a preferred speed. Pandy et al. (2010) was in agreement with MacKinnon & Winter (1993) that frontal plane alignment of the stance limb is of paramount importance in dictating the direction of the body's ML COM acceleration. However, in contrast to MacKinnon & Winter (1993) who reported gravity accelerated the body's COM medially based upon a single-inverted-pendulum model, Pandy et al. (2009) using a double-inverted-pendulum model found that gravity accelerated the COM laterally during single limb support up until the onset of terminal stance at about 35% of gait cycle. Additionally, in contrast to MacKinnon & Winter (1993) who assigned the hip abductors as being primarily responsible for laterally accelerating the COM through its action on the pelvis to regulate the gravitational COM moment (i.e. shifting the HAT closer to the stance limb), Pandy et al. (2009) found that muscles previously known for their role in vertical support and forward progression also contributed to ML COM acceleration. In particular, Pandy et al. (2009) did not dismiss the small contribution made by both the plantarflexor invertors and plantarflexor evertors to ML COM acceleration during straight gait through their application of rotation moments/accelerations about the subtalar joint (plantarflexor-invertors accelerating the COM medially in concert with the gluteus medius anterior/posterior; whereas the plantarflexor-evertors in accelerating the COM laterally in concert with the hip adductors, vasti, gastroc-soleus, iliopsoas, and gravity). Noting mean peak ML COM acceleration measured 0.75 m/s^2 during straight gait at double-limb-support, Pandy et al. (2009) calculated the average peak contributions to the ML COM acceleration across the entire stance phase for each of the above muscles as follows: [units in m/s^2 with a negative sign indicating medial COM acceleration: medial COM accelerators (-): gluteus medius anterior -0.7(.2), gluteus medius posterior -0.7(.1), plantarflexor-invertors -0.1(.1); lateral COM accelerators (+): soleus +0.8(.3), gastroc +0.6(.2), hip adductors +0.5(.1), vasti +0.4(.2), plantarflexor-evertors +0.2(.1), and gravity 0.0(.5) with gravity switching direction in approximation of terminal stance at about 35% of the gait cycle).

Turn approach control mechanisms.

When turns are approached within the context of walking, linear deceleration of the forward progression, use of top-down axial segment re-orientation, a ML foot strategy and/or hip/trunk roll strategy, adaptations in GRF, and spatial-temporal gait changes contribute to decelerating the forward velocity and medially-laterally re-directing the center of mass (COM) into the new path of travel (Patla, Prentice, Robinson, and Neufeld, 1991; Patla, Adkin, and Ballard, 1999; Hollands, Sorensen and Patla, 2001; Hase and Stein, 1999; Strike and Taylor, 2009; Sreenivissa, Frissen, Souman, and Ernst, 2008; Paquette, Fuller, Adkin and Vallis, 2008; Xu, Carlton, and Rosengren, 2004; Glaister, Orenduff, Schoen, Bernatz and Klute, 2008).

Linear deceleration of forward progression

As already mentioned, Cao et al. (1997) reported that 99% of turn failures within a spatial-constrained environment were the consequence of the inability to arrest forward momentum. This highlights the importance of efficient deceleration prior to turning unexpectedly. Hase & Stein (1999) compared turning strategies and lower extremity EMG activity in young adults who were randomly cued in temporal-proximity of right & left heel strike to perform rapid 180^0 turns while ambulating at preferred speed. Hase & Stein (1999) reported a similar distal-to-proximal deceleration mechanism as that which they had previously observed during rapid unexpected termination of gait (Hase & Stein, 1998). Namely, during execution of a right step turn upon cuing at right heel strike as the right lower extremity was the forward stance limb (i.e. penultimate footfall), an extensor synergy was initiatly activated with the sequence of the vastus lateralis, soleus, biceps femoris & erector spinae to brake the forward momentum; however, once becoming the trail-stance-limb, the right lower extremity employed a flexor synergy consisting of inhibition of the soleus and activation of the tibialis anterior to minimize the power of push off. Moreover, in the left lower extremity, a similar deceleration “stopping” extensor synergy was also noted when it served as the forward stance limb (i.e. ultimate pivot limb); however, since the left lower extremity also functioned as the pivot leg (turn axis) when performing a right step turn, push-off power was perserved and activation of the biceps femoris & gluteus medius was no different than during the stopping task. Interestingly, Hase & Stein (1999) did report a second burst of stance phase erector spinae activity when turning to help stabilize the trunk and control against anterior COM displacement (unlike in rapid stopping where only one burst of erector spinae activity prevented forward trunk motion prior to contra-lateral heel strike). Moreover, Hase and Stein (1999) reported that when cued in proximity of left heel strike to trigger a right spin turn to the right, activation of the right biceps femoris during swing of the soon-to-be ultimate pivot limb, followed by the vastus lateralis & soleus just prior to right foot contact and subsequent erector spinae activity (as right biceps femoris activity persisted) again decelerated the body's forward momentum. Hase and Stein (1999) suggested that deceleration "buys time" to allow use of either a foot or hip strategy to then ML accelerate the COM into the turn direction. Based upon the similarity in the distal to proximal muscle activation pattern between rapid stopping and the initial part of rapid turning, Hase & Stein (1999) suggested the neural mechanisms for the two locomotor tasks were similar.

Top-down axial segment reorientation

When turning a cephalo-caudal re-orientation sequence as been identified, beginning with head yaw and progressing through the trunk before terminating in ML foot placement. There is some suggestion of spatial invariance with regards to the onset on head reorientation relative to the AP linear distance from a turn point around an obstacle. This sequence of initiating a direction change with head rotation is believed to be important not only for visual, vestibular & proprioceptive control of steering, but also provides a reference-frame upon which the body realigns itself along the new travel path.

Prevost, Ivanenko, Grasso & Berthoz (2002) measured the onset of head reorientation in young adults who ambulated a distance of 6m at various speeds (mean slow 0.8, natural 1.2, fast 1.6 m/s) before performing early-cued 90^0 turns around a 1.8m high tripod obstacle with and without vision. Prevost et al. (2002) noted that regardless of walking speed, the onset of head reorientation occurred approximately 1.1 m (slightly less than stride-length) prior to assuming the new travel path direction or 0.3 m before the obstacle interception point (defined as the meeting point of a perpendicular line drawn from the tripod to the linear direction of travel), although the onset time to the interception point decreased as gait speed increased. Moreover, head re-orientation onset and peak angle (approximately 30^0) were independent of vision and right/left direction change. In light of speed having no effect on the onset distance, Prevost et al. (2002) proposed anticipatory head re-orientation is an invariant feature of turning navigation and is essential since the head-neck provides important visual, vestibular and proprioceptive sensory input about the new travel location required for gait adaptations. Moreover, since anticipatory head re-orientation was present with and without vision, Prevost et al. (2002) suggested head reorientation may provide a reference frame for interpreting sensory cues, with spatial invariance supporting egocentric guidance of turning rather than optic flow. The application of spatial invariance of head-orientation across various turn angles has also been demonstrated. Sreenivasa, Frissen, Souman, & Ernst (2008) had young adults perform a series of early-cued 45-135^0 turns while walking around obstacles along either an unconstrained or constrained path (0.5 m turn radii marked on floor with chalk. Sreenivasa et al. (2008) reported that across 45^0-135^0 turn angles, head re-orientation was initiated approximately 1.1 m prior to reaching the obstacle independent of whether the turn path radius was constrained or not. Moreover, maximum yaw between the head and trunk (or heading) increased with turn angle. Sreenivasa et al. (2008) proposed their findings extend spatial invariance of the onset of head re-orientation to cover a wide range of direction angles. Sreenivasa et al. (2008) considered that the anticipatory spatial threshold for head re-orientation may be a fixed number of steps rather than a fixed distance although advised further research was needed.

Hollands, Sorensen & Patla (2001) late-cued young adults for 30 & 60^0 step-turns and reported a cephalo-caudal axial-segment reorientation onset sequence relative to penultimate foot contact consisting of head yaw, trunk yaw, trunk roll, center of mass (COM) lateral translation, and finally ipsilateral foot medial-lateral displacement. Hollands et al. (2001) reported the onset of head orientation preceded lateral translation of the COM by about 250 msec. Hollands et al. suggested early head re-orientation may provide an egocentric visual reference frame that regulates body re-orientation. Furthermore, Hollands et al. noted the onset of medial-lateral foot displacement into the turn was delayed 170 msec. after the initiation of toe-off (note, given step time is approx 500 ms, this suggest ML foot displacement is initiated at approx 1/3 of the swing duration), Thus, when executing the step-turn, the swing foot advanced forwards a distance before shifting lateral i.e. stepping-out. While not discussed by Hollands et al. (2001), this delay in the ML trajectory of the turn execution swing limb may conceivably pose a risk for tripping over one’s feet given the anticipatory narrowing in BOS reported when approaching turns combined with the elderly being more proactive in decreasing step-length (Paquette et al., 2008). This may be relevant in light of Berg et al. (1997) reporting tripping-over-ones-own-feet/for-no-apparent-reason as the sixth most frequent reason surrounding a fall at 10%.

It is worth noting that Patla et al. (1999) reported a late cue onset sequence that differed from Hollands et al. (2001). When cued-early, Patla et al. (1999) found an axial re-orientation sequence which was initiated with head yaw; however, when cued-late, trunk roll preceded head yaw which disagreed with Holland et al. (2001). Hollands et al. attributed the discrepancy to experimental protocol, as Patla et al (1999) had participants perform only straight v. right turns (no left turns). However, possibly more important, Patla et al. (1999) placed the visual cue signal-lights eye level at the end of the straight walking path, whereas Hollands et al. positioned the cue lights on the floor at the end of each designated travel direction. Thus when cued-late, the participants in the study by Patla et al. (1999) likely required prolonged attention & gaze on a forward travel path in order to ascertain the direction of their destination; and may have had little time to process the indirect information of the late-cue to align the head & gaze with the corresponding environmental path. This issue may be of importance as similar to Patla et al.

(1999), the direction signal cue lights in the present study were positioned at the end of the straight walk path and may have altered the nature axial segment re-orientation sequence.

Two strategies to accelerate the COM in the frontal plane: hip/trunk roll strategy and ML foot placement

Within the context of turning, the requirement for ML regulation of the COM is amplified and the use of a ML foot and hip mechanism are essential. When early-cuing of direction allows for a pre-planned response, use of ML penultimate foot placement has been suggested as a strategy to lessen the burden on the hip/trunk roll to displace the COM into the new travel direction. Patla, Adkin & Ballard (1999) had young adults walk along a 9 m path and randomly perform 0^0 (continued straight walking), 20^0, 40^0 or 60^0 right step-turns at the midway point after being visually cued either early at the start of walking or late upon penultimate footfall contact 1 step prior to ultimate pivot foot placement on the turning point. Patla et al. (1999) observed the use of two strategies to regulate ML displacement of the COM along the new travel path:

1. ML foot strategy when an early-cue permitted in which the penultimate footfall was medially displaced towards midline [higher negative values = greater medial foot placement: straight gait 0°: -92.5 mm; early-cue 60^0 step-turn: -120 mm; late-cue 60^0 step-turn: -93.6 mm (note: greater negative = greater medial right penultimate foot placement).

2. Hip-Trunk-roll strategy when cued both early and late in which the trunk & lower extremities were shifted along the frontal plane in opposite directions during the turn-execution stride i.e. trunk rolls (laterally flexes) to the left away from the turn & pelvis/lower extremities shift to the right into the turn. The magnitude of left trunk roll increased with turn-angle [straight gait 0°: 1.62°; 20°: -4.24°; 40°: - 7.91; 60°: -10.9° (note: greater negative = greater left trunk roll)]; and trunk roll was initiated at approximately right mid-stance of the penultimate foot, although sooner for the early-cue condition, reached its peak by left mid-stance of the ultimate pivot footfall, but persisted thru the swing-phase of the right turn-execution limb. Interestingly, although no early v. late-cue difference was seen in trunk roll amplitude, given left trunk roll away from the turn was initiated sooner when cued-early, COM displacement velocity into the turn was lower, leading Patla et al. to speculate the hip strategy contributes less when cued-early as opposed to late. Patla et al. (1999) suggested that use of a medial penultimate foot placement strategy has the effect of minimizing COM acceleration opposite the intended direction change (i.e. lessen COM acceleration leftward), while hip-trunk roll away from the turn direction (in the form of opposite frontal plane inclination of the trunk v. lower extremities about the hips & ankles) displaces & controls the COM into the turn in a double pendulum fashion during the turn execution stride. Patla et al (1999) believed the trunk/hip roll strategy was of lesser importance when cued-early for 60^0 turns since the medial foot placement strategy was

also available. Finally, given the large inertia of the pendulum, Patla et al. (1999) did not believe the ankle invertors/evertors of the ultimate pivot limb (i.e. an ankle strategy) were capable of effectively controlling the COM in the frontal plane.

In addition to early-cue use of a foot strategy (medial penultimate foot placement), a late-cue foot strategy has also been identified. Hollands, Sorensen & Patla (2001) visually late-cued young adults 1 step prior to ultimate pivot foot contact for 30 & 60^0 right and left step-turns while walking at preferred speed, and identified a lateral ultimate pivot foot placement strategy at both angles (stance width ending in ultimate pivot foot placement: straight gait 12 cm v. 60^0 step-turn 15 cm. It is also worth noting that stance width ending in the turn execution footfall for 60^0 turns was further widened to 30 cm.). Hollands et al (2001) found no difference in the amount of ultimate pivot footfall lateral displacement when comparing 30 & 60^0 late-cued step-turns, although similar to Patla et al (1999) reported trunk roll away from the turn direction increased with turn angle. Hollands et al. (2001) suggested the use of an utimate pivot foot strategy when late-cued (lateral placement away from the turn) increases the COP-COM distance and hence enhances COM acceleration into the turn. Interestingly, when the head was immobilized to the trunk, the onset of lateral COM displacement preceded trunk roll by about 30 ms, and only small changes COM amplitude was seen, yet no change in amplitude of lateral displacement of the ultimate pivot footfall. Based upon linear regression analysis, 78% of the variation in lateral COM displacement during the transition stride was attributed to opposite direction lateral trunk roll. Thus, in agreement with Patla et al. (1999), Hollands et al. (2001) suggested modulation in the placement of footfalls (whether ultimate or penultimate) may provide for crude proactive regulation of lateral COM acceleration, with trunk roll providing later fine adjustments as gravity fells the COM into the desired direction during swing of the turn execution step. However, Hollands et al. (2001) advised additional research was needed to further sort out the contributions of each strategy to COM displacement during the turning task, and until then restraint should be adopted in assessing turn performance on the basis of trunk roll alone.

While greater trunk roll into the turn direction has been reported at larger turn angles at preferred speeds regardless of cuing, lateral body leaning into the turn direction has been reported at faster speeds during circular path walking such that the COM is placed towards the center beyond the inner foot. Orenduff, Segal, Berge, Flick, Spanier, and Klute (2006) performed three-dimensional motion and force plate analysis on young adults (who walked clockwise around a 270^0 1 m radius circular path at a constant speed using a natural self-selected and 0.6 -1.3 m/s range. Orenduff et al., (2006) reported that as walking speeds increased, the lateral impulse of the outer limb and the medial impulse of the inner limb both increased, likely as a consequence of the need for greater counter (centripetal) force towards the center of the turn. Moreover, unlike the typical sinusoidal oscillations of the COM between foot contacts during straight gait, when turning the COM followed a circular trajectory at speeds above 1.0 m/s, falling over the inner foot at the natural speed, but inside (lateral to) the inner foot at the fast speed. Contrary to Patla et al., (1999) & Hollands et al., (2001) who noted a lateral trunk roll strategy away from the turn direction at preferred speed, Orenduff et al., (2006) reported a lateral trunk lean into the turn direction, but only at the faster speeds which helped shift the COM trajectory inside the inner foot. However, at the slower speed of 0.6 m/s, no trunk leaning was evident, which contributed to the loss smoothness in the circular COM trajectory, and the appearance of hexagonal apices near the outer foot. Given the absence of a sizable increase in joint moments or powers relative to straight gait, Orenduff et al., (2006) concluded that medial-lateral impulses generated through trunk leaning were primarily responsible for altering COM trajectory during circular path turning. Based upon these findings, Orenduff et al. (2006) suggested strengthening alone is unlikely to be of benefit to safe turning. Instead, Orenduff et al. (2006) advocated for gait training to anticipate changes in momentum & direction, and modify medial-lateral impulses needed to displace the COM. However, given the circular path turning task was performed at a constant speed, Orenduff et al. (2006) cautioned consideration must also be given to the forward progression braking requirement of online turns off a straight path.

Body leaning into the turn direction has not just been reported during circular path turning but also during online walking turns at faster speeds as well, to the extent that when cued-early for 90^0 step-turns, the COM has been reported to fall lateral to (outside) the BOS posing a fall-risk beginning with the penultimate footfall. Xu, Carlton, & Rosengren (2004) used video, motion and force plate analysis on young adults (n=8, mean 21 years) who performed straight 0^0 walks, and 45^0 & 90^0 right step-turns (land left, turn right) & right spin-turns (land right, turn right) at normal [1.35 (.15) m/s] & fast [1.85 (.15) m/s] walking speeds. Xu et al (2004) noted two anticipatory postural adjustments (APA's) in the penultimate footfall (prior step) when approaching turns. First, Xu et al. (2004) reported lateral leaning of the body into the turn direction during the penultimate footfall, which was most apparent during the fast speed 90^0 step-turn when the COM trajectory fell lateral to the COP trajectory of the right penultimate footfall generating COM acceleration to the right. Thus, Xu et al. (2004) found the distance between the COP and COM at both the penultimate and ultimate footfalls was significantly affected by both turn angle and speed. As actual COP-COM distances were only provided for mid stance of the ultimate footfall during these right turns, given the COM displaced right-ward into the right turn direction, the COP-COM distance decreased or became negative for a right pivot foot spin-turn (further right-ward than the right pivot foot): [preferred speed straight .060m, right 45^0 .030m, right 90^0 .008m; fast speed straight

.050m, right 45^0 -.010m, right 90^0 -.040m]; while the COP-COM distance increased for a left pivot foot step-turn: [preferred speed straight .055m, right 45^0 .075m, right 90^0 .085m; fast speed straight .050m, right 45^0 .120m, right 90^0 .150m]. The second anticipatory postural adjustment reported by Xu et al. (2004) during the penultimate footfall when approaching turns was a systematic increase in the push-off phase (toe-off) support angle (i.e. backward leaning of the body) that ensured the COM was not displaced forward to the same degree as in straight walking. Xu et al. (2004) proposed this backward body leaning during push-off of the penultimate footfall helped minimize postural disturbances by slowing the forward trajectory to allow greater control when turning and lessen the risk of falling. Xu et al. (2004) suggested early postural adjustments during the penultimate footfall which commence needed disequilibrium to change direction (i.e. COM trajectory lateral to right penultimate footfall during fast speed 90^0 step-turns), could potentially precipitate a fall should they persist without accompaniment of other necessary anticipatory postural adjustments (i.e. backward leaning to aid deceleration for greater control) . Finally, interestingly, Xu et al. (2004) did not report use of a second ML foot strategy, but instead attributed COM regulation primarily to body leaning, although considered the possibility of the instructions participants received to not alter gait as discouraging changes in foot placement.

Other researchers have likewise reported lateral body leaning into the turn direction when cued early for turns at fast speed, and expressed concern about how leaning into the turn may increase the required coefficient of friction needed to prevent foot slippage. Fino, Lochhart & Fino (2015) used motion analysis and two force plates (before & after the corner pylon) to investigate the effect of speed (on COM trajectory in young adults (n=10, mean age = 25.3 years) who performed early-cued left 90^0 step-turns & spin-turns around pylons of various heights while walking across a range of slow, preferred 1.43(.36) m/s, & fast 2.03(.27) m/s speeds. In order to quantify the degree of body lean into the turn direction, Fino et al (2015) assessed the ML component of the angle between the vertical axis and a line connecting the COM to the pivot foot COP along the frontal plane of the participant (i.e. the ML COM-COP angle or θ_{ML}). [Although not discussed by Fino et al., 2015), it appeared that both out-of-phase- trunk-pelvic-motion (i.e. trunk-pelvic + pelvic-femoral) & lower-limb inclination from frontal plane motion about the STJ could contribute to this angle]. Fino et al. (2015) found that the faster the walking speed, the greater the degree of body lean into the turn (ML COM-COP angle θ_M: slow 4.4 $(6.0)^0$, preferred $6.8(6.1)^0$, fast $12.7(7.0)^0$], and the greater the radial distance of the pivot foot COP relative to the obstacle [radial COP distance: slow 45(12) cm, preferred 46(14) cm, fast 51(13) cm, with fast speed distance greater than both preferred & slow]. Fino et al., (2015) suggested that based upon the formula, $F_C=mv^2/r= mvk$, a faster speed would necessitate a greater centripetal force (likewise a larger/sharper curvature in the COM trajectory, k = 1/r, as used around taller obstacles since the lean required the COM to move away from the turning corner). Hence, Fino et al. (2015) proposed the greater anticipatory leaning into the turn when walking fast added to the centripetal force by medially displacing the COM. Noting centripetal force is supplied through friction when turning, the RCOF at weight acceptance of the pivot foot was found to be larger when turning fast as opposed to at preferred speed. [Note, although Fino et al., (2015) found slower speeds displayed a larger curvature during the first-half of stance, given RCOF is proportional to velocity squared (v^2) times curvature (k), the faster velocity was able to prevail over the reduced curvature to increase the RCOF at faster speed]. Additionally, one speed*strategy interaction was reported in that except at fast speed, spin-turns were performed with less curvature in the COM trajectory during the first-half of stance of the ultimate pivot foot. Hence, when disregarding speed, spin-turns were otherwise executed with less leaning into the turn direction [θ_{ML} in degrees: spin-turns 3.4 $(4.4)^0$ v. step-turns $14.6(5.0)^0$]; and not surprisingly during the first-half of stance had a lower RCOF possibly making foot slippage in comparison somewhat less likely [RCOF spin-turns 0.33(.09) v. step-turns 0.35(.09)]. Nonetheless, of greater clinical importance, although COM displacement beyond the single-limb-stance BOS was further at faster speeds, Fino et al., (2015) reported that across speeds & strategies, during these early-cued 90^0

turns the COM trajectory remained lateral-to (i.e. beyond) the BOS (into the turn direction) throughout the first-half of stance. Moreover, as the RCOF value during the loading phase (10% of stance) for both strategies exceeds that established for straight gait ($u \geq 0.20$), Fino et al. (2015) proposed that given the COM is beyond the BOS (into the turn) throughout the first half of pivot-limb stance regardless of speed or strategy, a slip during loading while turning may have a greater chance of precipitating a fall than a slip during loading of straight gait. Finally, in contrasting the finding of Fino et al., (2015) with regard to the COM trajectory with that of either Xu et al., (2004) who found the COM to track lateral the COP primarily at fast speed, or Taylor et al., (2005) who reported smaller percentages of the COG falling outside the BOS, it may help to consider that Fino et al. assessed the COM trajectory across the first-half of stance, Xu et al., considered only the mid-stance phase, whereas Taylor et al measured across the entire stance phase from initial contact to toe-off.

Related to this point of which phase of stance is examined and its bearing on the findings, in a prior work Fino & Lockhart (2014) had originally assessed the push-off phase of the turn when the peak RCOF was at its greatest, and suggested the risk for slips during the late-phase of stance may be more of an issue for spin-turns. Noting RCOF (u) is computed as the resultant sum of the F_x + F_y horizontal forces divided by the vertical force, F_z, and a small vertical GRF from double limb support inflates the RCOF both at heel-strike & prior to toe-off yet fails to precipitate an observable slip since the vertical component is too-small a % of BW, Fino & Lockhart (2014) only assessed RCOF measures which met a minimum vertical force threshold of 50 N. (Hence the reason the assessment by Fino & Lockhart (2014) was carried-out at push-off). With regards to the findings, in a similar fashion to that seen during the first half of stance by Fino et al, (2015), Fino & Lockhart (2014) reported that during late-stance at push-off the peak RCOF increased with speed [peak RCOF seen at push-off: slow .38(.10); preferred .45(.11); & fast .54(10)]. However, unlike Fino et al. (2015), no speed*turn-strategy interaction was seen by Fino & Lockhart (2014) in the peak RCOF at the late-stance phase of push-off, and neither was there a difference between strategies at push-off after collapsing for speed [RCOF when collapsing for speed: step-turn .48(.11); spin-turn .47(.13)]. Nonetheless, given at fast speed the peak RCOF value at push-off (u = .54) exceeded the minimum static COF recommendation set by OSHA (u ≥ 0.50), Fino & Lockhart (2014) suggested a slip during push-off may be more problematic for spin-turns since the COM has previously been shown to be displaced lateral to the BOS for a longer percentage of pivot limb stance (Taylor & Strike, 2005).

Irrespective of any discussion of RCOF or the phase of stance across which it is assessed, as can be seen thus far in this background review of the two strategies (trunk & foot) available to ML regulate the COM, there appears to be some inconsistencies with regards to the direction of both trunk roll (lean) & pivot foot placement (i.e. away or into the turn direction). Thus, although both Patla et al. (1999) and Hollands et al. (2001) were in agreement with regards to the use of both a foot and trunk strategy to regulate COM acceleration into the turn direction, when late-cued only Hollands et al reported lateral placement of the ultimate pivot foot (i.e. an increase in stance width), whereas Patla et al found no change in pivot foot ML placement. Nonetheless, Patla et al., (1999) did suggest lateral displacement of the pivot footfall away from the turn direction mey be used to increase the COP-COM distance and ML acceleration into the turn; however, cautioned this could adversely affect the subsequent left swing phase by lengthening its required swing distance. In trying to explain this descrpancy between Patla et al. (1999) and Hollands et al (2001) with regards to pivot foot placement, one possible explanation may be that Patla et al. late-cued for straight v. right-turns only, whereas Hollands et al late-cued for left step-turns as well. Moreover, the findings of Orenduff et al. (2006), Xu et al. (2004), and Fino et al. (2015) of body leaning into the turn when direction was known in advance (a priori) particularly at faster speeds are likewise in conflict with the findings of both Patla et al. (1999) when early-cued & Hollands (2001) when late-cued for trunk roll opposite the turn-direction at preferred speed (based an inverted double-pendulum model of trunk roll away, but pelvic/lower extremity rotation about the STJ into the turn). In searching for an explanation for this descrpancy between both Orenduff et al. (2006), Xu et al. (2004), &

Fino et al. (2015) verse both Patla et al. (1999) & Hollands et al. (2001) with regards to the direction of body lean during the turn execution stride, consideration of not only the reference frame to assess trunk roll but whether or not the pivot limb actually rotated in the frontal plane about the STJ into the turn as predicted by the inverted pendulum model (Mackinnon & Winter, 1993), could iinfluence the interpreation of which direction of trunk roll was the most effective strategy.

Related to the assessment of which direction of trunk roll is most effective in shifting the pelvis into the turn direction, an understanding of the frontal plane kinematics of the pelvis & trunk during linear gait is helpful In particular, an out-of-phase pelvic v. trunk motion during preferred speed straight gait was described by Krebs, Wong, Jevsevar, Riley & Hodge (1992) who used motion analysis to assess trunk frontal plane (lateral flexion i.e. leaning) relative to both a global reference frame of the room (i.e. gravity) and a local reference frame of the pelvis in both young and healthy elderly participants (range 27-88 years of age). Krebs et al. (1992) noted that angular displacements of the trunk and pelvis were out-of-phase with each other. Thus, at the start of right stance up until left toe-off, as the trunk leaned into the right stance limb, the pelvis simultaneously dropped down on the left swing limb side. However, at the instant of left toe off a reversal occurred not only in the trunk, but also in the pelvis, in that as the trunk began to laterally displace in the direction of the left swing limb, the pelvis simultaneously started to elevate on the left swing limb side. Krebs et al. (1992) believed that this out-of-phase pelvis/trunk motion reduced frontal plane trunk movements relative to the room so as to explain why trunk movements relative to the pelvis were larger, and functionally helped minimize destabilizing oscillations of the COM & conserve energy during gait. Crosbie, Vachalathiti & Smith (1997) noted similar results during straight gait in young and older adults (range 20-82 years), and added speed increased the amplitude of movement in both the trunk and pelvic segments. Moreover, although older participants showed less motion at each segment, Crosbie et al (1997) attributed this amplitude reduction as a by-product of shorter step-lengths from slower “fast” walking speeds.

Applying this understanding of out-of-phase trunk v. pelvic motion to turning, Houck, Duncan, & De Haven (2006) likewise took into consideration the difference between lateral trunk motion relative to both a global reference frame (i.e. the room) v. a local reference frame (i.e. the pelvis) when using kinematic and force plate analysis to assess use of both a trunk & hip strategy across the first 30% of pivot limb stance during anticipated (a priori) and unanticipated (late cued 50-65% stride length distance prior to turning point) straight v. left 45^0 step-turns (side-step-cuts) in young adults walking at a fast but comfortable speed of 2.0 m/s. With regards to the use of a lateral pivot foot strategy (measured relative to the COM not as step-width), relative to both the early-cued & late-cued straight walks, as Houck et al., (2006) had the young participants walking at a fast-but-comfortable speed, Houck et al. reported an increase in lateral placement of the right ultimate pivot foot when early-cued for left step-turns, unlike Hollands et al. (2001) who although measured step-width found no change when young adults were early-cued for step-turns at a preferred speed. However, while the amplitude of lateral foot placement (relative to the COM) was the least when late-cued for left-step-turns, this displacement did not statistically differ from the two straight conditions [lateral foot displacement (cm) relative to COM with positive = lateral away: step-turn early-cue 13.8(5.6), straight early-cue 8.3(5.0), straight late-cue 7.2(3.9), step-turn late-cue 5.5(3.5)]. With regards to the trunk strategy, Houck et al. (2006) reported that when late-cued for left step-turns, the amplitude of right-ward (contra-lateral to the turn direction) lateral trunk orientation (i.e. roll or lean) [relative to the room based upon a global reference frame, as similarly measured by both Patla et al., 1999 & Hollands et al. (2001)] was greater than all other three conditions (yet the early-cue left-turn condition was unchanged relative to both the early & late-cue straight conditions) [lateral trunk orientation to the right (degrees) with positive = rightward away: step-turn late-cue 5.1^0 (3.3), straight early-cue 2.8^0 (3.0), straight late-cue 2.2^0 (3.3), step-turn early-cue 1.4^0 (3.5)]. Interestingly, Houck et al. (2006) found that rightward (opposite turn direction) lateral trunk flexion [using a local reference frame relative to the pelvis, and not measured by either Patla et al., 1999 or Hollands et al. (2001)] was similar across conditions[lateral trunk flexion to the right (degrees) with positive = rightward away: straight early-cue 11.1^0 (3.1), step-turn late-cue 10.7^0 (3.6), straight late-cue 9.2^0 (2.8), step-turn early-cue 8.2^0 (2.9)]. However, the simultaneous amplitude of left side pelvic-drop during the first 30% of pivot limb stance [pelvic drop on the side ipsilateral to the turn direction, again not measured by either Patla et al., 1999 or Hollands et al. (2001)] was reduced when late-cued to turn-left relative to the early-cued to turn left (yet the late-cue left-turn condition was unchanged relative to both the early & late-cue straight conditions) [left pelvic drop (degrees) with negative = left pelvic-drop: step-turn early-cue -12.7^0 (2.9), straight late-cue -10.3^0 (3.0), step-turn late-cue -9.8^0 (2.6), straight early-cue -9.2^0 (2.1)]. Moreover, in an effort to determine whether the trunk roll strategy accomplished its objective of inclining the pivot-limb into the turn direction [presumably via frontal plane motion about the STJ as predicted by the inverted pendulum model (MacKinnon & Winter (1993)], Houck et al. (2006) also assessed the right pivot limb hip abduction angle (relative to the pelvis) across the first 30% of stance [which again was not measured by either Patla et al., 1999 or Hollands et al. (2001)]. Accordingly, when late-cued to turn, Houck et al. (2006) noted that the right stance hip abduction angle was the smallest, yet the angle for the late-cued straight walk the largest [right hip angle using a local reference frame relative to the pelvis (negative = abduction in degrees): step-turn late-cue -6.6^0(4.7), step-turn early-cue -10.6^0 (4.6), straight early-cue -11.8^0 (2.7), straight late-cue -14.2^0

(3.6)]. Finally, with regards to the internal hip abductor moment during the loading phase of the ultimate pivot limb (10-30% of stance), given the Bonferroni correction for the 8 multiple comparisons being $p<0.006$, a non-statistical trend at $p=0.014$, Houck et al. (2006) reported a trend was seen as when late-cued to continue walking straight the hip abductor moment increased (i.e. became more negative, given negative = abduction) relative to when early-cued to walk straight, to the point of being similar in amplitude to the early-cued left-turn (suggesting anticipation & possibly learning of the hip moment requirement needed when early-cued to turn but not walk straight); yet, when late-cued to turn-left, the hip abductor moment decreased (i.e. became less negative although did not switch to positive = adductor) relative to when early-cued to turn-left, to the point of being similar in amplitude to early-cued straight walking (suggesting errant anticipation & possibly learning of the hip moment requirement needed when early-cued to walk straight but not turn left) [right pivot hip internal moment across 10-30% of stance (in Nm/kg) with negative = abduction: step-turn early-cue -1.62(.31), straight late-cue -1.59(.33), step-turn late-cue -1.39(.30), straight early-cue -1.34(.49)]. Houck et al. (2006) concluded that given the degree of rightward (opposite direction) lateral trunk orientation (i.e. roll or lean relative to the room) was greatest when cued-late, yet only the degree of left side pelvic-drop (relative to the room) changed (reduced) when late-cued to turn-left but the degree of rightward (opposite direction) lateral trunk flexion (relative to the pelvis) was consistent across conditions (between 8-11^0), the increase in opposite direction trunk roll when cued late was not the result of lateral flexion between the trunk & pelvis. Instead Houck et al. (2006) attributed the increase in trunk roll contra-lateral into the turn seen when late-cued, solely to the reduced pelvic drop ipsilateral the turn. For this reason, Houck et al. (2006) envisioned the trunk-pelvis moving en block as a unit. Moreover, given when late-cued no change was seen in both lateral placement of the pivot foot & hip abductor moment relative to early-cued straight-gait, and the pivot hip abduction angle was the smallest of all conditions [suggesting trunk roll away did not translate into frontal plane limb rotation into the turn about the STJ as otherwise predicted by the inverted pendulum model of MacKinnon & Winter, 1993]), Houck et al. (2006) proposed the increase in trunk roll away from the turn, and reduced hip abduction angle & moment during early stance of the pivot limb when late-cued demonstrated the importance of hip neuromuscular control in preserving ML trunk alignment & balance during single-limb stance (MacKinnon & Winter, 1993) when turning. Hence, the principal investigator of the present study would add that the findings of Houck et al. (2006) suggest the use of opposite direction trunk roll when late-cued may be less about effectively generating centripetal force to add to the GRF to propel the COM ML, and possibly more about being caught off-guard & defensive to maintain frontal plane stability when uncertainty about direction may have barred the use of other anticipatory postural adjustments.

In an attempt to find commonality between the findings of Houck et al. (2006), Patla et al. (1999), Hollands et al., (2001), Xu et al., (2004), and Fino et al., 2015) with regards to adaptive use of both a trunk roll & foot strategy during online turning off a straight-path, the principal investigator of the present study would suggest the following. First, trunk roll/lean into the turn direction during the turn execution stride, rather than away, may represent a more anticipatory, proactive & effective use of a trunk/hip strategy from the perspective of ML GRF (Orenduff et al., 2006) & centripetal force production (Orenduff et al., 2006; Fino et al., 2015) when the task is constrained by a fast speed. However, as trunk/body lean into the turn at fast speed places the COM further lateral (outside) the BOS of the penultimate footfall during step-turns (Xu et al., 2004) & ultimate footfall during spin-turns (Xu et al., 2004; Fino et al., 2015), aggressive centripetal force production can also pose a greater fall/slip risk (Xu et al., 2004; Fino et al., 2015) especially if a late-cue precludes other anticipatory postural adaptations (Xu et al., 2004). In my opinion, this may also need to be considered in interpreting whether the decrease in out-of-phase trunk/pelvic-femoral motion [i.e. pelvic-drop on the side of the turn, seen as increased trunk roll away when late-cued (Houck et al., 2006)] is looked upon favorably as being adaptive or not, regardless of step-turn or spin-turn strategy. From this standpoint, when walking fast and turn direction is not known in advance, the decrease in out-of-phase trunk/pelvic-femoral motion (seen as greater opposite direction trunk roll), regardless of step-turn or spin-turn, could actually be viewed as being adaptive in prioritizing balance over centripetal force production. The second suggestion the principal investigator of the present study would make is that lateral placement of the pivot foot away from the turn direction likely represents more effective use of a foot strategy to ML accelerate the COM (Winter, 1995) when the task is constrained by a late-cue during preferred speed step-turns (Hollands et al., 2001; Mak et al, 2008) & spin-turns (Hase & Stein, 1999). Yet, a lateral ultimate pivot foot strategy does not appear needed for both step-turns & spin-turns when the task is relatively unconstrained from the combination early-direction-cue & preferred walking-speed (Patla et al, 1999; Strike & Taylor, 2009; Paquette et al., 2008). MacKinnon and Winter (1993), while concluding that medial-lateral foot placement relative to the total body COM at initial contact (i.e. use of a ML change-in-BOS-strategy) is the primary factor responsible for generating medial COM acceleration, nonetheless considered a hierarchy of frontal plane balance strategies may be operant during gait with small changes in ML COM acceleration conceivably requiring only distal STJ “rocking” (i.e. a fixed-BOS-ankle-strategy using the invertors & evertors to change the COM-COP relationship during pivot single-limb-stance), whereas somewhat larger changes in ML COM acceleration possibly being satisfied with a more proximal fixed-BOS-hip strategy (i.e. using the hip abductor/adductor muscles to change the COM-COP relationship during pivot single-limb-stance, and in my opinion with or without trunk roll into or away). Finally, in addition to other possibilities, the absence of lateral pivot foot placement in young adults when cued-late for step-turns at preferred speed may represent a reactive strategy to reduce the turn-departure swing time/distance as suggested by Patla et al., (1999); or if lateral placement of the pivot foot is not seen (with a decrease in the hip abduction angle apparent during early stance) when late-cued for a step-turn especially at fast speed, an indication the neuromuscular ML hip control capacity may have been outspent either during pivot limb swing (MacKinnon & Winter, 1993; Winter, 1995) and/or pivot limb early-stance (Houck et a., 2006).

The contribution of ML foot placement v. trunk roll in regulating COM displacement may not only vary with speed & cue conditions, but also with the type of direction change task. Vallis and McFadyen (2003) used motion analysis to measure spatial-temporal gait changes and segmental orientation sequence in young adults who performed an equal number of right & left circumvent maneuvers around a 2m high x 0.23 diameter obstacle placed 3m directly in front without any temporal or spatial constraints. Vallis & McFadyen (2003) observed two circumvent strategies across participants including a lead-out strategy (i.e. execution limb away from obstacle, similar to a step-turn) used 48.3% of the time, and a lead-in strategy (execution limb close to obstacle similar to a spin-turn) used 51.7%. Although no change in step length or step velocity was apparent, Vallis and McFadyen, (2003) did observe sizeable step-width changes across the final three approach footfalls relative to straight gait and between strategies. In particular, relative to straight gait, when circumventing to the right with a lead-in strategy, step-width increased across all three final footfalls with the increase moderate at the right ante-penultimate, smallest at the left penultimate, and largest at the right ultimate FF; however, when circumventing to the left with a lead-out strategy, no change was seen at the right ante-penultimate, but a large increase at the left penultimate, and a moderate increase at the right ultimate pivot FF. With regards to axial reorientation, although trunk & head yaw angles were similar to that of turning, the young participants used negligible trunk roll during the circumvention task despite the large ML COM displacement. Vallis and McFadyen (2003) suggested that anticipatory ML foot placement step-width adjustments across the final approach steps alone were used to regulate COM displacement when circumventing without the participation of trunk roll.

There is also some indication in the literature that in addition to speed, cue and task affecting the use of both a foot & ankle strategy, age may also be another factor as the elderly appear to be more dependent upon the use of both a trunk and foot strategy when changing direction as opposed to young adults in most tasks involving a direction change. Paquette, Fuller, Adkin & Vallis (2008) early-cued young & elderly subjects for 40^0 right/left turns. Paquette et al. (2008) reported that while both age-groups initiated reorientation into the news travel path within one step prior to the turning point during penultimate foot contact, young adults initiated medial-lateral reorientation of the COM earlier than the elderly (ML COM reorientation prior to ultimate pivot foot contact: young 0.45 s v. elderly 0.08 s). Moreover, although both groups showed a progressive-incremental increase in trunk roll across the final three approach steps (antepenultimate, penultimate & ultimate pivot footfalls) to facilitate COM displacement into the direction change, trunk roll was initiated before ML COM displacement in older subjects, but afterwards in younger subjects but. Thus, when cued-early for 40^0 turns, the body segment reorientation sequence in young adults relative to heel-contact of the ultimate pivot footfall was: head yaw (0.734 s prior), trunk yaw (0.571 s prior), ML COM (0.447 s prior), trunk roll (0.177 s prior), & ML foot displacement (0.237 s after). Thus, trunk yaw & ML COM displacement occurred at approximately the same time in young adults. However, in older subjects the onset re-orientation sequence relative to heel-contact of the ultimate pivot footfall was: head yaw (0.848 s prior), trunk yaw (0.620 s prior), trunk roll (0.283 s prior), ML COM (0.080 s prior), & ML foot displacement (0.333 s after). Paquette et al. (2008) believed trunk yaw could not have been responsible for the COM displacement in young adults, as if trunk yaw were the cause of COM displacement, it should have preceded it. Paquette et al. (2008) suggested the two age-groups use different strategies to safely perform the turning task. Namely, when early-cued to turn, in addition to a medial-lateral foot placement strategy, the elderly appear more reliant upon an anticipatory hip strategy as well. Paquette et al. (2008) reported no difference in segment reorientation onset times between step-turns v. spin-turns when performing these early-cued 40^0 turns.

A circumvention study likewise suggests the elderly are more dependent upon the use of both strategies when late-cued. Paquette & Vallis (2010) provided late-cuing to young & elderly participants to circumvent right or left around a 2m high by 0.2 m wide cylindrical obstacle. Overall, following the late direction-cue, no difference in onset time was seen between use of a step-out v. cross-over circumvent strategy, however, overall the elderly initiated the onset of segment reorientation sooner than young adults. But more important, Paquette & Vallis (2010) found that when cued-late to circumvent, young adults initiated the re-orientation sequence with trunk & head yaw at about the same time and did not utilize trunk roll, but instead relied solely upon medial/lateral foot placement to displace the center of mass [segment reorientation onset time in ms prior to obstacle crossing in young: trunk yaw 980, No-Trunk-Roll, head yaw 950, eye gaze 870, ML foot placement 640 ms]. In contrast, the elderly used both trunk roll & med/lat foot placement, yet did not engage in head yaw [segment reorientation onset time in ms prior to obstacle crossing in elderly: trunk yaw 1200, trunk roll 1160, No-Head-Yaw, eye-gaze 940, ML foot placement 850 ms)]. Paquette & Vallis (2010) suggested the elderly may have avoided head yaw during this late-cued circumvent task possibly due to the transient nature of the direction change and to create a more stable reference frame for both visual gaze & scanning the adjacent environment surrounding the obstacle.

While most literature would appear to suggest the elderly are more dependent upon both use of a trunk & ML foot strategy when changing direction, there is at least one study which may indicate that for some tasks the elderly may actually curtail use of a trunk strategy. Kuo, Hong & Liau (2014) compared young (mean 20.9) and older adults (mean age 72.9) as they performed a 3m walk before making a 180^0 turn to the left in order to sit in a chair. Kuo et al. (2014) reported that during the turn execution step, the elderly showed less lumbar frontal plane angular displacement (i.e. less lumbar lateral flexion). Kuo et al. (2014) suggested the decrease in trunk frontal plane angular displacement may aid stability in minimizing COM displacement outside the BOS.

Changes in ground reaction forces

Beginning with the penultimate footfall, changes within the AP GRF plays a primary role in decelerating the forward progression and ML GRF adaptation initiate acceleration of the COM into the turn direction; and modifications progress into the ultimate pivot & turn-execution footfalls as well. Glaister, Orenduff, Schoen, Bernatz & Klute (2008) used motion analysis and two force plates to compute the horizontal ground reaction forces and impulses in young/middle-aged adult subjects (n=10, age range 24-47 years) during early-cued 90^0 step-turns while walking at preferred speed. Three steps/ footfalls were assessed including the initiation step (i.e. second-to-last approach step ending in penultimate foot placement), the apex step (final approach step ending in ultimate pivot foot placement), and the termination (turn execution) step. Due to access to only two force-plates (a stationary left followed by right), in order to acquire data across all three footfalls of the turn-execution stride, a left step-turn was used to collect data for the initiation (penultimate FF) and apex (ultimate FF) steps, but a right step- turn was necessary to collect data for the termination (turn-execution FF) step. Instead of a global reference frame to compute impulse, a local body reference frame axis aligned with the COM trajectory was used as determined by a two-sample point finite difference method. A body reference with a COM origin rather than a pelvic origin has been recommended when a low kinematic sampling rate is used i.e. 60 Hz (Glaister, Orendurff, Schoen, & Klute, 2007). The angle between the body reference frame and global reference frame was then calculated. Once this angle was known, the GRF's computed globally could then be rotated about the vertical axis to align with the local body reference frame using two-dimensional matrix multiplication. The rotated GRF's were then integrated with impulse computed in the units of (N x % stance phase)/kg. Based upon this method, Glaister et al. (2008) found that relative to straight gait which exhibited the typical brief medial (applied) impulse (4.1, shifts COM towards the stance foot) followed by a prolonged lateral (applied) impulse (33.9, shifts COM away from the stance foot and towards the swing limb), for the step ending in left penultimate foot placement, the medial applied impulse (53.3, towards the stance foot) was greater & evident for the entire stance phase, as no lateral applied impulse (0.3) was seen; and unlike straight gait which showed the typical early to mid-stance posterior braking impulse (55.4) which changed in later stance to an anterior propulsive impulse (52), during the penultimate step the braking impulse was greater (61.5) while the propulsive impulse less (41.0). For the step ending in right ultimate pivot foot placement, a huge lateral applied impulse (153.5, away from the stance foot into the step-turn direction) was evident for the entire stance phase as no medial applied impulse (0.3) was seen; and although the braking impulse was similar to straight walking (59.5) the propulsive impulse was larger (68.3). Finally, for the step ending in placement of the turn-execution footfall, a medial applied impulse (50.3, towards the stance foot into the step-turn direction) was evident for the entire stance phase similar to the penultimate step, with no appreciable lateral applied impulse (0.6) apparent; and the braking impulse was less than that for both straight walking and the preceding two turn steps (36.8) while its propulsive impulsive (58.8) was second in amplitude only to the ultimate pivot step. Glaister et al. (2008) proposed their method of rotating GRF's so as to use a body rather than global reference frame was the reason why previous studies either showed a progressive decrease or no change in late stance propulsion as the turn angle increased to 90^0, while Glaister et al. detected an increase in late stance ultimate pivot footfall propulsion relative to straight walking. Glaister et al. (2008) suggested that during early-cued 90^0 step-turns the penultimate footfall was the biggest contributor to deceleration when approaching turns, while the ultimate pivot footfall was the largest contributor to medial/lateral shift of the COM trajectory & propulsion into the new travel path. Glaister et al. (2008) considered the possibility the braking impulses during the turn execution stride may help control against excessive pivot.

In agreement and adding to the finding of Glaister et al (2008), other researchers have reported changes in the penultimate footfall with the increase in braking yet decrease in propulsion being greater at faster speeds, along with greater GRF changes in spin-turns. Xu, Carlton, & Rosengren (2004) early-cued young adults to continue walking straight or perform 45^0 & 90^0 right step-turns & spin- turns at preferred & fast walking speeds. Xu et al. (2004) noted that for the striking phase of the step prior (i.e. penultimate footfall not ultimate pivot), both the medial-lateral & anterior-posterior impulses increased with increased turning angle and speed; and when comparing strategies, spin-turns (to the right with a right pivot foot) produced a greater medial-lateral impulse at the penultimate footfall as opposed to step-turns (to the right with a left pivot foot). For the propulsive phase of the penultimate footfall, when combining strategies only the anterior-posterior (AP) impulse was higher during turns as opposed to straight gait, yet the AP propulsion impulse decreased with increased turning angle, and both the ML & AP impulses decreased with speed; and when comparing strategies, spin-turns (to the right with a right pivot foot) produced greater anterior-posterior & medial-lateral propulsive impulses at the penultimate footfall as opposed to step-turns (to the right with a left pivot foot). Xu et al. (2004) suggested anticipatory postural adjustments (APA's) (lateral & backward body leaning) contributed to the requisite GRF's and impulses needed to slow the forward momentum facilitating greater control and initiating the disequilibrium needed to ML accelerate the COM into the new path direction.

Strike & Taylor (2009) juxtaposed GRF impulse changes in the ultimate pivot footfall with approach stride spatial-temporal gait changes in young adults who were early-cued to perform rapid 90^0 right step-turns. Using the method of Glasiter et al (2008) to rotate GRFs about the COM across the turn, Strike & Taylor (2009) reported that relative to straight gait, an increase was seen in the braking AP impulse [90^0 step-turn 0.16(.06) v. straight 0.11(.03) LL/gravity], propulsion AP impulse [90^0 step-turn 0.14(.05) v. straight 0.11(.04) LL/gravity] and ML impulse [90^0 step-turn 0.32(.07) v. straight 0.07(.03) LL/gravity]. Strike & Taylor (2009) suggested the increase in braking impulse allowed a reduction in forward momentum to redirection the COM into the new travel path. Additionally, across the final approach stride ending in ultimate pivot footfall placement, Strike & Taylor (2009) reported a decrease in normalized stride-length [straight 1.78(.12) v. 90^0 step-turn

1.57(.23) LL] & stride-velocity [straight 1.42(.23) v. 90^0 step-turn 1.38(.17) m/s]; however, interestingly no change was seen in stride-width [straight 0.12(.05) v. 0.11(.07) LL] . Strike & Taylor (2009) interpreted the modulation in pivot foot GRF impulses and the decrease in both turn approach stride length & turn approach stride velocity as an anticipatory feed-forward strategy, and suggested such adaptations are likely important for successful turning.

Although there is indication the ML GRF impulse increases with speed upon striking of the penultimate footfall (Xu et al., 2004), a late-cue to turn when sprinting appears to reduce the ML GRF peak amplitude, prolong its time to peak amplitude, and necessitate greater hip internal moments. Kim, Lee, Kong, An, Jeong, & Lee (2014) used motion analysis, force plate and inverse dynamics to compute hip and knee moments in young male "middle-school" soccer players who performed anticipated and unanticipated (late-cued at 90% stride-length) 45^0 right side-cutting & left cross-cutting maneuvers (i.e. right step-turns & left spin-turns) while sprinting at a speed of 3.5(.2) m/s. Kim et al (2014) reported the unanticipated (i.e. late-cue) condition resulted in smaller peak vertical & ML GRF amplitudes for both strategies [vertical GRF as a % of BW for step-turns: anticipated 2.76(.39) v. unanticipated 2.32(.32), for spin-turns: anticipated 2.62(.3) v. unanticipated 2.36(.33); ML GRF as a % of BW for step-turns: anticipated 0.80(.13) v. unanticipated 0.58(.16), for spin-turns: anticipated 0.74(.12) v. unanticipated

0.63(.14)]; and longer times to peak vertical & ML GRF (with vertical peaks taking longer in unanticipated spin-turns than unanticipated step-turns) [time-to-peak (s) just for ML GRF for step-turns: anticipated 0.55(.09) v. unanticipated 0.60 (.09), for spin-turns: anticipated 0.55(.10) v. unanticipated 0.61(.11)]. Interestingly, unlike Houck et al., (2006) who reported a decrease in the stance hip abductor moment (from 10-30% of stance) when late-cued for left step-turns v. straight walks, Kim et al. (2014), who measured moments across the entire stance phase of the pivot limb, found that when late-cued the peak stance phase hip abduction moment increased during step-turns [hip abduction moment for step-turns in N/kg with negative = abduction moment: anticipated -1.12(2.14) v. unanticipated -4.26(3.24) N/kg] as did the peak stance phase hip adduction moment during spin-turns [hip adduction moment for spin-turns in N/kg with positive= adduction: anticipated +3.44(.78) v. unanticipated +4.45(1.95) N/kg]. Moreover, unlike the decrease in hip abduction angle reported by Houck et al., (2006) across the first 30% of stance), Kim et al (2014) found a larger peak stance phase hip abduction angle for step-turns, yet no early v. late difference in the peak stance phase hip adduction angle of spin-turns [hip abduction angle for step-turns with negative= abduction: anticipated -17.7(6.1) v. unanticipated -23.1(5.8); hip adduction angle for spin-turns with positive = adduction: anticipated +13.3(4.5) v. unanticipated +14.5(4.9)]. Kim et al (2014) suggested that direction-cue time constraints rather than choice of turn strategy appear to have a greater impact on kinematic and kinetic variables. Obviously, the difference in testing procedure & assessment method between Kim et al., (2014) [right step-turns v. left spin-turns, late-cued at 90% stride-length to turning point while sprinting at 3.5 m/s, assessed across the entire stance phase], as opposed to Houck et al. (2006) [left step-turns v. straight, late-cued at 50-60% stride-length to turning point at a fast-but-comfortable speed of 2.0 m/s, assessed only across early stance i.e. first 30% of stance] may explain the difference in findings between Kim et al. reporting an increase in both the hip abductor moment & hip abduction angle verse Houck et al. reporting a decrease in both the hip abductor moment & hip abduction angle.

Although GRF changes between strategies have been compared, the principal investigator of the present study is unaware of studies comparing age-related differences in GRF when turning. Nonetheless, Tirosh & Sparrow (2004) used motion analysis and two force plate to compare stopping-time, stopping-distance (normalized to height), number of steps (one or two), and ground reaction forces in young (n=16, mean age= 25 years) and healthy active community dwelling older l (n=16, mean age = 69) following an early (10 msec. after left swing limb heel strike) or late (450 msec. prior to left swing limb toe-off) visual cue to rapidly terminate gait. As the stopping cue in both the early and late condition was applied during the left stance phase, one-step response was defined as stopping with the right foot without the left leaving the force plate, and a two-step response defined as the left foot needing to make a second heel contact regardless of landing in front (long-step) or behind (short-step) the right. Tirosh & Sparrow (2004) reported the elderly more frequently required two steps to terminate gait when collapsing for early and late cuing (one step: elderly 30.2 v. young 61.4%; two-step: elderly 69.8 v. young 38.6). Elderly subjects preferred two-steps to stop for both the early and late cued conditions (use of two steps: early 60%, late 82%) while young adults preferred two steps to stop only for the late cued condition (use of two steps: early 18%, late 61%). Moreover, when combining the means for the one and two-step responses, the elderly took longer time to stop (574 v. 463 ms); however, given the majority of elderly two-step responses were of the of the short-step variety, the average stopping distance was similar at 0.4(.1) of stature, although stopping distance in both groups was greater for the late as opposed to early cue condition (late 0.45 v. early 0.34 of stature). Whether the faster young adult walking speed (1.29 v. 1.17 m/s) contributed to the similar stopping distance is unclear. With regards to GRFs, Tirosh & Sparrow (2004) noted that relative to straight walking, when stopping left limb propulsive forces were reduced only in the young subjects as the elderly did not modulate left push off. Although both age-groups increased peak horizontal braking and reduced peak horizontal propulsive GRF in the right lead foot relative to unconstrained walking, lead foot braking forces were smaller and propulsive forces greater in the elderly. (Note, in my view the left & right limbs in this stopping task would have equivalence to the penultimate & ultimate footfalls, respectively, when approaching turns). Tirosh & Sparrow (2004) proposed an age related decline in neuromuscular stance limb performance may be the reason for the less proficient modulation of propulsive forces and restraint of horizontal COM velocity; and suggested that some falls experienced by the elderly may be caused by object contact from needing to take an extra step to stop. This finding of Tirosh & Sparrow (2004) is in agreement with Cao et al. (1998) who attributed a prolonged elderly deceleration time to a lower reduction in the duration of stance-limb push-off once cued to turn.

Turn Behavior with Aging

Elderly turn strategy preferences across speeds and turn angles when direction is known in advance

As mentioned, research using temporal constraints to compare strategy preferences and gait adaptations in both young and older adults within the same study has not been carried out for a turning task requiring a permanent direction change. However, elderly turning preferences has been studied across different speeds & turn angles when direction is known in advance. One such study has suggested an overall elderly preference for spin-turns except when gait is hurried and making large direction changes. Akram, Frank and Chenouri (2010) used motion analysis to investigate the effect of walking speed (slow, preferred, fast) and turn angle magnitude (45^0 or 90^0) on turn strategy preference (step-turn v. spin-turn) in elderly community dwellers (n=19, mean 66 years) who had advanced knowledge of turn direction (early cued). Similar to the present study, participants were free to initiate gait and pivot on either foot. Akram et al. (2010) observed the reorientation process often occurred across two ML steps including a small preparatory step, and a main step in which the medial-lateral displacement was greater. Akram et al. (2010) differentiated step-turns verse spin-turns with regards to which of the two re-orienting steps initiated a larger medial-lateral displacement towards the turn direction, and did not include a mixed-turn category as did Thigpen et al. (2000). Although right and left turns were performed, only right turns were analyzed and as such a step-turn was defined as the right foot having greater ML displacement toward the right turn direction, and a spin-turn defined as the left foot having a greater ML displacement toward the right turn direction. Using logistic regression, Akram et al. (2010) reported that with regards to main effects, turn magnitude did not predict turn strategy preference although walking speed did as the elderly participants preferred spin-turns when walking both slower and faster than preferred speed; however, the interaction term of the large magnitude 90^0 *fast-speed predicted step-turns. Moreover, as Akram et al. (2010) also calculated odds ratios for step-turns relative to a spin-turn for the main and interaction terms, and reported that for the covariate of a slow walking speed the odds for a step-turn was less likely at 0.39 (95% CI: 0.13, 0.85), whereas for the interaction of the covariates large magnitude 90^0 *fast-speed the odds for a step-turn was more likely at 3.20

(95% CI: 1.08, 9.49). [The percentages of step-turns across speeds & turn magnitudes were as follows: slow speed at 45^0 22/57 trials = 39%, at 90^0 turns 30/57 trials = 47%; preferred speed at 45^0 34/57 trials = 60%, at 90^0 31/57 = 54%; fast speed at 45^0 23/57 trials = 40%, at 90^0 35/57 = 61%]. Akram et al. (2010) concluded that when collapsing for turn angle magnitude (45 v. 90^0) & walking speed (slow v. preferred v. fast) with direction known in advance, the elderly have an overall preference for spin-turns, and only when walking fast & required to make a large direction change (90^0) did the elderly prefer step-turns. Akram et al. (2010) suggested that given spin-turns require greater pivot limb hip abductor/ankle invertor moments, greater transverse plane motion, and offer less toe-to-toe clearance, the sizeable 39% prevalence of spin-turns during fast 90^0 turns may be implemented in elderly falls. Again, this study by Akram et al. (2010) involved advanced knowledge (early cuing) of turn direction, did not include a group of young participants, and though a turning zone circle of 0.5 m was drawn on the floor to give participants an idea of where to turn, the turning zone was without spatial constraints. Moreover, participants were required to ambulate with arms folded across their chest in order to minimize its affect on gait, which appeared to lower walking speed across conditions relative to the present study [Akram et al (2010) straight gait speed values with arms crossed: slow 0.59 (.13), preferred 1.02 (.15), fast 1.41 (.18) m/s; in the present study in which arm swing was unhindered elderly values for straight gait speed not normalized to leg-length: preferred 1.39 (.14), fast 1.92 (.23) m/s].

In contrast to the above suggestion of an overall elderly spin-turn preference except during the interaction of a fast walking speed with large turn-angle, other research has shown an elderly step-turn preference when direction is known in advance and executing a small angle turn with just one ML step. Fuller, Adkin and Vallis (2007) early-cued elderly subjects (72-92 years, some of whom had a history of falls but did not require an assistive device, and others with self-described balance issues) to perform right & left preferred speed small-angle 40^0 turns. Participants walked at a preferred speed (mean .69 m/s) were free to turn using their own strategy although a turning point junction was clearly defined. Fuller et al. (2007) observed that following the initiation of head yaw into the turn direction, the elderly participants required two ML steps to complete the 40^0 direction change in the majority of trails (180/260 = 69.2%) as opposed to just a single ML step (80/260 = 30.8%), with right v. left direction having no effect on the use of a double or single step strategy. Moreover, when using a single-step strategy for early-cued 40^0 turns, 75% of trials were described as a "step-out" step-turn v. 25% as a "cross-over" spin-turn, thus suggesting an elderly step-turn preference. However, unlike single-step strategy, the double-step strategy could not easily be categorized either as a "step-out" or "cross-over" turn due to widening or narrowing adaptations in the BOS of the ultimate pivot footfall.

Thus, in some instances Fuller et al. (2007) reported a decrease in ultimate pivot footfall BOS preceding a "step-out" step-turn (i.e. medial displacement of the ultimate pivot footfall into a step-turn), while in other instances an increase in ultimate pivot footfall BOS preceding a "cross-over" spin-turn (i.e. lateral displacement of the ultimate pivot footfall into the spin-turn direction). Fuller et al. (20007) also reported that although each individual elderly participant utilized both a single-step strategy and a double-step strategy over the course of all their trials, use of a double-step turn strategy correlated with a low balance confidence score ($r^2 = .44$, $p < .01$). Finally, Fuller et al. (2007) observed rotation of the pivot foot into the turn direction accompanied the double-step strategy, and suggested pivot limb rotation into the turn may facilitate greater use of the stronger plantarflexors / dorsiflexors and less demand on the weaker invertors / evertors when laterally accelerating the COM. It is important to point out the similarity in finding of an association between the preference for two step small 40^0 turning with low balance confidence as noted by Fuller et al., (2007), and the previous review of the work of Thigpen et al. (2000) showing greater prevalence for 3-4 step large 180^0 turning in elderly with self described turning difficulty (use of 3-4 steps to turn 180^0: young 0%, elderly without turning difficulty 38%, elderly with turning difficulty 54%). Thus, the 2 step turning strategy as described by Fuller et al. (2007) for 40^0 turns has resemblance to the mixed-turn strategy as observed by Thigpen et al. (2000) during larger angle turning.

Elderly/middle-aged turn strategy preferences when response time is constrained as gleaned from control group performance in patient-based studies

Some turn research involving patient groups such as Parkinson, Stroke & Ataxia have utilized temporal direction cue constraints, and in such studies healthy age-matched participants often serve as a control group. From these studies, we can glean information regarding healthy older adult (middle-aged & elderly) turning behavior.

In a Stroke-related study using early v quasi-late direction cues, similar to that previously found in young adults (Patla et al., 1999), middle-aged/elderly controls also medially displaced the penultimate footfall away from the turn direction when time permits. Hollands, van Vliet, Zietz, Wing, Wright, & Hollands (2010) early and quasi-late-cued (two steps prior to the turning point upon ante-penultimate foot contact) right & left 45^0 step-turns in those with stroke and healthy age-matched controls (n = 14, mean age 60.4 years) to compare axial segment re-orientation and spatial-temporal gait changes prior to turning. The middle-aged/elderly controls were required to walk at a slower than preferred speed to match their stroke counter-parts; and since outcome measures for right v. left turns showed no difference in the controls, data from both turn directions were combined. As all participants reportedly turned using a different number of steps, late-cue gait outcome measures were only provided for the turn trials. When comparing early v. late cuing, Hollands et al. (2010) reported that when cued-late, middle-aged/elderly controls walked slower across straight trials (controls: early .92 v. late .90 m/s); and except for a later onset of head yaw, the onset orientation sequence in controls relative to ante-penultimate foot contact was similar across cue conditions (early-cue condition: head -0.5 s, thorax +0.7 s, pelvis +0.8 s, COM +1.35 s; late-cue condition: head +0.6 s, thorax +0.95 s, pelvis +1.0s, COM +1.5 s). Moreover, across the final three approach steps when cued-late to turn, step-width of the penultimate footfall was narrower than the other two approach steps in the middle-aged/elderly control group [step-width computed as stride-width: ante-penultimate footfall: 20.0 cm, penultimate footfall 15.0 cm, ultimate pivot footfall 20.0 cm]. Hollands et al. (2010) were in agreement with both Patla et al (1999) and Paquette et al. (2008) in that narrowing of the penultimate step minimizes COM acceleration contra-lateral to the turn direction. It is interesting to note that when cued-late Hollands et al. (2010) did not report an increase in step width for the ultimate pivot footfall, unlike that observed by Hollands et al. (2001). It is possible the use of a smaller turn angle (45^0 v. 60^0) and constraint of a slower-than-preferred walking speed in the Hollands et al. (2010) study may account for this difference.

There is some indication from Parkinson-related research that healthy elderly controls do not show a preference either way for step-turns v. spin-turns whether cued early or late when walking at preferred speeds; but potentially just as important, the amplitude of cross-over may be smaller during spin-turns when cued-late possibly creating a stability issue.

Conradsson, Paquette, Lokk and Franzen (2017) compared turn strategies when initiating a 180^0 direction change in healthy elderly controls (n= 17, mean age 72 +/-5 years) who received early v. late-cuing (1 step-prior for a response distance of 0.6 m) in a Parkinson-related study. The healthy-elderly controls were required to walk at a slower-than-preferred speed within 1 SD of their Parkinson group counter-parts [straight gait preferred speed: Parkinson group 1.24(.14) v. healthy elderly controls 1.46(.15) m/s]. Similar to Akram et al., (2010), Conradsson et al. (2017) observed preparatory ML displacement steps in approach of the turn, and for that reason established a turn-execution threshold of >2SD the ML displacement of straight gait across two-consecutive steps in order to identify the onset of turn-initiation. As participants performed both right & left direction turns, Conradsson et al. (2016) scored a step-turn when the 1st turn-execution footfall to meet the ML displacement threshold was on the ipsilateral side as the cued-turn-direction, whereas a spin-turn was scored when the 1st turn-execution footfall to meet the ML displacement threshold was on the contralateral side as the cued-turn-direction. Based upon these operant definitions, Conradsson et al. (2017) found no early v. late-cue difference in step-turn v. spin-turn preferences in the healthy elderly control group (healthy elderly control step-turn % along with 95% confidence interval: early 47 (39-54)% v. late 48 (41-55)%). Interestingly, Conradsson et al. (2017) reported a delay in the healthy controls for the onset of ML displacement for the 1st turn-execution step as a consequence of the late-cue, which corresponds to about 1 step beyond the turn point or anywhere between 1-2 footfalls post-late-cue (early-cue 0.09 s before the turn-point v. late-cue -0.45 s after the turn-point). However, despite the delay in initiating turn execution when cued-late, no mention was made of the delay impacting turn strategy scoring. As the 180^0 turn-angle required 3 turn-execution footfalls to complete, an alternating pattern of step-width (BOS) changes were seen across the three turn-execution footfalls with the patterns being opposite between strategies i.e. the pattern for step-turns (widening, cross-over, widening) v. the pattern for spin-turns (crossing-over, widening, crossing-over). Additionally, for the healthy control group, Conradsson et al. (2017) reported mean step-width (BOS) values for the 1^{st} turn execution step during step-turns were similar regardless of cuing (early 0.13 v. Late 0.17 m); however, for spin-turns mean step-width values for the 1^{st} turn-execution step was negative indicating a cross-over beyond the line of progression of the contra-lateral foot, with the cross-over greater when cued-late as opposed to early (early -0.03 v. late -0.13 m). Interestingly, when comparing groups for the 1^{st} turn-execution footfall of the late-cued spin-turn condition, BOS was more negative (i.e. larger cross-over amplitude) in the controls v. those with Parkinson. Conradsson et al. (2017) suggested the reduction in cross-over amplitude during spin-turns as seen in the Parkinson group may impair ML stability when turning as limb cross-over is believed to contribute to trunk rotation & regulation of COM acceleration. Finally, it is worth noting that although the healthy elderly control group in Conradsson et al. (2017) were required to walk at a slower-than-preferred speed within 1SD of the Parkinson group, the preferred elderly straight walking speed in the present study was 1.39 (.14) m/s and also close to that same range.

From a second Parkinson-related study utilizing late direction cues is suggestion that when cued-late for 60^0 turns, similar to that previously shown in young adults (Hollands et al., 2001), the elderly controls likewise laterally displace the ultimate footfall opposite the step-turn direction to facilitate ML COM acceleration. Mak, Patla, Hui-Chan (2008) late-cued (one step prior to the turning point upon penultimate foot contact) right & left 30 & 60^0 step-turns in those with Parkinson disease and healthy age- matched controls [mean 64.5 (5.4) years] to compare the sequence of trunk reorientation and spatial-temporal gait changes during the turn stride. As no differences in right v. left turn spatial-temporal dependent variables were noted in the healthy controls (and even the Parkinson group), the values for both right & left turn directions were combined during data analysis. Mak et al. (2008) reported healthy elderly controls (and Parkinson group) were able to complete the 60^0 step-turns within 2 steps (1 stride) following the late cue, however, the healthy controls turned with a greater turn angle [60^0 turns: 54.0^0 (5.4) v. 40.2^0 (8.2)]. Moreover, Mak et al. (2008) measured step width across the footfalls of the turn execution stride as the medial-lateral distance between successive heel makers, and the normalized step-width values to that of straight gait. Relative to step-width ending in penultimate footfall placement which is when the late-cue was delivered, an increase in step-width was seen at the ultimate pivot footfall, and a further increase at the turn execution footfall [healthy elderly control step width across turn execution stride expressed as a percentage of straight gait during the 60^0 turn: penultimate footfall 100(15) %, ultimate pivot footfall 150(25) %, turn-execution footfall 580(160) %]. Of interest, the difference between step-width of the ultimate pivot footfall minus step-width of the penultimate footfall positively correlated with the step-width of the subsequent turn-execution footfall (r = 0.57). This suggests the more the ultimate pivot foot is laterally displaced away from the turn direction, the greater the upcoming turn execution step width. Not surprisingly, the Parkinson group had significantly narrower step-width at both the ultimate pivot footfall and turn execution footfall. Mak et al. (2008) cited the work of Winter (1995) who proposed foot placement dictates the position of the COP, and medial/lateral COM acceleration is dependent upon the horizontal distance between these two centers. Mak et al (2008) suggested a narrow COP-COM distance points to less stability when turning.

From an Ataxia-related study utilizing an acoustic late-direction cue is suggestion that when cued-late large regulation of turn execution stride-width for large angle (90^0) as opposed to small angle direction changes may be more problematic for spin-turns than for step-turns in healthy middle-aged controls. Mari, Serrao.,Casli, Conte, Ranovolo, Padua, Francesco et al.

(2012) used motion analysis to compare spatial-temporal gait changes in those with cerebellar ataxia and healthy middle-age matched controls [n = 10, mean 48.1 (10.8) years] who were acoustically late-cued (one step prior upon penultimate foot contact) as whether to continue walking straight or turn with the magnitude (30^0 v. 90^0) & direction (right spin-turn v. left step-turn) received before each trial. The middle-aged controls were required to walk at a slower-than-preferred speed in order to match their ataxic peers [0.81 (.14), instead of 1.15 (.16) m/s]. Mari et al. (2012) reported that healthy middle-aged controls turned successfully (i.e. within 10% of targeted angle) between 82-85% of the time across directions & magnitudes; and again just for the control group, when comparing large 90^0 v. small 30^0 amplitude turning with regards to the % of control participants needing > 2 steps to complete the cued-direction change, a higher % of > 2 steps was seen only for the larger amplitude spin-turn but no difference for the larger amplitude step-turn (% of middle-aged control participants needing > 2 steps i.e. choosing not to complete turn within the turn execution stride for a right spin-turn: 5% @ 30^0 v. 48% @ 90^0; for a left step-turn: 20% @ 30^0 v. 35% @ 90^0). Preferring not to complete a right spin-turn within the 2 steps of the turn-execution stride once cued on the penultimate footfall implied taking an extra step so as to delay the response one footfall in order to execute a right step-turn instead; and on the flip-side, not completing a left step-turn within 2 steps but delaying the response one footfall to execute a left spin-turn instead. With regards to spatial-temporal parameters in the healthy middle-age controls across the initial turn-stride following late-cuing on the penultimate footfall contact, relative to left 90^0 step-turns, right 90^0 spin-turns showed shorter double-limb support [9.23 (2.19) v. 12.95 (2.82) % GC], narrower stride-width [-14.6 (6.3) v. 33.1 (4.1) cm, or when normalized to mean walking stride-width -1.33 (0.89) v. 3.00 (1.24) note the negative sign for the stride width for the right spin-turn indicates the right pivot foot was displaced medial to the left stride line], and longer normalized step length [normalized to leg length 0.59 (.09) v. 0.30 (.09)], but no difference between strategies was seen for stride time, or % of stance or swing. Not surprisingly, when comparing groups, Mari et al (2010) noted that relative to controls, ataxic patients showed a higher % of > 2 step turns for both strategies, which was accompanied by less of an ability to modulate turn execution stride-width (i.e. ataxic patients had less of a turn-execution stride-width reduction during right spin-turns, and less of a turn-execution stride-width increase during ipsilateral step-turns). Moreover, ataxic patients never “crossed-over” to execute a 90^0 contra-lateral spin-turn. Hence, ataxic patients adapted by implementing a multi-step strategy rather than cross-over with a spin-turn. Mari et al. (2012) proposed the greater stride-width modulation (decreased with spin-turns or increased with step-turns) required for large-angle turning imposes a challenge most notably in the ataxic group; and suggested a multi-step strategy (in ataxic patients) may represent a trade-off between turning efficiency and greater stability. Finally, the finding in healthy middle aged adults of just a 5% avoidance of spin-turns at small-amplitude angles (30^0) is in agreement with the data of Akram et al (2010) which suggest the largest spin-turn % to be at small angles (slow walking spin-turn preference 61% @ 45^0; fast walking spin-turn preference 60% @ 45^0). Patla, Prentice, Rietdyk, Allard & Martin (1999) reported that when young adults were cued late (one step prior) for alternate foot placement to avoid normal expected footfall, medial foot placement was preferred 63% of time. Patla et al 1999 suggested that medial foot placement satisfied the requirement of minimal foot displacement and demanded less effort to transfer weight to that foot. Interestingly, Patla et al 1999 further noted that when visually late-cued to avoid typical footfall placement, 95% of the time the medial foot displacement was less than ½ the foot length. Although there is some conflicting suggestion of an elderly step-turn preference when turning at a 40^0 angle (Fuller et al., 2007), preference for medial-foot placement may in part explain both the low percentage of the taking extra footfalls to avoid small-amplitude spin-turns (Mari et al., 2012) and the apparent spin-turn preference at small angles (Akram et al., 2010)..

Chapter III

METHODS

Design

The present study employed a quasi-experimental repeated measures design. The design was quasi-experimental as a convenience sample was used without randomization (Potney & Watkins, 2009). The study was a repeated measures mixed-design as it utilized a grouping attribute between-factor variable: age (young adults v. elderly), and three independent within-factor variables each with two-levels apiece that were repeated across both groups with counter-balancing (Portney and Watkins, 2009). The three independent variables included the categorical variable o walking speed (preferred v. fast), direction-cue time constraint (early v. late), and direction (straight v. right-turn). The dependent variables measured included turn strategy preferences (step-turn, spin-turn, mixed-turn) which were nominal data; and spatial-temporal gait parameters (speed, right stride-length, right & left heel-to-heel base of support) which were ordinal data.

Operant Definitions

Turn strategy operant definitions

Standardized operant definitions are lacking

In the present study, qualitative video analysis was used to assess turn strategy preferences. Video analysis has often been used to classify turn strategies (Hase & Stein, 1999; Thigpen et al., 2000; Taylor et al, 2005). Yet while the literature has provided an overall general description to contrast step-turns (pivot on left foot to turn right) v. spin-turns (pivot of right foot to turn right) (Hase & Stein, 1999; Taylor et al, 2005; Paquette et al. 2008; Strike & Taylor, 2009; Xu et al., 2004; Akram et al., 2010; Fino et al., 2015; Conradsson et al., 2017), standardized operant definitions which are universally applied are lacking, especially with regards to what defines a mixed-turn. For example, Dixon, Stebbins, Theologis, & Zavatsky (2013) distinguished 90^0 step-turns from spin-turns in children based upon identifying the stance-limb in which the most horizontal pelvic rotation into the turn direction took place, with a spin-turn scored when the stance limb with the greatest pelvic rotation was ipsilateral v. spin-turn when contra-lateral. Yet in elderly subjects early-cued to perform 30^0 & 90^0 turns across different speeds, Akram et al. (2010) defined the onset of the direction change based upon a 2SD change in ML foot displacement, and observed the reorientation process often occurred across two steps including a small preparatory step, and a main step in which the medial-lateral displacement was greater. Akram et al.

(2010) differentiated step-turns verse spin-turns based upon which of the two re-orienting steps initiated a larger medial-lateral displacement towards the turn direction, yet despite the use of re-orienting steps, did not consider a mixed-turn category. As only right turns were analyzed, Akram et al. (2010) defined a right step-turn as the right foot having greater ML displacement toward the right turn direction, and a right spin-turn when the left foot had a greater ML displacement toward the right turn direction. Some of the difference in operant definitions of turn strategies may in part stem from the use of varying task constraints (i.e. turn angles, walking speeds, response times) and sample groups (i.e. young, elderly, patient-groups).

With this awareness of the lack of clarity in classifying turn strategies, there have been recent attempts to validate quantitative biomechanical markers against the “gold standard” of visual video rating, with some techniques employing algorithms and motion analysis to either tract pelvic COM trajectory, or inertial measurement devices to assess trunk & limb angular velocities (Golyski & Hendershot, 2017; Fino, Frames, & Lockhart, 2015). While these quantitative techniques appear to show promise based upon good-to-excellent accuracy relative to visual video rating (i.e. accuracy relative to video: pelvic COM method+90%, angular velocity method +80%), accuracy is slightly less when late-cues for direction are employed and when assessing patient groups such as amputees (Golyski & Hendershot, 2017). Moreover, in addition to being costly, at present these quantitative measures of turn performance do not account for the use of a multi-step strategy i.e. mixed-turns (Golyski & Hendershot, 2017).

As mentioned, there is no minimum threshold of change in step-width or base of support upon which to differentiate step-turns v. spin-turns, let alone mixed-turns. Nonetheless, it can be gleaned from the literature that relative to straight gait, when making 60^0 step-turns, young adults show about a 3 fold increase in stride-width upon turn execution, while the elderly about a 2.6 fold increase. For example, Huxham, Gong, Baker, Morris & Iansek (2006) reported the following stride-width changes in young adults early-cued for 60^0 step-turns: straight gait 9.8(2.5), turn-execution 31.1(3.8) cm; and Huxham, Baker, Morris, & Iansek (2008) for healthy elderly-controls (in a Parkinson related-study) making early-cued 60^0 right step-turns: straight gait 10.9(2.4), turn execution 28.0(5.7) cm. Moreover, for 90^0 step-turns, the increase in turn-execution stride width may be slightly higher at 3-3.5 fold increase. This is suggested from the stride-width changes of Mari, Serrao, Casli, Conte, Ranovolo, Padua, Francesco, et al. (2012) for healthy middle-aged controls (in an ataxia-related study) making late-cued 90^0 right step-turns: turn-execution 33.1(4.1) cm, or when normalized to straight gait 3.00(1.24); and in the data of Strike & Taylor (2009) for young adults making early-cued 90^0 right step-turns [stride-width normalized to leg-length: straight gait .12(.05) LL, turn execution .42(.1) LL. Objective measures for stride-width changes during spin-turns are harder to come by. Nonetheless, Huxham et al. (2008) reported that when making early-cued 120^0 right turns, healthy elderly controls followed an initial step-turn maneuver with a second cross-over maneuver (i.e. a spin-turn) which resulted in a negative turn execution stride-width of -13.3(6.1) cm, or a -1.2 fold decrease when normalized to straight gait.; and Mari et al. (2012) for healthy middle-aged controls making late-cued 90^0 left spin-turns: turn execution -14.6 (6.3) cm or when normalized to straight gait a -1.33(.89) fold decrease. While the above review of turn-execution stride-width changes provides specific references numbers in terms of cm or percentage of leg length, these reference numbers cannot be applied to the present study since 3D motion analysis was not used. Notwithstanding, these reference numbers reinforce the notion that relative to straight gait, stride-width during spatially-unconstrained 90^0 step-turns easily doubles, whereas turns negative when crossing-over during 90^0 spin-turns.

Framework & approach used for turn strategy assessment

Given the one camera video analysis methods employed in the present study could not reliably quantify turn-execution stride-width changes in units of cm (interval data), the turn-strategy operant definitions were instead based upon the work of Donelan, Kram & Kuo (2001) who suggested preferred step-width during straight gait approximates foot-width and represents a compromise between opposing metabolic costs for step-to-step COM displacement (with greater costs at wider step-widths) and swing-limb deflection (with greater costs at narrower step-widths). In particular, Donelan et al. (2001) measured metabolic costs (VO_2 & CO_2 consumption over 3-min of steady-state treadmill walking) and mechanical costs (GRF & moments walking across two force plates) in young adults whose step-width was manipulated between 0.0- 0.45 leg-length (LL). Donelan et al. (2001) found the observed preferred step-width of 0.13(.03) (LL) did not differ from either the lowest metabolic cost inferred at 0.12(.05) LL from a quadratic fit of the data points, or the average participant foot-width value of 0.11(.01) LL = 10(1) cm. Moreover, Donelan et al. (2001) noted for step-widths beyond that preferred, the increase in both metabolic & mechanical costs was not linear, but a function of the square of step-width. Hence, metabolic and mechanical costs showed a positive direct relationship to each other, increasing 45% and 54%, respectively, as step width widened from 0.15 LL to 0.45 (LL). Additionally, the metabolic costs for a narrow step-width of 0.0 LL was 8% greater than that seen at 0.10 LL. Donelan et al. (2001) suggested a wider than preferred step-width increases metabolic cost as greater mechanical work is needed to accelerate the COM from one limb to the other (i.e. step-to-step transition cost); and in the case of a narrower than preferred step-width, higher metabolic demand is required for the greater lateral limb swing to avoid stance limb contact.

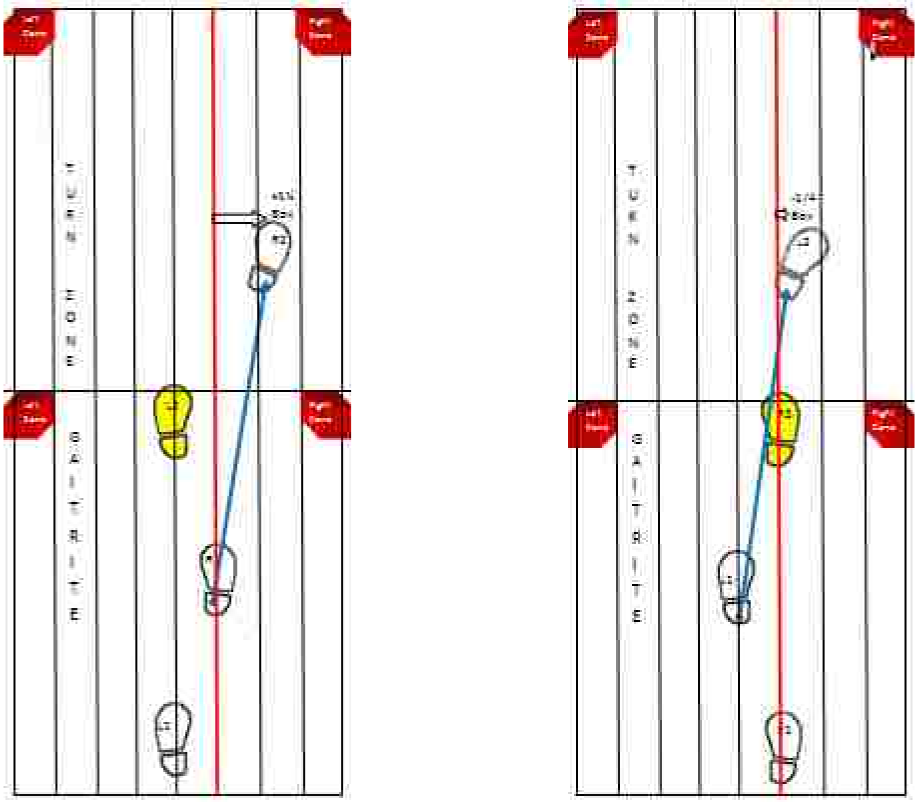
Kinovea software

In order to crudely quantify the amount of change in step-width during turn execution, the present study used Kinovea[a] Video Analysis Software (v.

0.8.15). Kinovea is a video player that can be downloaded free of charge at https://www.kinovea.org Movement performance videos can be uploaded to Kinove to allow basic analysis functions including calibrating to measure distance (i.e. width). Thus, the Kinovea software was used to overlay a perspective grid on the plane of the video image of the Gaitrite and its adjoining turn zone, which allowed the widening or narrowing of the turn execution stride to be quantified in ordinal units of average foot width. This was possible since the perspective grid partitioned the Gaitrite and its adjoining turn zone into eight equal lanes or boxes along its entire depth. Given the Gaitrite has a known width of 89 cm, and its plane was perpendicular to the video camera axis, each one of the eight lanes (or boxes) ≈ 11 cm in the frontal plane, which approximated both the average step-width of straight gait & average foot-width as measured by Donelan et al. (2001). As the Kinovea software also includes a tool which permitted the drawing of lines between successive ipsilateral right & left ankle-centers atop the perspective grid, this facilitated the measurement of turn execution step-width in ordinal units of the number of frontal plane “lanes” also referred to as “boxes”. Hence this method of measuring a relative change in step width based upon the number of horizontal boxes is referred to as the “Box Method” for scoring turn strategy.

Operant definitions used for step-turn and spin-turn

Given the literature suggest that relative to straight gait, during spatially-unconstrained 90^0 direction changes, stride-width easily doubles during step-turns, yet turns negative during spin-turns (Huxham et al., 2006, 2008; Strike & Taylor, 2009: Mari et al., 2012), and an increase in metabolic costs for locomotion ensues as step-width widens or narrows from its preferred straight-gait value which approximated foot width (Donelan et al., 2001), in the present study a right step-turn was operationally defined when the increase in ML horizontal distance across two-successive ipsilateral right ankle-centers met a minimum threshold of ≥ +1¼ horizontal box units with the widening in the same direction as the right turn; whereas a right spin-turn was defined when the decrease in ML horizontal distance across an ipsilateral right followed by contra-lateral left ankle-center resulted in a negative separation meeting a minimum threshold of ≤ -¼ horizontal box units with the crossing in the same direction as the right turn (*Figure 1.* and *Figure 2.*). Please note, all figure and table displays contained throughout this dissertation manuscript, including videos, photographs, drawings, charts & graphs, were created by the principal investigator of the present study.



a. right step-turn ≥ +1¼ box

b. right spin-turn ≤ -¼ box

Figure 1. Schematic drawings of the minimum threshold of relative change in step-width during turn execution for a step-turn (a) and spin-turn (b) based upon the Box Method. A perspective grid is shown overlaid the plane of the Gaitrite and its adjoining turn zone, and given the Gaitrite has a width of 89 cm, each of the eight boxes (or lanes) contained in the grid has a width ≈ 11 cm which approximates both the preferred step-width and width of the foot (Donelan et al., 2001). For the present study, the reference for a relative change in step-width when assessing a right step-turn was the AP line of forward progression bisecting the ankle of the previous right penultimate footfall; whereas the reference for a relative change in step-width when assessing a right spin-turn was the AP line of forward progression bisecting the ankle of the preceding right ultimate pivot footfall. For each strategy, the AP reference line is shown bolded in red, and the ultimate pivot footfall is highlighted in yellow. For the sake of clarity, the bolded red AP reference line and the 4th line from the right of the perspective grid are made to coincide, however, in reality this was often not the case.

a. right step-turn +2¼ boxes b. right spin-turn -2 boxes

Figure 2. Photo image of a right step-turn (a) and right spin-turn (b).The right step-turn shows an increase in the ML horizontal distance across two-successive ipsilateral right ankle-centers equaling +2¼ boxes (a), and the right spin-turn showing a decrease in the ML horizontal distance across an ipsilateral right followed by contra-lateral left ankle-center equaling -2 boxes of separation (b).

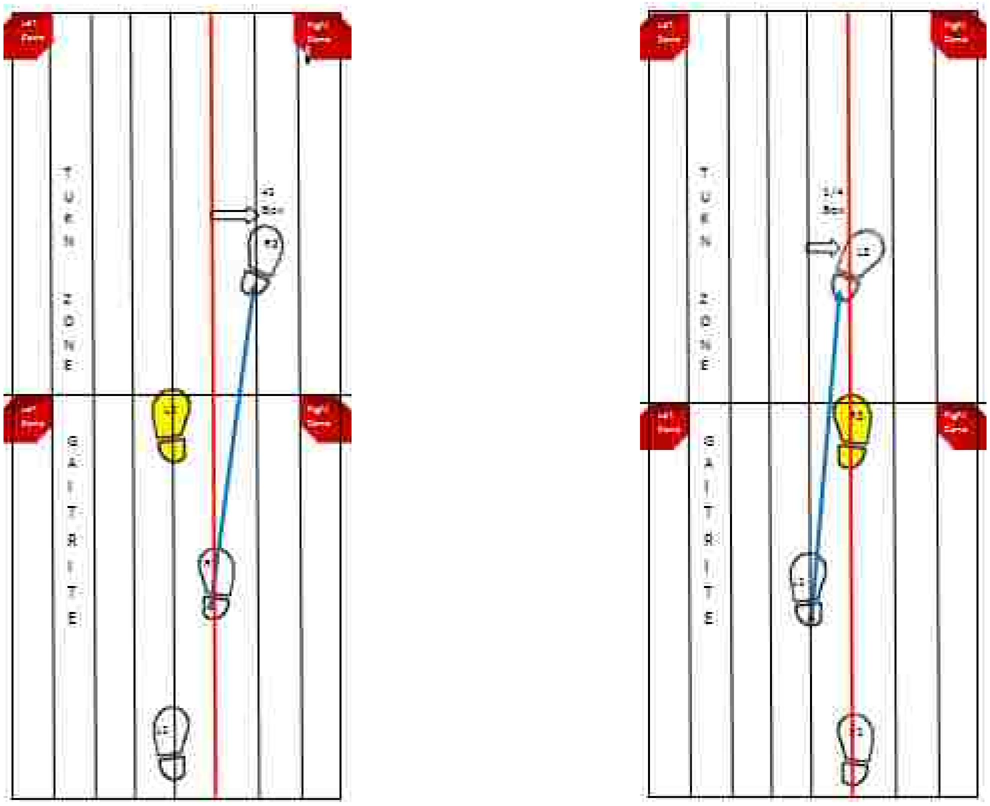
Operant definitions used for mixed-turns

The operant definition of what constitutes a mixed-turn is even less conceived in the literature. Thigpen et al. (2000) was the first researcher to use the phrase “mixed type of turn” in contrasting age-related differences in performance of the 180^0 turn of the TUGs, as young adults were described as using a discreet pivot resembling a rapid feed-forward open-looped task, as opposed to the elderly who at times executed a mixed-strategy consisting of a series of partial pivots & extra steps simulating a more feedback closed-looped task.

Small amplitude mixed-step-turn & mixed-spin-turn

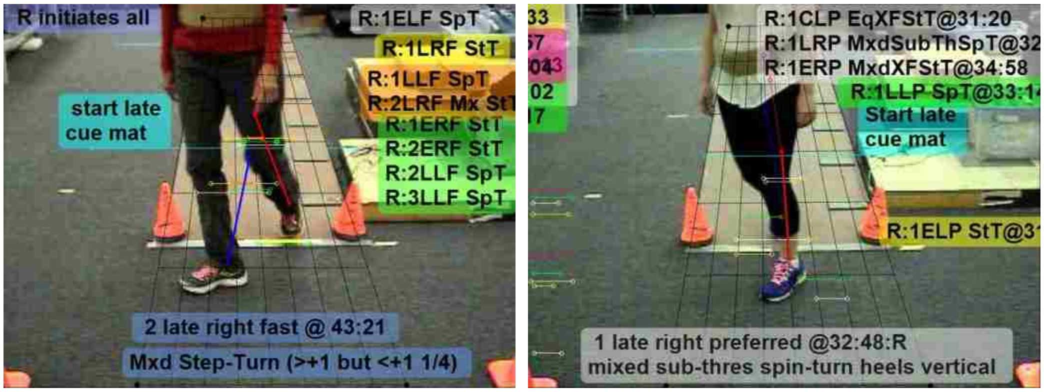
Although Thigpen et al. (2000) appears to be unique in describing a mixed-strategy and suggesting its use as an early indicator of turning difficulty in the elderly, several other authors have reported a decrease in the capacity to modulate turn execution stride-width in both Parkinson and ataxic populations i.e. less of an increase in turn execution stride-width during step-turns which may pose an increased threat to stability, and less of a reduction in turn execution stride-width during spin-turns which may diminish trunk rotation & regulation of COM acceleration (Mak et al., 2008; Mari et al., 2012; Conradsson et al., 2017; Huxham et al.,2008). It is interesting to note Leach, Mellon, Palumbo, Coni, Bandinelli & Chiari (2016) reported smaller turn angles in retrospective recurrent fallers and suggested it may indicate a narrower window of stability when changing direction. Additionally, narrower turn-execution stride-width has also been reported during discrete step-turns when cued-late as opposed to early. Patla et al.,(1999) early-cued v. late-cued 60^0 step-turns in young adults without spatial constraints and reported turn-execution stride-width was wider during for the early cued-condition (53.6 v. 47.4 cm). However, in a Parkinson-related study, Conradsson, Paquette, Lokk & Franzen (2017) early v. late-cued for a 180^0 direction change and when just reporting on the healthy elderly control group, step-width (BOS) values for the 1st turn execution step during step-turns across cue conditions were similar (early 0.13 v. late 0.17 m), however, for spin-turns the crossover (denoted by a negative) was greater when cued-late as opposed to early (early -0.03 v. late -0.13 m). In interpreting these conflicting findings between Patla et al. (1999) and Conradsson et al., (2017) with regards to early v. late-cued turn-execution step-width changes, it is important to consider the smaller 60^0 step-turn of Patla et al. required just one turn execution step, whereas the larger angle 180^0 turn of Conradsson et al. necessitated a series of about 3 turn execution steps.

Thus, for the purposes of the present study, small-amplitude turning was considered one type of mixed-turn strategy with a mixed-step-turn operationally defined when the increase in ML horizontal distance across two-successive ipsilateral right ankle-centers was ≥ +1 but < +1¼ horizontal box units; and a right mixed-spin-turn was defined when the decrease in ML horizontal distance across an ipsilateral right followed by contra-lateral left ankle-center resulted in a separation between +1/4 to 0 box yet failed to turn negative (*Figure 3.*).



a. mixed-step-turn ≥ +1 but < +1¼ box b. mixed-spin-turn +¼ to 0 box

Figure 3. Schematic drawings of the relative change in step-width during turn execution for a right mixed-step-turn (a) and right-spin-turn (b) based upon the Box Method.



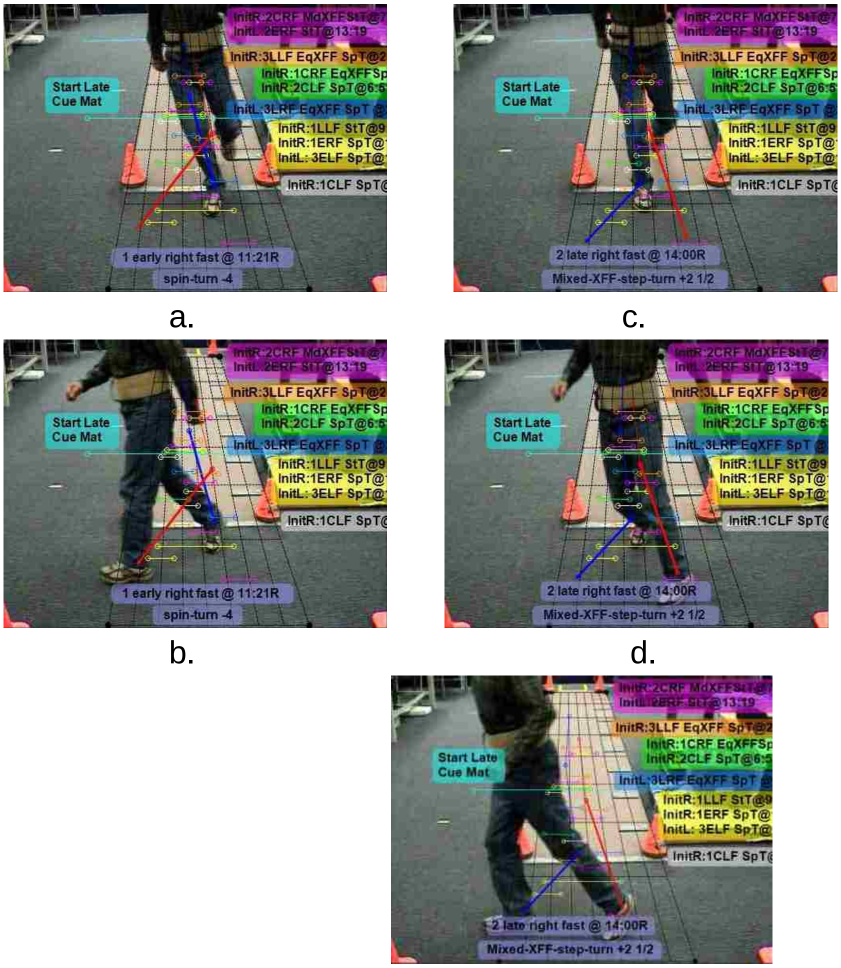
a. right mixed-step-turn b. right-mixed-spin-turn

Figure 4. Photo image of a right mixed-step-turn (a) and right mixed spin-turn (b). The right mixed-step-turn shows an increase in the ML horizontal distance across two-successive ipsilateral right ankle-centers equaling ≥ +1 but < +1¼ boxes (a), and the right mixed-spin-turn shows a decrease in the ML horizontal distance across an ipsilateral right followed by contra-lateral left ankle-center equaling a separation between +1/4 to 0 box (i.e. heels vertical) as the lack of cross-over failed to turn the separation negative (b).

Extra footfall mixed-step-turn & mixed-spin-turn

As noted above, Thigpen et al. (2000) observed that relative to young adults, across trials healthy elderly less frequently completed the 180 deg turn of the TUGS just using 2 discreet pivots or less (100% v. 58%), with 7 of the 15 healthy elderly participants requiring 3-5 total steps. Additionally, as also previously noted, Fuller et al. (2007) found that in the elderly use of a double as opposed to single-step strategy when early-cued to turn 40^0 correlated with a low balance confidence score. Related to this issue of the elderly requiring additional steps to turn, there is some suggestion from the data in a Parkinson-related study that when cued-late 1step prior (.6 m), healthy elderly controls took an extra step before turning. Thus although Conradsson et al. (2017) found no early-cue v. late-cue difference in step-turn v. spin-turn preference, when late-cued healthy elderly controls nonetheless delayed the onset of ML foot displacement about 1 step beyond the location chosen to initiate an early-cue turn (early-cue 0.09 s before the turn-point v. late-cue -0.45 s after the turn-point). As previously stated, 99% of turning failures are believed to be due to the inability to arrest forward momentum, with the elderly on average requiring greater warning time (115 ms) & distance (15 cm) when the response time is temporally constrained under 750 msec. due to a delay in transitioning from acceleration to deceleration during the turn approach step (Cao et al; 1997, 1998). Moreover, there is some suggestion the elderly may be more inclined when late-cued to take an extra step or footfall when spatially configured for a spin-turn as opposed to a step-turn. Gilchrist (1998) reported that when late-cued during straight gait, relative to young adults, the elderly were less capable of a rapid lane shift after just 1 post-cue center lane footfall (elderly 26% v. young 58% of trials), especially when the lane-shift necessitated a "cross-over" spin-turn maneuver as opposed to "side-step" step-turn maneuver (frequency of 1 post-cue center lane footfall: spin-turn maneuvers: elderly 1.5% v. young 31.2% of trials; step-turn maneuvers: elderly 51.6% v. young 84.9% of trials). Gilchrist (1998) suggested the greater threat to balance imposed by the crossing of limbs during the cross-over maneuver likely accounted for it not being the preferred first option strategy when needing to execute a rapid lane shift within just 1 post-cue center lane footfall. Gilchrist (1998) proposed the greater overall frequency of the elderly needing to take more than 1 post-cue center lane footfall when cued-late to shift lanes likely permitted a more incremental ML displacement of the COM; however, the prolonged distance of forward progression brought-about by the taking of an extra footfall could increase the risk of contact with nearby objects. A similar finding can be gleaned from an ataxia related study whereby Mari et al. (2012) found that healthy middle-aged controls [mean 48.1 (10.8) years] acoustically late-cued were inclined to take an extra step to avoid a large 90^0 v. small 30^0 right spin-turn (48 v. 5%) yet were not inclined to take an extra step to avoid a large 90^0 v. small 30^0 left step-turn (35 v. 20%).

Given the suggestion that the use of extra footfalls may be an early indication of a decline in elderly turn performance (Thigpen et al., 2000), and may be a strategy to avoid the instability of late-cue limb crossover (Gilchrist, 1998) particularly for large angle (90^0) spin-turns (Mari e al., 2012), the present study considered the use of extra steps/footfalls when turning as a second type of mixed-turn strategy. However, determination of when an extra footfall may have been taken was individually based for each participant. Thus, for the present study the operant definition of an extra footfall mixed-turn was failing to ML displace one's footfall the required threshold of either a mixed-step-turn (+1 to < 1¼ box) or mixed-spin-turn (+1/4 to 0 box), subsequent to the contralateral footfall being planted at a similar anterior-posterior spatial location where it served as the pivot foot for a step-turn or spin-turn executed in another trial (i.e. the reference trial) of the same speed-block & which had been initiated from the start box with the same ipsilateral foot. (The reference trial is often an early-cue trial). As such two sub-types of extra footfall mixed-turns are recognized: a mixed-extra-footfall step-turn whereby the extra step avoids a spin-turn; and a mixed-extra-footfall spin-turn whereby the extra step avoids a step-turn (see *Figure* 5. and *Figure* 6.). Finally, it is worth recalling that when late-cued to turn, both young adults & the elderly (Patla et al.,1991; Cao et al., 1997, 1998) require a minimum response time of 1 post-late-cue step prior to initiating the turn response in order to decelerate, plan & ML re-direct the COM. As such, another requirement before scoring an extra footfall mixed-turn is that participants must have been allowed a minimum response time of 1-post-late-cue-footall.

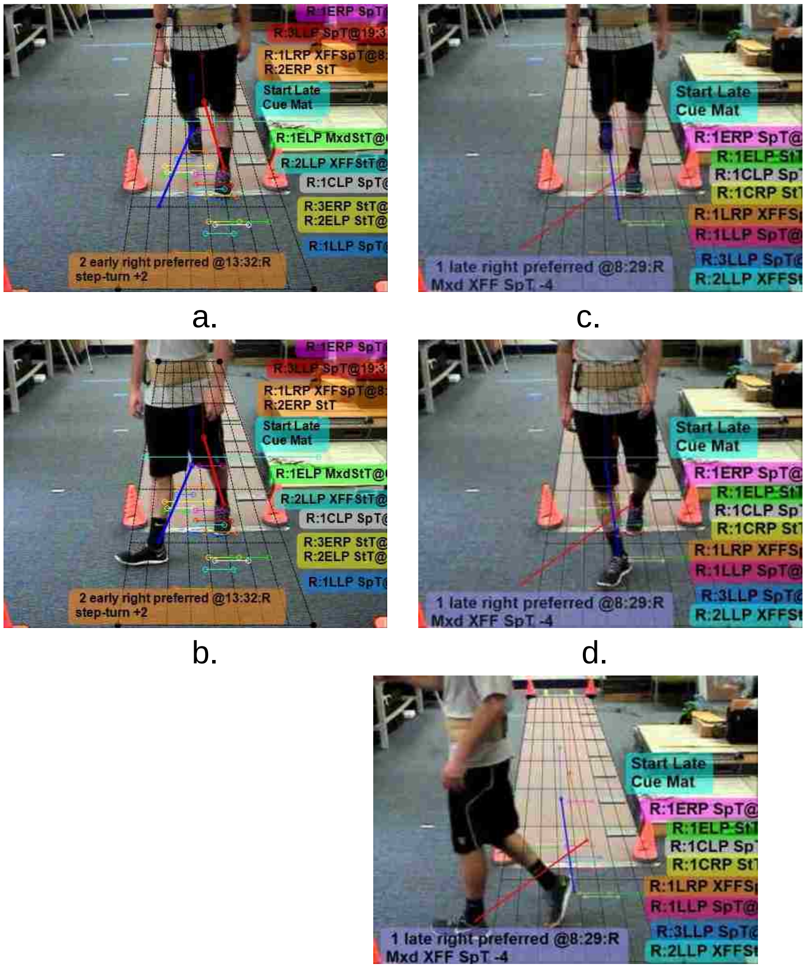


a. c.

b. d.

e.

Figure 5. Photo image showing the early-cue fast speed right spin-turn reference trial (a-b), and a late-cue fast speed right mixed-extra-footfall-step-turn (c-e). Note that despite the same AP spatial location of the right foot in photos a-d, the spin-turn threshold (≤ -¼ box) is met in b, but not even a mixed-spin-turn threshold (+1/4 to 0 box) is met in d. Instead the spin-turn is avoided as an extra-step/footfall allows for a step-turn in e.



a. c.

b. d.

e.

Figure 6. Photo image showing the early-cue preferred speed right step-turn reference trial (a-b), and a late-cue preferred speed right mixed-extra-footfall-spin-turn (c-e). Note that despite the same AP spatial location of the left foot in photos a-d, the step-turn threshold (≥ +1¼ box) is met in b, but not even a mixed-step-turn threshold (+1 to < +1¼ box) is met in d. Instead the step-turn is bypassed or avoided as an extra-step/footfall allows for a spin-turn in e.

Finally, based upon the above operant definitions for all three strategies (step-turns, spin-turns & mixed-turns), Kappa (K) intra-rater reliability (agreement) of turn strategy scoring of the same trial across two sessions was carried-out for right turns only given left turns were not included in the analysis. The Kappa intra-rater reliability (K) for scoring turn strategy performance across two separate sessions was found to be K = 0.945, (*p* <0.000), 95% confidence interval (0.908, 0.982). According to Portney & Watkins (2009), a K > 0.80 is considered excellent agreement. Thus, based upon the kappa analysis, the principal investigator of the present study who performed the video analysis for turn strategy preferences was found to be a reliable rater based upon the approach of using Kinovea software and the operant definitions established for step-turns, spin-turns, and mixed-turns in the present study. (Appendix A).

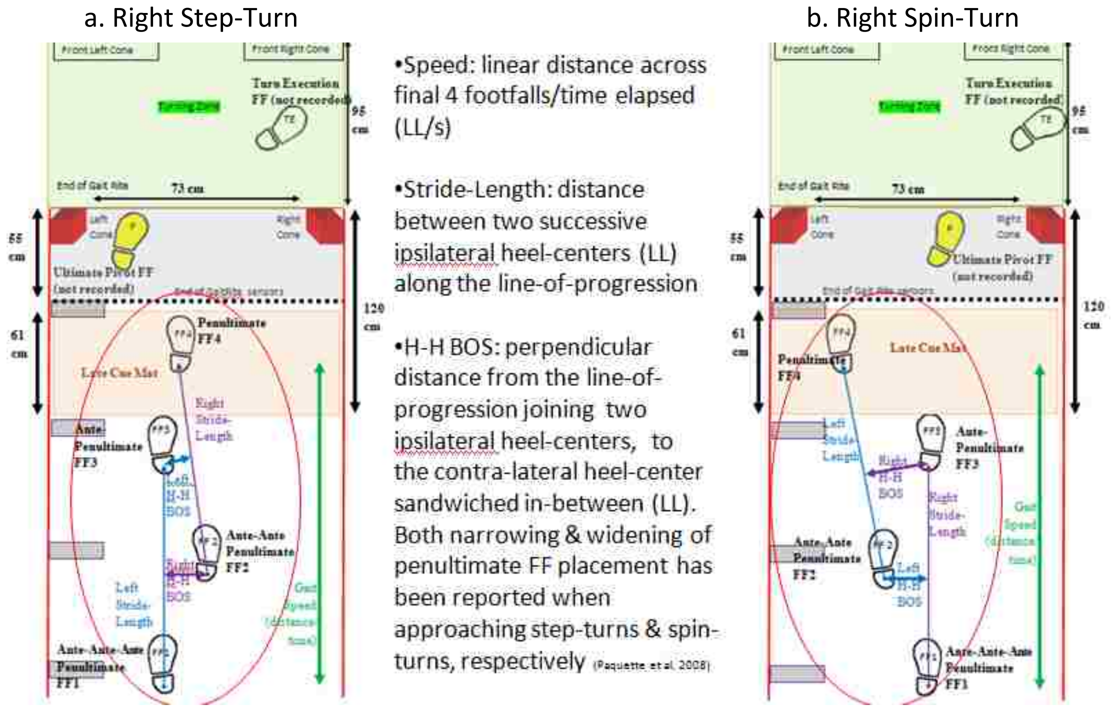
Spatial-temporal gait operant definitions

The Gaitrite

The spatial-temporal gait variables analyzed in the present study included gait speed, stride-length, and right & left heel-to-heel base of support. The GAITRite^{TM} 14-Foot Gold[b] was used to record these variables. The GAITRite^{TM} 14-Foot Gold is an electronic 518.2 cm long x 90.2 cm wide x .0.6 cm thick walkway mat with embedded pressure sensors connected to a computer via an interface cable. The active area of the mat is 427 cm long x 61 cm wide and the spatial resolution is 1.27 cm. Data is collected at a sampling rate of 80 Hz. As a participant walks over the mat, the sensors close under pressure, enabling collection of spatial and temporal gait parameters. The GAITRite^{TM} system is both reliable and valid for measuring spatial and temporal gait parameters in the young adults and the elderly at both a preferred and faster than preferred walking pace for most spatial and temporal parameters (McDonough, Batavia, Chen, Kwon, & Ziai , 2001; Lord, Rochester, Baker & Nieuwboer, 2008; Bilney, Morris, and Webster, 2003). Moreover, individual step measurements have been reported to be within 1.5 cm and 0.02 seconds thus validating calculations for step-to-step variability (Webster, Wittwer, & Feller, 2005). A commercially available gait belt that is routinely used by physical therapists during ambulation training was placed around the participant in order to provide additional safety precautions during walking.

Limited to final four recorded footfalls absent the pivot

As the work of Paquette et al.(2008), which analyzed the final four approach footfalls ending in ultimate pivot footfall placement, suggest anticipatory spatial-temporal changes relative to straight gait are initiated a least as early as the penultimate footfall, only the final four footfalls recorded on the Gaitrite were included for analysis in the present study. The Gaitrite requires a minimum of 4 consecutive footfalls to compute data, and 4 footfalls was the minimum cut-off used by McDonough et al. (2001) in their Gaitrite reliability/validity study. Thus, within the context of the present study, each of the gait variables was computed by the Gaitrite using only 4 footfalls. Moreover, it is also important to note that the last 55 cm of the Gaitrite carpet lacks pressure sensors and is not an active area. (Figure 7.). As such the present study was rarely able to record Gaitrite data for the all important ultimate pivot footfall and hence was eliminated for the sake of consistency. Instead the final recorded footfall on the Gaitrite corresponded to the penultimate footfall (FF) in 76% of trials & to the antepenultimate FF in 24% of trials (Appendix B). Thus in the majority of trials the order of the final four recorded approach footfalls (FFs) was as follows: ante-ante-ante penultimate (FF1), ante-ante penultimate (FF2), ante-penultimate (FF3), and penultimate (FF4). (Figure1.) Unfortunately, the ultimate pivot footfall is believed to be the footfall which makes the greatest contribution to ML accelerating the COM into the turn direction (Glaister et al., 2008), and the only footfall capable of doing so when late-cued and a reactive feedback response is required (Hollands et al., 2001). Accordingly, in only a small percentage of trials (overall about 16%) was a post-late cue footfall recorded (Appendix C). The percentage of trials with a post-late cue footfall was especially low at fast speed [1 post-late cue FF: right-turns 11% (15%preferred, 7% fast) & straight 22% (preferred 32%, fast 12%)]. The absence of ultimate pivot footfall and post-late cue footfall data is a major limitation of the study.



a. Right Step-Turn

b. Right Spin-Turn

•Speed: linear distance across final 4 footfalls/time elapsed (LL/s)

•Stride-Length: distance between two successive ipsilateral heel-centers (LL) along the line-of-progression

•H-H BOS: perpendicular distance from the line-of-progression joining two ipsilateral heel-centers, to the contra-lateral heel-center sandwiched in-between (LL). Both narrowing & widening of penultimate FF placement has been reported when approaching step-turns & spin-turns, respectively (Paquette et al, 2008)

Figure 7. Schematic drawing illustrating absence of sensors across the last 55 cm of Gaitrite and spatially temporal operant definitions. The region of the Gaitrite lacking sensors in shaded in gray, the region of the late-cue mat is shaded in orange, and the turn zone is shaded green. The four final footfalls which were included in the analysis are enclosed within a red circle. Due to the absence of Gaitrite sensors beyond the late cue mat yet before the turn zone, the ultimate pivot footfall could not be analyzed, few post-late footfalls were included, and in the majority of trials the final recorded footfall (FF4) corresponded to the penultimate foot. While the same spatial-temporal operant definitions applied for step-turns & spin-turns, anticipatory penultimate step-width narrowing has been reported when approaching step-turns (a), whereas penultimate step-width widening has been reported when approaching spin-turns (b) (Paquette et al., 2008).

Operant definitions of Gaitrite variables of interest: speed, stride-length, heel-to-heel base-of-support

The Gaitrite variables which were the focus of this study were: normalized speed, combined right/left normalized stride-length, right normalized H-H BOS, and left normalized H-H BOS (Figure 7.). In agreement with the Gaitrite technical reference manual (CIR Systems, Inc., 2013), speed was operationally defined as the linear distance (cm) from the heel-center of the first footfall to the heel-center of the final fourth footfall, divided by the time (s) spanning first sensor contact of the first footfall to first sensor contact of the final fourth footfall. Speed was then normalized to leg length (LL/cm), such that normalized gait speed was expressed in units of LL/s. Stride-Length was operationally defined as the distance (cm) between two successive ipsilateral heel-centers along the line-of-progression (CIR Systems, Inc., 2013). Stride-length was then normalized to leg-length (LL/cm), such that normalized stride-length was expressed in units of LL. Given only the final four footfalls were analyzed, the Gaitrite computed one left stride-length measure and one right stride-length measure. However, as participants were free to initiate gait at the start of each trial leading with either foot, the right v. left stride-sequence varied across trials and was not 50%/50% across groups and conditions (Appendix C). In light of this variation in stride sequence, a decision was made to combine (collapse) right & left normalized stride-length measures to get an average.

Heel-to-heel base of support (H-H BOS) was operationally defined as the perpendicular distance from the line-of-progression joining two ipsilateral heel-centers, to the contra-lateral heel-center sandwiched in-between (LL) (CIR Systems, Inc., 2013) . In the case of right H-H BOS the right foot is intermediate, and in the case of left H-H BOS, the left foot is intermediate.

This operant definition used by the Gaitrite for H-H BOS is the equivalent of stride-width, given both represent the perpendicular distance of the contralateral heel-center to the line of progression (direction of progression); and for linear straight gait, stride-width and step-width are both equivalent (Huxham, Gong, Baker, Morris, & Iasek, R. (2006). Each BOS measure was then normalized to leg-length (LL/cm), such that right & left normalized H-H BOS was expressed in units of LL. Similar to stride-length, the four recorded footfalls allowed the Gaitrite to compute one H-H BOS measure on each side; however, unlike stride-length, the right and left measures were not combined or averaged as Paquette et al. (2008) reported opposing step-width (i.e. medial-lateral placement) changes in the penultimate footfall (relative to the ante-penultimate footfall & straight gait) when comparing early-cued 40^0 step-turns (narrowing) v. spin-turns (widening) (Figure 7.). Moreover, along with a trunk/hip roll strategy, ML ultimate & penultimate foot placement is the second strategy employed in augmenting ML COM acceleration (Patla et al., 1999; Hollands et al., 2001; Paquette et al., 2008). It is also important to consider that medial foot placement (i.e. step-width narrowing) of the penultimate footfall will contribute to narrowing of the H-H BOS corresponding to the preceding antepenultimate FF, whereas lateral foot placement (i.e. step-width widening) of the penultimate footfall will contribute to widening of the H-H BOS corresponding to the preceding antepenultimate FF. Finally, as just mentioned, when comparing the change in step-width as reported by

Paquette et al (2008) across the ante-penultimate v. penultimate footfalls relative to straight gait for each turn-strategy individually, a greater extent of step-width narrowing was seen across the step corresponding with penultimate footfall placement as opposed to the antepenultimate footfall during step-turns, and a greater extent of step-width widening was seen across the step corresponding with penultimate footfall placement as opposed to the antepenultimate footfall during spin-turns. Thus, given that in the present study data for only right turns were included in the analysis, it seems reasonable to assume that the data showing a H-H BOS increase (i.e. right H-H BOS widening) primarily reflects data recorded during right spin-turns, whereas data showing a H-H BOS decrease (i.e. left H-H BOS narrowing) primarily reflects data recorded during right step-turns (Figure 7.).

Inclusion of partial penultimate & antepenultimate Gaitrite footfalls

As previously mentioned, due to the absence of sensors across the last 55 cm of length of the Gaitrite carpet the, the ultimate pivot footfall was scarcely captured (only about 7% of trials), and hence for consistency was omitted from the analysis. Accordingly, in an effort to otherwise preserve as many footfalls in as close proximity of the turn zone as possible, partial penultimate & antepenultimate fourth final footfalls (FF4) were not eliminated but were instead included in the analysis. In order to preserve and include partial final footfalls (FF4) in the analysis, a simple formula was developed which when applied viewing the Gaitrite data in Excel, essentially substituted the foot length of the previous ipsilateral second footfall (FF2) in place of the partial fourth final footfall (FF4) in order to estimate a correction for spatial parameters (Appendix E).

Subjects

The subjects included healthy community-dwellers: 10 young (21-40 years) and 10 elderly (65 to 75 years) volunteer subjects. All young participants were recruited from the Seton Hall University community through either word of mouth, or through the placement of on-campus advertisement flyers. The majority of senior participants were recruited through the principle researcher visiting and making an appeal at local fitness & community centers and senior organizations with only a few being recruited from the SHU community. The inclusion criteria included: independent ambulator (no assistive device); intact cognitive ability ≥ 24/30 on the Mini Mental State Examination; functional balance to suggest low fall risk ≥ 20/24 on Dynamic Gait Index; balance confidence to suggest a non-faller ≥ 67% on Activities-specific Balance Confidence Scale; and right-handers/right-footers. The exclusion criteria included: fall history over the previous year; vestibular involvement / dizziness with head movements; uncorrected visual impairment; muscular-skeletal injury over past 6 months; neuro-muscular disease; cardio-respiratory insufficiency; uncontrolled diabetes; and uncontrolled high blood pressure; shortness of breath; debilitating arthritis; leg weakness; limited motion; pain; and pregnancy.

The study was approved by the Seton Hall Institutional Review Board (Appendix F). Thus, upon arrival to the testing session, all potential subjects were required to read an informed consent form (Appendix F), and as participation in this study required video recording, individuals were also required to read a separate video consent form. (Appendix G). Individuals were given the opportunity to ask questions. If after reviewing the consent forms and asking any related questions potential subjects were still willing to volunteer to participate, they were required to sign both consent forms and were advised they may withdraw from the study at any time. Participants were provided with a hard copy of the signed consent forms.

Standardized tools, other Instrumentation and Lab Set-Up

In addition to use of the Kinovea[a] video analysis software and the Gaitrite[b], which were previously described, standardized tests and other instrumentation were also used in the study.

The Mini-Mental State Examination (MMSE) (Appendix H) served as a means to quantify cognitive function and screen for cognitive loss in study participants. The MMSE consists of 11 items which test an individual on orientation, attention, calculation, recall, language and motor skills. The maximum possible score on the MMSE is 30/30. The MMSE is both reliable and valid for measuring cognitive impairment (Folstein,, Folstein, & McHugh, 1975; Mitrushina & Satz, 1991; Molloy and Standish, 1997). Both adequate test–retest reliability after one year (r=.45-50) (Mitrushina & Satz, 1991) and adequate inter-rater reliability (ICC=.69) (Molloy and Standish, 1997) have been demonstrated. Good concurrent validity has been shown with the Wechsler Adult Intelligence Test verbal IQ (r=.78) and performance IQ (r=66) (Folstein,, Folstein, & McHugh, 1975). A minimum score of 24 points on the MMSE has been suggested to be typical of elderly community dwellers (Folstein, Folstein & McHugh, 1975). However, both its sensitivity and specificity have been shown to be effected by both age and education (Anthony, LeResche, Niaz, von Korff, & Folstein, 1982; Tombaugh, Hubley, McDowell & Kristjason, 1996).

The Dynamic Gait Index (DGI) (Appendix I) was used to asses participants' ability to modify gait in response to changing task demands (Whitney, Wrisley & Furman, 2003). The DGI is effective in predicting the likelihood for falls in community-dwelling older adults. The DGI consists of eight different gait tasks that include: walking at different speeds, walking with horizontal and vertical head movements, walking around and over objects, walking and abruptly stopping after a 180^0 pivot turn, and ambulation up and down stairs. Performance of these tasks are rated using an ordinal scale from 0 (poor) to 3 (excellent). Scores on the Dynamic Gait Index range from 0 to 24. The DGI as a measure of functional balance capability has been found to be both reliable and valid (Wrisley, Walker, Echternach, & Strasnick, 2003; Hall & Herdman, 2006; Shumway-Cook, Baldwin, Polissar, and Gruber, 1997; Whitney, Wrisley & Furman, 2003; Cattaneo, Regol, & Meotti, 2006). Inter-rater reliability in young and older subjects (27-88 years) with vestibular dysfunction has been shown to be poor to excellent for individual items with Cohen k values in the range of .35-1.0; however, good overall inter-rater reliability noted with k=.64, and excellent total score inter-rater reliability with r_s = .95 (Wrisley, Walker, Echternach, & Strasnick, 2003). In young and older subjects (29-78, mean 51.8) with vestibular dysfunction test-retest reliability within the same session has been shown to be poor to very good with ICC's in the range of .04-.90, however, good total score test-retest reliability has been noted with an ICC =.86 (Hall & Herdman, 2006). Concurrent validity with the Berg Balance Scale, an instrument used to measure both static / dynamic balance and postural control, has been shown to be moderate in elderly community dwellers with r_s = .67 (Shumway-Cook, Baldwin, Polissar, & Gruber, 1997); moderate in subjects with vestibular disorder with r_s = .71 with the DGI deemed to be more sensitive than the Berg at identifying falling risk (Whitney, Wrisley & Furman, 2003); and good in subjects with multiple sclerosis with r_s= .78 (Cattaneo, Regol, & Meotti, 2006). In elderly community dwellers, a score of 19 or below on the DGI has been shown to correctly identify true positive fallers with a sensitivity = 59% and true negative non-fallers with a specificity = 64% (Shumway-Cook, Baldwin, Polissar, & Gruber, 1997); and a score of 19 or less in subjects with vestibular dysfunction has been shown to indicate a 2.38 times greater likely hood of sustaining a fall in older adults (> 65 years) and a 3.55 times greater chance in younger adults (Whitney, Hudak, & Marchetti, 2000).

The Activities-specific Balance Confidence (ABC) Scale (Appendix J) is a 16-item continuous measure that was used to quantify the psychological aspect of balance-related behavior in participants across activities of varying difficulty (Powell and Myers, 1995; Myers, Powell, Maki, Holliday, Brawley & Sherk, 1996). This instrument asked the participant to contemplate (not perform) hypothetical tasks of varying balance difficulty and self-rate her / his confidence in not losing balance or becoming unsteady on a scale ranging between 0% (no confidence) to 100% (completely confident). The ABC scale is both reliable and valid for measuring balance confidence in elderly community dwellers and those with vestibular involvement (Powell and Myers, 1995; Myers, Powell, Maki, Holliday, Brawley & Sherk, 1996; Whitney, Hudak & Marchetti, 1999). In a group of subjects over the age of 65 considered to be of high and low mobility, the ABC scale has been demonstrated to be reliable over a duration of two-weeks with $r = .92$, $p < .001$, and it has been shown to have high internal consistency with Cronbach's alpha =.96 (Powell & Myers, 1995). Discriminate validity has been shown to be very good with the Functional Efficacy Scale (FES), a dichotomous measure of the fear of falling based upon common activities of daily living, with $r = .84$, $p < .001$, with the ABC considered to be a better discriminator for high v. low mobility (Powell and Myers, 1995; Myers, Powell, Maki, Holliday, Brawley & Sherk, 1996).

Moderate convergent validity has been shown with the Physical Self-Efficacy Scale, an instrument which assess both perception of one's physical abilities and confidence in physical self-presentation (including appearance) with r = .49, p<.001, however higher correlations where noted when only comparing the physical abilities subscale score with r=.63, p<.001 (Powell and Myers, 1995). Discriminate validity has been shown by low correlation with the Positive and Negative Affectivity Scale which assesses emotionality with r=.12 (Powell & Myers, 1995). In the previously stated group of subjects over the age of 65 considered to be of high and low mobility, a comparison of both the ABC and FES with performance measures revealed that although both had a moderate correlation with posturography (postural sway) with r ranging between .37-.61, the ABC alone had a significant moderate correlation with gait speed with r=.56, p<.0; and only the ABC was capable of detecting a significant difference between the high and low confidence groups (defined by median score of 80) for both these performance measures (Myers, Powell, Maki, Holliday, Brawley & Sherk, 1996). In young and elderly subjects (mean 62 with range of 26-88 years) with vestibular dysfunction, the ABC scale has been shown to exhibit moderate concurrent validity with the Dizziness Handicap Inventory, which quantifies self-perceived vestibular related limitations (higher scores equate with greater perceived handicaps) with a negative correlation of r = -.64 (Whitney, Hudak & Marchetti, 1999). In elderly community dwellers an ABC scale cut-off score of 67% has been shown to correctly classify true positive fallers with sensitivity = 84.4% and true negative non-fallers with specificity = 87.5% (Lajoie & Gallagher, 2004).

The following additional instrumentation was also used in the present dissertation study.

A Sony Digital HandyCam (model DCR/TRV 33)[c] video camera and Windows Live Movie Maker Software for Windows 7[d] were used to capture video to qualitatively determine turning strategies via observational analysis. The camera was attached through the use of a 15.24 cm high adjustable universal pan tilt video mount bracket atop a 76.20 cm high wooden furring strip, secured to a 91.44 cm height adjustable microphone stand. The camera resided immediately superior & posterior to a 0.61 m high x 1.22 m wide black wooden board that was also secured atop the height adjustable microphone stand and housed the LED turn direction lights. The camera along with the LED turn direction lights board were placed at a height of 1.83 m above the ground and 3.05 m beyond the edge of the Gaitrite (i.e. front boundary of the turning zone). This camera location allowed video to be captured of the subject walking down the walkway and at minimum two steps after the turn in the turning zone.

Three pair of amber LED KapscoMoto mirror signal lights[e] were mounted on a black wooden board (122 cm wide x 61cm high) placed 3.05 m beyond the front boundary of the turning zone. These LED lights were placed at eye level and used to signal turn direction. One pair of LED lights were secured in the center pointing in the up direction to signal walking straight ahead, while the other two pairs were secured at the far ends of the board pointing to the right and left directions to signal either a right or left turn, respectively. Only one direction signal was given per trial.

Turn direction was cued using a pair of two Tapeswitch switching mats-model CVP[f] placed side by side to each other and beneath the Gaitrite carpet. Within each switching mat pair is one larger mat measuring 58.42 cm wide x 43.18 cm deep x 0.64 cm high, and a smaller mat measuring 58.42 cm wide x 15.24 cm deep x 0.64 cm high. Thus when two mats were placed side-by-side each other along their width they provide a greater depth of surface area to ensure foot contact (i.e. 58.42 cm wide x 58.42 cm deep x 0.64 cm high for both the early turn direction cue mat and the late turn direction cue mat).These mats, which were sensitive to a minimum of 2.27 kg of weight, were placed beneath the Gaitrite carpet such that they were activated by the pressure of the participant's foot as they walk along the walkway. The two switching mat pairs were connected to a custom built control box powered by a 12 volt battery with a 1 amp safety fuse. Triggering of the switching mats resulted in the selective lighting of one of three pairs of signal lights mounted on the black direction board located 305 m beyond the turning zone. The control box allowed selective pairing of either the early or late cue switching mats with the left, straight or right signal LED lights. Since the switching mat pairs were placed beneath the Gaitrite carpet, none will come in contact with the subject, and participants were unaware of their location. Additionally, the low height of the switch mats did not cause any appreciable un-leveling of the walking surface.

The early turn direction cue switching mat pair was located beneath the beginning of the Gaitrite carpet with the front boundary of the switching mat pair approximately 4.45 m before the front boundary of the turning zone which was approximately equivalent to 7 steps warning time prior to turning. The late turn direction cue switching mat pair was placed further towards the end of the walkway such that the front boundary of the switching mat pair was approximately 1.2 m before the front boundary of the turning zone, allowing approximately 2 steps warning/response distance prior to turning. Thus, the distance separating the early v. late cue mats was approximately 325 cm). The Turning Zone (Figure 8.) was the spatial location where turns were performed after the subjects stepped off the Gaitrite walkway. It was defined & bordered by four orange-red neon colored safety hazard floor cones and encompassed a trapezoid shaped area about 73 cm wide in the front, 155 cm wide in the back, and 95 cm deep beginning at the edge of the Gaitrite carpet. The two front cones were smaller (22.5 cm high with a 14.0 cm base) than the two rear cones (45.7 cm high with a 26.3 cm base). Two 1.52 m high x 2.54 cm diameter PVC pipes spray painted an orange-red neon florescent color were placed in the center holes of the two rear safety cones so at least the back border of the turning zone would be at eye level. It is important to note the final sensor pad of the Gaitrite further confined the entrance to the turn zone. Hence, the front cones and Gaitrite final sensor pad collectively created a “bottle-neck” at the entrance to the turn-zone which was spatially confined to a width of about 70 cm (28”) at the level of the feet. Thus, as a consequence of both the direction cue signal board & the “bottle neck” at the entrance to the turn zone, and in light of the step-width changes used when approaching & executing turns (Patla et al., 1999; Hollands et al., 20001; Paquette et al., 2008), the task required a good deal of visual processing.

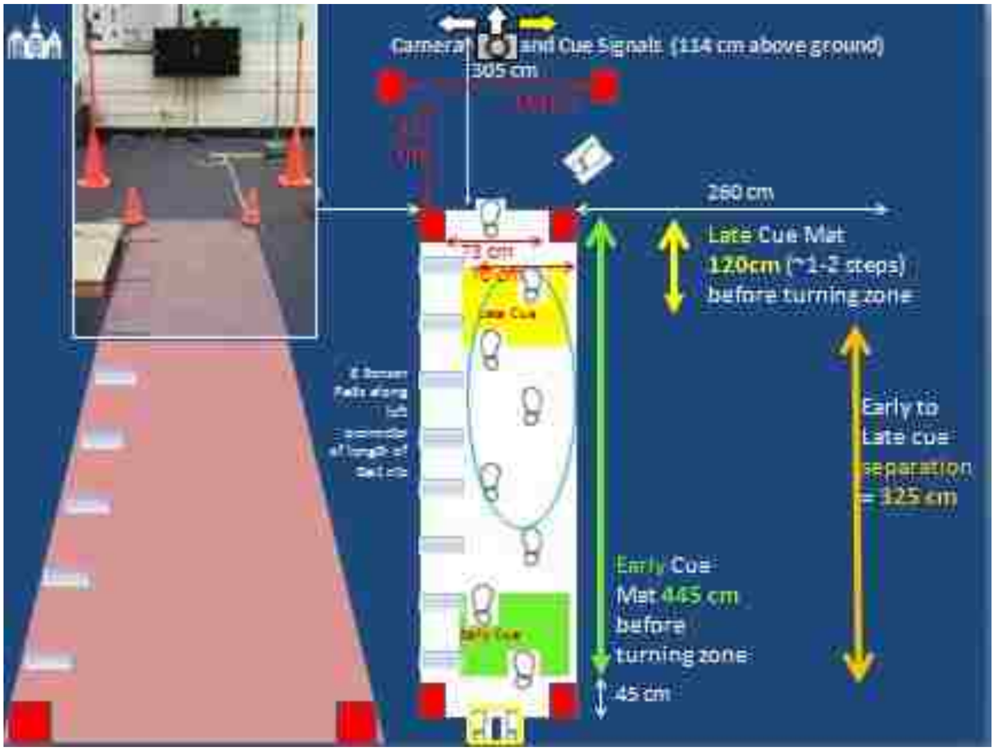


Figure 8. Photo of the Turning Zone with a schematic drawing of the larger lab set-up. Note the "bottle-neck" created by the cones and Gaitrite sensor pad at the entrance to the turn-zone which was spatially confined to a width of about 70 cm (28") at the level of the feet.

Procedures

Prior to setting up a test session appointment, potential subjects responding to the advertisement flyers (Appendix F) or by word of mouth were pre-screened using a questionnaire (Appendix L) either by phone or in person with regards to the inclusion / exclusion criteria. There were a couple of individuals who when prescreened did not meet the inclusion/exclusion criteria. For those who did meet the inclusion criteria, a convenient appointment was scheduled with potential subjects advised to wear a tee-shirt or sweat-shirt, shorts or sweat-pants, and a pair of comfortable walking shoes or sneakers to the testing session.

Following the signing of the informed and video consent forms (Appendix F & Appendix G), potential subjects were asked to complete a demographic sheet (Appendix K) which included information on their date of birth, age, gender, medical history (musculoskeletal, neurological, respiratory insufficiency, uncontrolled diabetes or high blood pressure, uncorrected visual impairments, vestibular involvement or dizziness with head movement, medications) history of falls in the past year, use of assistive walking devices, level of education, and foot preference by asking them to self-identify hand preference and which foot they would use to write in the sand, roll a golf ball, and kick as high as possible up a wall height chart (Chapman et al., 1986; Gentry & Gabbard, 1995). In order to ensure anonymity, each subject was assigned a random code number, and the code number was used on all research data forms, standardized tests and videos to ensure anonymity.

After demographic data was obtained at the testing session, standardized clinical testing was carried out including the Mini Mental State Examination (Appendix H) to screen for cognitive impairment, the Dynamic Gait Index (Appendix I) to screen for falling risk, and the Activities-specific Balance Confidence Scale (Appendix J) to screen for low balance confidence. The Mini Mental State Exam was administered first in the screening sequence to ensure participants had adequate cognitive function to follow instructions for the remaining screening tests.

The use of all instruments followed the standard protocols as outlined in their procedural manuals. Note, during screening with the Dynamic Gait Index, participants wore a Velcro adjustable gait safety waist belt and were closely guarded by the researcher or a research assistant trained in guarding subjects. Additionally, as a physical therapist, I, Dennis Torre, (the principal investigator of the present study) have been trained in the administration and interpretation of these standardized measures and was proficient in their use. (See Appendix M –flow chart of the procedures for screening using standardized clinical measures)

After completing the standardized screening tests, the PI reviewed the subject’s scores to ensure that they meet the inclusion criteria as identified above. All screened participants did indeed meet the study inclusion criteria, and proceeded onto the data collection portion of spatial temporal parameters associated with turning behavior.

Prior to collecting the spatial temporal and video data for turn performance, subject height and right/left leg length were measured (greater trochanter to the floor) utilizing a standardized flexible cloth tape, and weight was recorded with a bathroom scale. Leg length measures in particular were required by the Gaitrite software in order to address differences in height across subjects (i.e. normalize variables). All data related to subject height, leg length and body weight were documented at the bottom of the demographic sheet and entered into the Gaitrite software.

The GaitRite[b] was then used to compute the spatial-temporal gait parameters (speed, stride-length and H-H base of support) for the turn approach walk while a standard digital video[c,d] camera simultaneously captured the turning strategies employed as a result of early and late direction cues when ambulating at a preferred and faster than preferred pace.

For each trial, subjects were instructed to initiate walking from a stationary position standing in the starting box located at the midpoint just before the leading edge of the Gaitrite carpet. This allowed walking to be initiated from the same location every trial. It was not necessary to have the starting box placed 1m beyond the Gatrite edge to achieve steady-state gait prior to stepping on the mat since only the final four footfalls were analyzed. The subjects negotiated the entire length of the 5.18 m Gaitrite carpet walkway at a steady pace while looking straight ahead at the black LED direction board; and based upon which pair of LED arrow lights[e] were triggered to blink from early or late switching mat foot contact, either continued walking straight or performed a 90^0 right or left turn upon stepping off the Gaitrite carpet into the turning zone (Figure 7). The subjects were advised to continue to walk beyond the boundaries of the turning zone until reaching the end of the side or forward path whether cued to turn 90^0 right/left or walk straight, respectively. The right/left side paths extended 260 cm beyond the side edge of the Gaitrite, while the straight forward path extended about 300 cm beyond the back edge of the Gaitrite. The instructions each participant received were standardized as follows: “You’re going to walk along the carpet at a steady pace and after you reach the end of the carpet either continue walking straight or turn to the right or left depending upon which signal you receive from the direction board.”

Three trials for each of the three different direction cues (left, straight, right) under both temporal constraints of early and late cuing were performed with randomization and approximately one minute rest between trials. These 18 random trials were performed in two separate blocks at both the preferred and fastest comfortable walking speed with counterbalancing across subjects to control for order effects. Subjects were free to ask for breaks throughout the testing session as needed and provided a standard arm chair to sit if they so desired. (See Appendix N –flow chart of the procedures for collecting spatial-temporal gait data and turn strategy preferences).

All participants wore a Velcro adjustable gait safety waist belt and were closely guarded by the PI or a research assistant during each trial. The research assistants included Mr. Anthony Porcelli & Mr. Kweku Agyerman both of whom were trained by the principal investigator in the proper technique of closely guarding individuals as they walk and turn at different speeds, and both of whom demonstrated proficiency in performing such close guarding as determined by the principal investigator. Dr. Gerard Fiordalisi, DPT also participated as a research assistant in guarding study participants.

Statistical Analysis

Turn strategy preferences using loglinear analysis & chi-square

A four-way 2x2x2x3 Loglinear Analysis $p<0.05$ was used to assess the relationship between the interaction of the factors age, test-speed, cue-time constraint and turn strategy preference for right-direction turns only. Although only right turns were analyzed, since both direction (straight, right, left) and cue-constraint (early, late) were randomized across the 18 trials within each separate speed block, and participants were free to initiate the start of each trial with the foot of their choice, the requirement of independence of each trial (data) was assumed. To facilitate the interpretation of lower-order interactions, separate Chi square test of independence were used to more closely examine the location & strength of any significant 2 x 3 two-way relationships (Fields, 2009) between age, walking speed or direction cue time constraint with turn strategy preference. This was particularly relevant given the Turn-Strategy factor had greater than 2 categories (step-turn, spin-turn, mixed-turn). Thus, breaking down any significant two-way (2 x 3) interactions into two separate 2x2 contingency tables and conducting Chi square analyses, aided appropriate interpretation of these associations (Field, 2009, p. 720); and provided computation of effect-size (Cramer's V), post-hoc power, & facilitated manual computation of odds ratios using mixed-turns as the reference (Fields, 2009; Portney & Watkins, 2009) & their 95% confidence intervals (Szumilas, 2010) (Appendix O). As 2 x 2 contingency tables are known to lower α values, consideration was given to Yates's Continuity Correction to guard against the increased risk for type-I error; however, there is suggestion Yates's may over-correct and go too far in reducing Chi-square values (Field, 2009, p.691). All analyses were performed using PASW Statistics GradPack 18[g], (SPSS Inc), except for those computations performed manually as noted. The significance level was set at $p<0.05$.

A priori computation of sample size for the Chi Square Test of Independence (Goodness-of-fit Contingency Table) of the relationship between age & turn strategy (step-turn, spin-turn, mixed-turn) was performed with G* v. 3.1.7[h] (Faul, Erdfelder, Lang, & Buchner, 2007). Using the input parameters of a small-medium effect size (w) = 0.2 (Cohen, 1988), an α error probability = 0.05, Power (1-β error probability) = .80, and Dof = (row-1)(column -1) = (2-1)(3-1)= 2, yielded a total sample size (n) = 241. Given in the present study each subject made 3 early & 3 late right turns at both a preferred & fast speed, each subject generated a total of 12 trials. Thus, the a priori computation of adjusted n=241/12 = 20.08, which suggested a minimum of 10 young and 10 elderly subjects.

Spatial-temporal gait adaptations using mixed-design ANOVA

A four-way 2x2x2x2 Mixed-Design AVOVA $p<0.05$ was used to assess age-group differences in spatial-temporal gait modifications (DVs) across the final-four recorded approach footfalls based upon the interaction of the independent categorical variables (i.e. within-factors) test-speed, cue-time constraint, and direction. Although only straight & right turn trials were included in the spatial-temporal analysis, left turns were proportionately performed among the 18 randomized trials within each speed block (6 straight trials, 6 right turn trials, and 6 left turn trials). Thus, each participant generated 24 trials to the spatial-temporal analysis (12 at preferred speed, 12 at fast speed); and when collapsing across conditions, a total of 480 trials were analyzed (20 participants x 24 trials each = 480 combined straight / right trials, and of those 240 were performed by young adults & 240 were performed by the elderly trials).

The 2x2x2x2 mixed-design ANOVA was performed of each of the four spatial-temporal dependent variables of interest: normalized speed (LL/s), combined right/left normalized stride-length (LL), normalized right HH BOS (LL), and normalized left H-H BOS (LL). All analyses were again performed using PASW Statistics GradPack 18[g], (SPSS Inc), and significance level was set at $p<0.05$. Each 2x2x2x2 mixed-design ANOVA generated a total of 15 family-wide contrasts (1 from the Tests of Between-Subjects Effects, and 14 from the Tests of Within-Subjects Contrasts). Thus, for each of the four dependent variables, the family wise error = $1-(1-\alpha)^n = 1-(1-0.05)^{15} = .54$; and based-upon statistical theory, the chance of at least one test being significant was actually no longer 0.05 but instead 0.54. Use of Bonferroni correction would require alpha be lowered to 0.0034 [$1-(1-\alpha)^{1/n} = 1-(1-0.05)^{1/15} = .0034$]. However, Perneger (1998) has argued that use of Bonferroni correction is too conservative for biomedical purposes. First and foremost, Perneger (1998) notes that such corrections are intended to guard against faulty hypotheses. Perneger (1998) reported the original “statistical” intent of adjusting for multiple comparisons was to facilitate repetitive decision making, not to evaluate evidence from a study. However, on the other hand, Perneger (1998) did not completely dismiss the use of Bonferroni adjustments, as merit was seen when undertaking an exploratory study in which there are no prior established relationships upon which to base an educated hypothesis. Notwithstanding, even when applying a Bonferroni correction, Perneger (1998) still advocated against having it restrict meaningful data interpretation and allowing others to extract sound conclusions. In summary, Perneger (1998) suggested a finding should be interpreted within the context of whether it is physically plausible v. whether accidental; and concluded Bonferroni corrections for family-wise or study-wise error rate offers limited benefits, and are best avoided when evaluating results in which hypotheses have been stated. In light of the present study having hypotheses solidly ground in the literature, a decision was made to forgo use of Bonferroni correction for the

15 family-wise contrasts in each 2x2x2x2 mixed-design ANOVA, and significance for each contrasts was held at $\alpha = 0.05$ for all contrasts.

In each 2x2x2x2 mixed-design ANOVA, for each of the 15 contrasts,SPSS also computed an estimate of effect-size (partial eta squared, η^2) and the observed power based upon $\alpha = 0.05$. However, given Fields (2009,p. 389)) reports η^2 may be slight biased in that it is not adjusted in order to be estimated to the population. Finally, given that $r^2 = \eta^2$, and as DOF = 1 for the model of all contrasts (i.e.were focued involving only 2 groups), the effect size, r, for each contrast was manually computed for each contrast using the formula: $r = \sqrt{F(1,df_R)} / \sqrt{[F(1,df_R) + df_R]}$ (Fields, 2009).

In regards to interpreting between which pair of means the difference resides for any significant interaction as reported in the Tests of Within-Subjects Contrasts table, the approach taken in the present involved looking at estimated marginal means & interaction plots (i.e. slopes, differences between points). Portney & Watkins (2009) note that standard post-hoc multiple comparison procedures (i.e. Tukey) are not usually employed for repeated measures analyses as they are not logically compatible, given post-hoc comparisons are formulated from overall group differences and not within-subject comparisons. Additionally, Fields (2009) makes no mention of using multiple comparison tests when interpreting significant interactions as reported in the Tests of Within-Subjects Contrasts. Instead, Fields (2009) advises to use interaction plots and examine the estimated marginal means. More specifically, when assessing such interaction plots, Fields (2009) suggest to look at the steepness of the slopes of the lines in the plots, and the vertical distance separating the x-axis comparison points of the two lines.

A priori computation of sample size for a 2 x2 Mixed Design F tests: Repeated Measures, Between Factor was performed with G*Power v. 3.1.7[h] (Faul, Erdfelder, Lang, & Buchner, 2007). Using the input parameters of a small-medium effect size (w) = 0.2 (Cohen, 1988), an α error probability = 0.05, Power (1-β error probability) = .80, number of groups = 2, number of measurements = 2, and correlation among repeated measures = 0.5, yielded a total sample size (n) = 150 (75 young, 75 elderly). When computing a compromise power analysis using the input parameters of a small-medium effect size (w) = 0.2 (Cohen, 1988), β/α ratio= 4, total sample size = 20 (as from the Chi square power analysis), number of groups = 2, number of measurements = 2, and correlation among repeated measures = 0.5, yielded a Power (1-β error probability) = .35, α error prob. =0.16, β error prob. = 0.65.

A priori computation of sample size for a 2 x2 Mixed Design F tests: Within Factor & Within-Between Interaction was likewise performed with G*Power v. 3.1.7[h]. Using the input parameters of a small-medium effect size (w) = 0.2 (Cohen, 1988), an α error probability = 0.05, Power (1-β error probability) = .80, number of groups = 2, number of measurements = 2, correlation among repeated measures = 0.5, and Nonsphericity correction ϵ = 1, yielded a total sample size (n) = 52 (26 young, 26 elderly). When computing a compromise power analysis using the input parameters of a small-medium effect size (w) = 0.2 (Cohen, 1988), β/α ratio= 4, total sample size = 20 (as from the Chi square power analysis), number of groups = 2, number of measurements = 2, and correlation among repeated measures = 0.5, yielded a Power (1-β error probability) = .55, α error prob. =0.11, β error prob. = 0.45. Thus, as a decision was made to use n = 20 based upon the minimum n requirement for Chi square, the compromise analysis with the same n =20 suggest low a priori power for the spatial-temporal gait variables heading into the analysis.

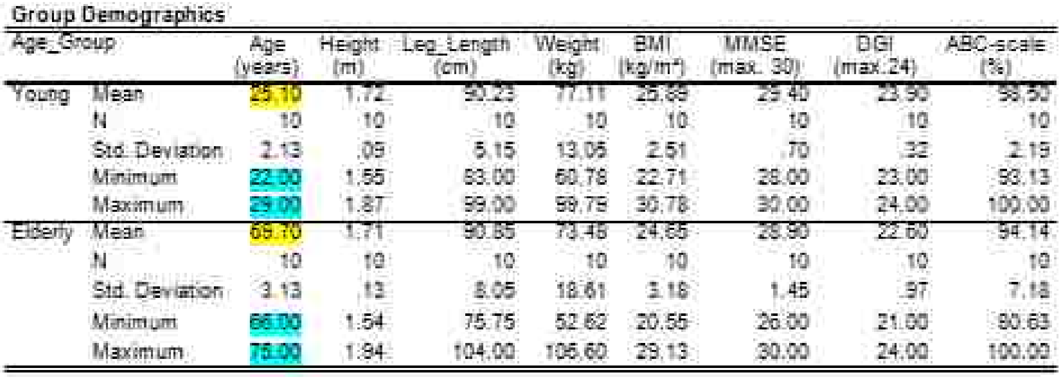
Chapter IV

RESULTS & DISCUSSION

Results of Participant Demographics

The 10 young participants (5 females, 5 males) had a mean age of 25.10 (2.13) with the range between 22-29 years. The 10 senior participants (5 females, 5 males) had a mean age of 69.70 (3.13) with a range between 66-75 years (Table 1).

Table 1

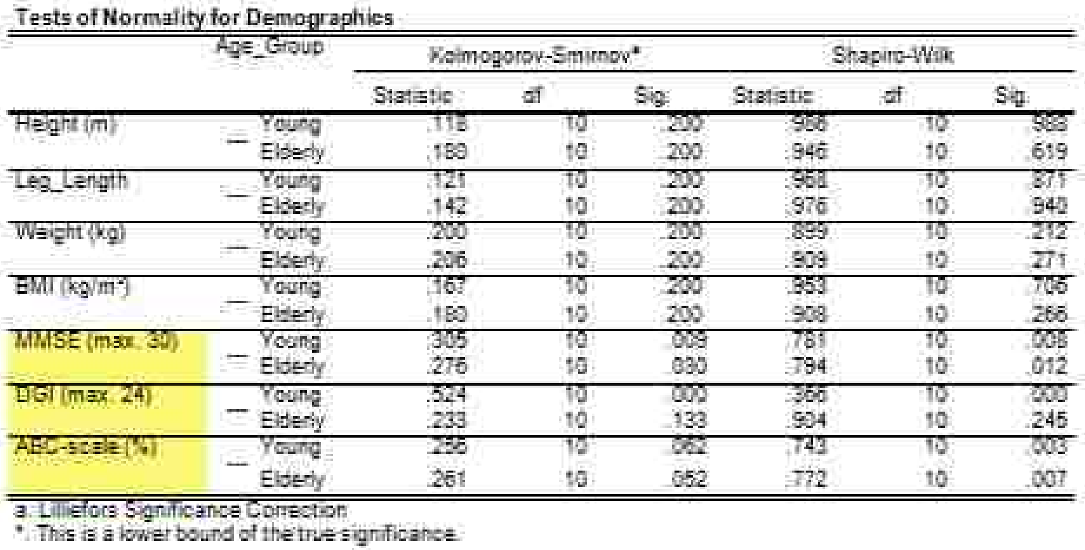


Group Demographics

Age_Group		Age (years)	Height (m)	Leg_Length (cm)	Weight (kg)	BMI (kg/m²)	MMSE (max. 30)	DGI (max.24)	ABC-scale (%)
Young	Mean	25.10	1.72	90.23	77.11	25.89	29.40	23.90	98.50
	N	10	10	10	10	10	10	10	10
	Std. Deviation	2.13	.09	5.15	13.05	2.51	.70	.32	2.15
	Minimum	22.00	1.55	83.00	60.78	22.71	28.00	23.00	93.13
	Maximum	29.00	1.87	99.00	99.79	30.78	30.00	24.00	100.00
Elderly	Mean	69.70	1.71	90.85	73.48	24.65	28.90	22.60	94.14
	N	10	10	10	10	10	10	10	10
	Std. Deviation	3.13	.13	8.05	18.61	3.18	1.45	.97	7.18
	Minimum	66.00	1.54	75.75	52.62	20.55	26.00	21.00	80.63
	Maximum	75.00	1.94	104.00	106.60	29.13	30.00	24.00	100.00

A comparison of the two groups for the attribute variables of weight (kg), height (kg), body mass index (kg/m^2), and leg-length (cm) was performed using separate independent t-tests; however, due to violations of normality (Table 2), separate Mann-Whitney U tests compared group performance on the screenings for cognitive impairment (MMSE), functional balance (DGI) and psychological balance confidence (ABC-scale).

Table 2



Tests of Normality for Demographics

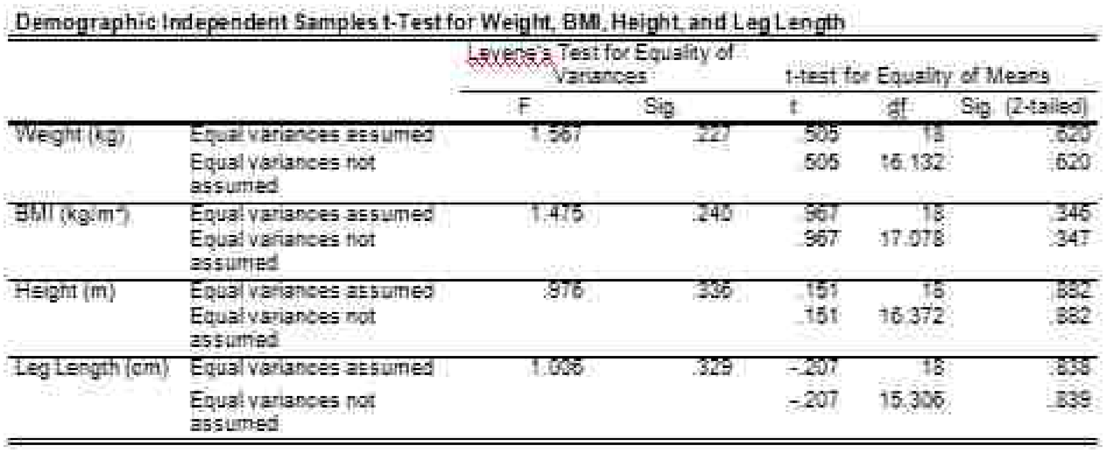
	Age_Group	Kolmogorov-Smirnov^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Height (m)	Young	.118	10	.200	.986	10	.988
	Elderly	.183	10	.200	.946	10	.619
Leg_Length	Young	.121	10	.200	.968	10	.871
	Elderly	.142	10	.200	.976	10	.940
Weight (kg)	Young	.200	10	.200	.899	10	.212
	Elderly	.206	10	.200	.909	10	.271
BMI (kg/m²)	Young	.167	10	.200	.953	10	.706
	Elderly	.183	10	.200	.908	10	.266
MMSE (max. 30)	Young	.305	10	.009	.781	10	.008
	Elderly	.276	10	.030	.794	10	.012
DGI (max. 24)	Young	.524	10	.000	.366	10	.000
	Elderly	.233	10	.133	.904	10	.245
ABC-scale (%)	Young	.256	10	.062	.743	10	.003
	Elderly	.261	10	.052	.772	10	.007

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

The independent t-test revealed the young adults and elderly were similar for weight, height, body mass index, and leg-length (Table 3). However, although the two groups performed similarly on the screenings for cognitive impairment (MMSE) and balance confidence (ABC-scale), not surprisingly with regards to functional balance (DGI) the Mann-Whitney U test revealed the elderly did not perform as well as young adults [U=12.5, z=-3.13, *p*=.002] (Table 4). Based upon the DGI z-score = -3.131, and using the equation r= z/√n to convert the z-score into an estimate of effect-size, this represents a large effect size for Age-Group on DGI (Field, 2009, p.550) [r= -3.131/√N =-3.131/√20 = -3.13/√4.47 = .70].

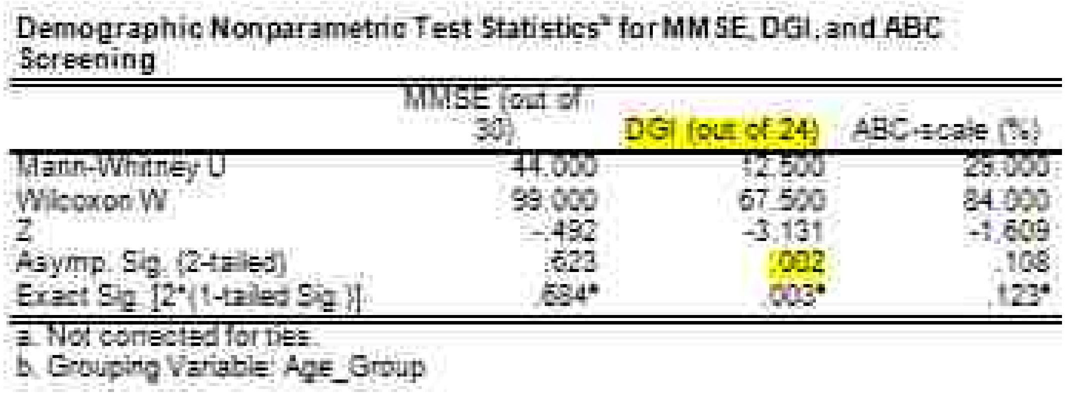
Table 3



Demographic Independent Samples t-Test for Weight, BMI, Height, and Leg Length

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Weight (kg)	Equal variances assumed	1.567	.227	.505	18	.620
	Equal variances not assumed			.505	16.132	.620
BMI (kg/m²)	Equal variances assumed	1.475	.240	.967	18	.346
	Equal variances not assumed			.967	17.078	.347
Height (m)	Equal variances assumed	.976	.336	.151	18	.882
	Equal variances not assumed			.151	16.372	.882
Leg Length (cm)	Equal variances assumed	1.006	.329	-.207	18	.838
	Equal variances not assumed			-.207	15.306	.839

Table 4



Demographic Nonparametric Test Statistics[b] for MMSE, DGI, and ABC Screening

	MMSE (out of 30)	DGI (out of 24)	ABC-scale (%)
Mann-Whitney U	44.000	12.500	29.000
Wilcoxon W	99.000	67.500	84.000
Z	-.492	-3.131	-1.609
Asymp. Sig. (2-tailed)	.623	.002	.108
Exact Sig. [2*(1-tailed Sig.)]	.684[a]	.003[a]	.123[a]

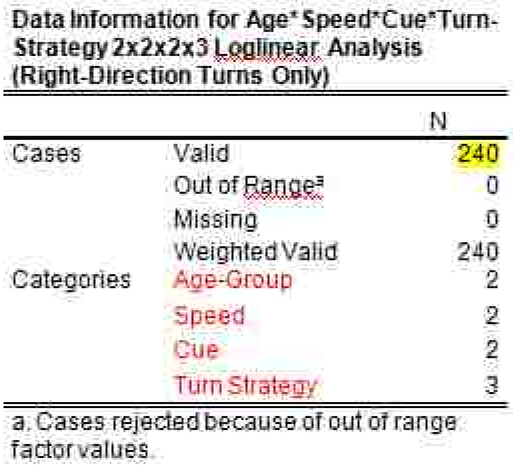
a. Not corrected for ties.

b. Grouping Variable: Age_Group

Results of Loglinear Analysis of Turn-Strategy Preferences

The four-way loglinear performed to assess the relationship between the interaction of the categorical variables of Age-Group*Speed*Cue*Turn-Strategy analyzed n= 240 cases (trials) given each of the 20 participants contributed 12 trials.

Table 5



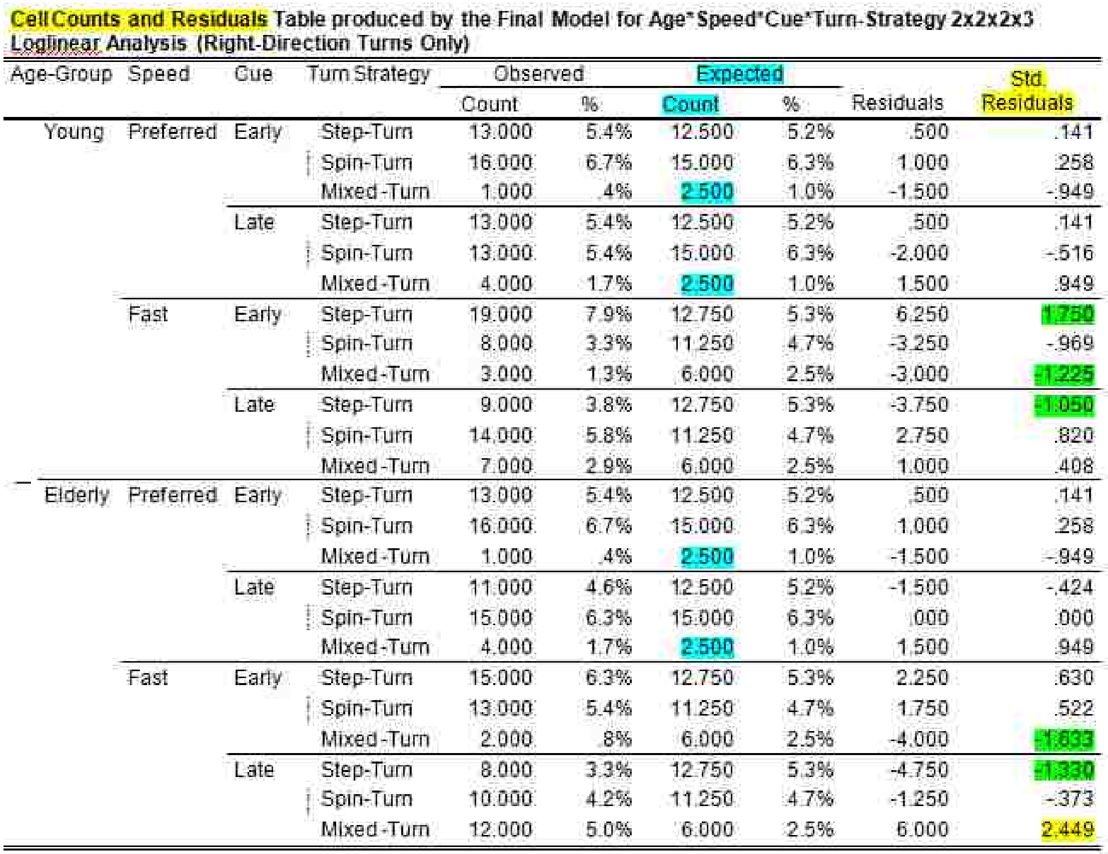
Data Information for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

		N
Cases	Valid	240
	Out of Range^a	0
	Missing	0
	Weighted Valid	240
Categories	Age-Group	2
	Speed	2
	Cue	2
	Turn Strategy	3

a. Cases rejected because of out of range factor values.

Inspection of the expected counts produced in the Cell (Table 6) shows the assumptions for loglinear analysis (Field, 2009, p. 710, 712) were met in that no cell had an expected count < 1 (lowest expected count was 2.5), and no greater than 20% of cells had an expected count < 5 (only 4/24 cells = 16.67% had an expected count < 5). It is worth noting that across conditions, for both groups the observed counts for step-turns & spin-turns were ≥ 8; whereas in both age-groups the observed mixed-turn counts were ≤ 4, except for the fast*late interaction cell (elderly 12, young 7). Furthermore, the only cell with a standardized residual outside a z-score +/- 1.96 and thus significant at $p < 0.05$ (Field, 2009, p. 699), was the cell corresponding to elderly*fast*late*mixed-turn at +2.45 (Figure 9.)

Table 6



Cell Counts and Residuals Table produced by the Final Model for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

Age-Group	Speed	Cue	Turn Strategy	Observed		Expected		Residuals	Std. Residuals
				Count	%	Count	%		
Young	Preferred	Early	Step-Turn	13.000	5.4%	12.500	5.2%	.500	.141
			Spin-Turn	16.000	6.7%	15.000	6.3%	1.000	.258
			Mixed-Turn	1.000	.4%	2.500	1.0%	-1.500	-.949
		Late	Step-Turn	13.000	5.4%	12.500	5.2%	.500	.141
			Spin-Turn	13.000	5.4%	15.000	6.3%	-2.000	-.516
			Mixed-Turn	4.000	1.7%	2.500	1.0%	1.500	.949
	Fast	Early	Step-Turn	19.000	7.9%	12.750	5.3%	6.250	1.750
			Spin-Turn	8.000	3.3%	11.250	4.7%	-3.250	-.969
			Mixed-Turn	3.000	1.3%	6.000	2.5%	-3.000	-1.225
		Late	Step-Turn	9.000	3.8%	12.750	5.3%	-3.750	-1.050
			Spin-Turn	14.000	5.8%	11.250	4.7%	2.750	.820
			Mixed-Turn	7.000	2.9%	6.000	2.5%	1.000	.408
Elderly	Preferred	Early	Step-Turn	13.000	5.4%	12.500	5.2%	.500	.141
			Spin-Turn	16.000	6.7%	15.000	6.3%	1.000	.258
			Mixed-Turn	1.000	.4%	2.500	1.0%	-1.500	-.949
		Late	Step-Turn	11.000	4.6%	12.500	5.2%	-1.500	-.424
			Spin-Turn	15.000	6.3%	15.000	6.3%	.000	.000
			Mixed-Turn	4.000	1.7%	2.500	1.0%	1.500	.949
	Fast	Early	Step-Turn	15.000	6.3%	12.750	5.3%	2.250	.630
			Spin-Turn	13.000	5.4%	11.250	4.7%	1.750	.522
			Mixed-Turn	2.000	.8%	6.000	2.5%	-4.000	-1.633
		Late	Step-Turn	8.000	3.3%	12.750	5.3%	-4.750	-1.330
			Spin-Turn	10.000	4.2%	11.250	4.7%	-1.250	-.373
			Mixed-Turn	12.000	5.0%	6.000	2.5%	6.000	2.449

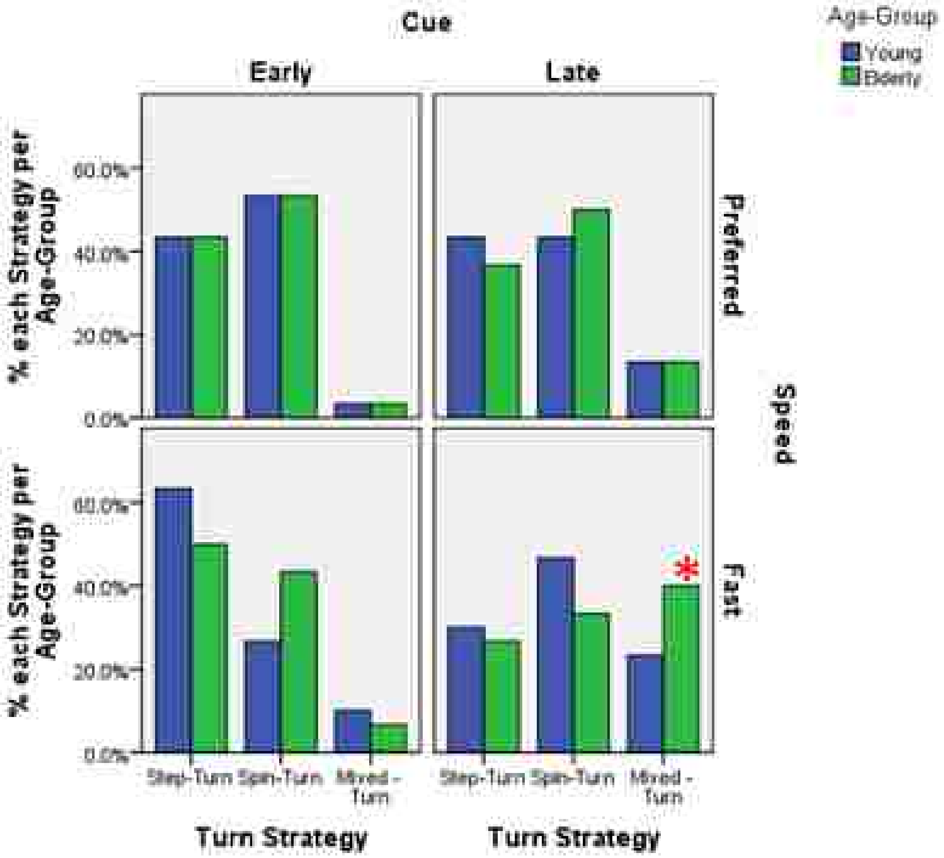
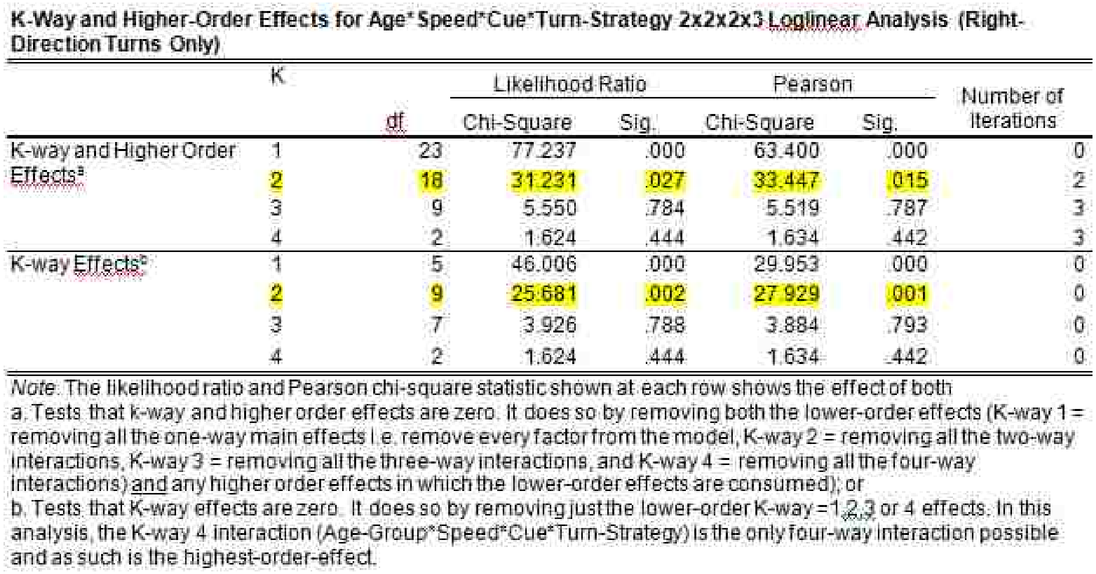


Figure 9. Age*Speed*Cue*Turn-Strategy (Right Direction Turns Only). The asterisk * above the elderly*fast*late*mixed-turn cell signifies the absolute value of the standard residual z-score ≥ 1.96 and thus significant at $p< 0.05$.

K-way & higher-order effects, and the K-way effects

The loglinear K-way & Higher-Order Effects, and the K-way Effects both indicated that removing all two-way interactions would have a significant adverse effect on how well the model fits the data (Table 7), although this information does not yet identify which one or more of the two-way interactions is/are the significant predictor(s)

Table 7



K-Way and Higher-Order Effects for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

	K	df	Likelihood Ratio Chi-Square	Likelihood Ratio Sig.	Pearson Chi-Square	Pearson Sig.	Number of Iterations
K-way and Higher Order Effects[a]	1	23	77.237	.000	63.400	.000	0
	2	18	31.231	.027	33.447	.015	2
	3	9	5.550	.784	5.519	.787	3
	4	2	1.624	.444	1.634	.442	3
K-way Effects[b]	1	5	46.006	.000	29.953	.000	0
	2	9	25.681	.002	27.929	.001	0
	3	7	3.926	.788	3.884	.793	0
	4	2	1.624	.444	1.634	.442	0

Note. The likelihood ratio and Pearson chi-square statistic shown at each row shows the effect of both

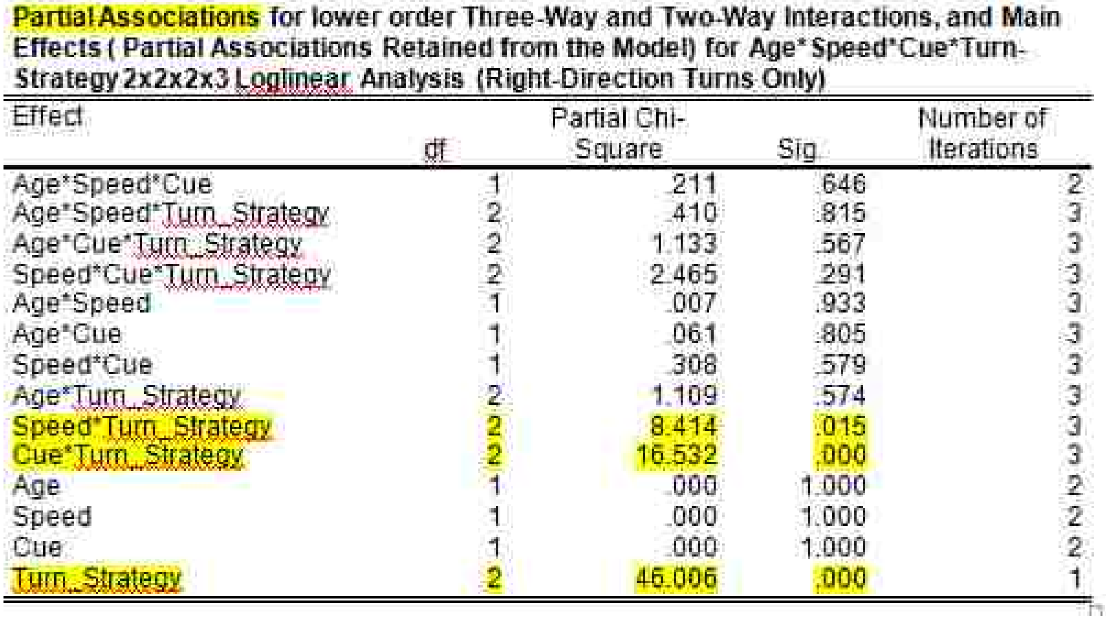
a. Tests that k-way and higher order effects are zero. It does so by removing both the lower-order effects (K-way 1 = removing all the one-way main effects i.e. remove every factor from the model, K-way 2 = removing all the two-way interactions, K-way 3 = removing all the three-way interactions, and K-way 4 = removing all the four-way interactions) and any higher order effects in which the lower-order effects are consumed); or

b. Tests that K-way effects are zero. It does so by removing just the lower-order K-way =1,2,3 or 4 effects. In this analysis, the K-way 4 interaction (Age-Group*Speed*Cue*Turn-Strategy) is the only four-way interaction possible and as such is the highest-order-effect.

Partial associations

The loglinear partial associations indicated the following two-way interactions both significantly predicted the observed data: Speed*Turn-Strategy [X^2 (2) =8.41, p=.015], and Cue*Turn-Strategy[X^2(2)=16.53,p=.000] (Table 8).

Table 8



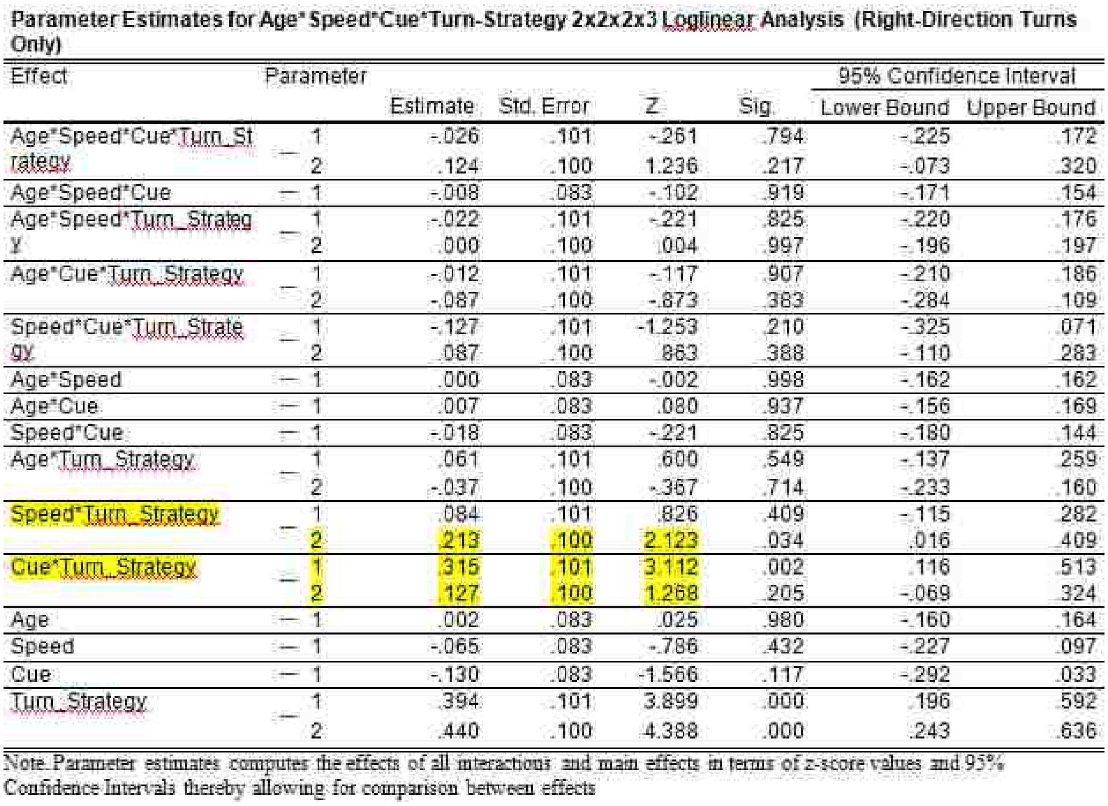
Partial Associations for lower order Three-Way and Two-Way Interactions, and Main Effects (Partial Associations Retained from the Model) for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

Effect	df	Partial Chi-Square	Sig.	Number of Iterations
Age*Speed*Cue	1	.211	.646	2
Age*Speed*Turn_Strategy	2	.410	.815	3
Age*Cue*Turn_Strategy	2	1.133	.567	3
Speed*Cue*Turn_Strategy	2	2.465	.291	3
Age*Speed	1	.007	.933	3
Age*Cue	1	.061	.805	3
Speed*Cue	1	.308	.579	3
Age*Turn_Strategy	2	1.109	.574	3
Speed*Turn_Strategy	2	8.414	.015	3
Cue*Turn_Strategy	2	16.532	.000	3
Age	1	.000	1.000	2
Speed	1	.000	1.000	2
Cue	1	.000	1.000	2
Turn_Strategy	2	46.006	.000	1

Parameter estimates

The loglinear parameter estimates collaborate the results of the Partial Association table. Parameter estimates allows a ranking on the importance of each effect in the model. Thus, when ignoring lower order main effects (Field, 2009), the top 3 parameters of importance in effecting the model were derived from the two-way interaction of Cue*Turn-Strategy and Speed*Turn-Strategy. As the factor Turn-Strategy had 3 categories (range defined as 1=step-turn, 2=spin-turn, 3=mixed-turn), by default SPSS used the last category (i.e. the 3rd category of mixed-turn) as the baseline or reference to make comparisons (Field, 2009, p. 280, 301; Pickering, 2003). Accordingly, Cue*Turn-Strategy and Speed*Turn-Strategy each supplied two parameters effects in the model. When disregarding lower order main effects (Field, 2009) , the parameter estimates table indicates that the first most important parameter effect in the model was the 1st parameter of the Cue*Turn-Strategy interaction (early/late, step-turn/mixed-turn) with a z-score = 3.11; the second most important parameter effect in the model was the 2nd parameter of the Speed*Turn-Strategy interaction (preferred/fast, spin-turn/mixed-turn) with a z-score = 2.12; and the third most important parameter effect in the model was the 2nd parameter of the Cue*Turn-Strategy interaction (early/late, spin-turn/mixed-turn) with a z-score = 1.27. (Table 9).

Table 9



Parameter Estimates for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

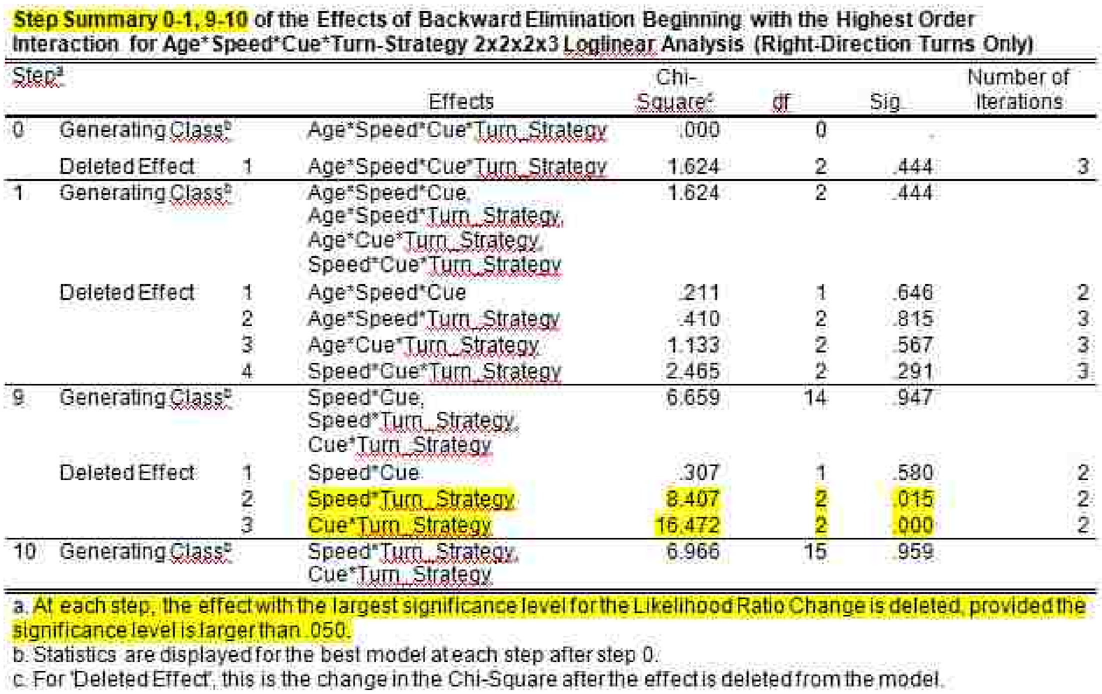
Effect	Parameter	Estimate	Std. Error	Z	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Age*Speed*Cue*Turn_Strategy	1	-.026	.101	-.261	.794	-.225	.172
	2	.124	.100	1.236	.217	-.073	.320
Age*Speed*Cue	1	-.008	.083	-.102	.919	-.171	.154
Age*Speed*Turn_Strategy	1	-.022	.101	-.221	.825	-.220	.176
	2	.000	.100	.004	.997	-.196	.197
Age*Cue*Turn_Strategy	1	-.012	.101	-.117	.907	-.210	.186
	2	-.087	.100	-.873	.383	-.284	.109
Speed*Cue*Turn_Strategy	1	-.127	.101	-1.253	.210	-.325	.071
	2	.087	.100	.863	.388	-.110	.283
Age*Speed	1	.000	.083	-.002	.998	-.162	.162
Age*Cue	1	.007	.083	.080	.937	-.156	.169
Speed*Cue	1	-.018	.083	-.221	.825	-.180	.144
Age*Turn_Strategy	1	.061	.101	.600	.549	-.137	.259
	2	-.037	.100	-.367	.714	-.233	.160
Speed*Turn_Strategy	1	.084	.101	.826	.409	-.115	.282
	2	.213	.100	2.123	.034	.016	.409
Cue*Turn_Strategy	1	.315	.101	3.112	.002	.116	.513
	2	.127	.100	1.268	.205	-.069	.324
Age	1	.002	.083	.025	.980	-.160	.164
Speed	1	-.065	.083	-.786	.432	-.227	.097
Cue	1	-.130	.083	-1.566	.117	-.292	.033
Turn_Strategy	1	.394	.101	3.899	.000	.196	.592
	2	.440	.100	4.388	.000	.243	.636

Note. Parameter estimates computes the effects of all interactions and main effects in terms of z-score values and 95% Confidence Intervals thereby allowing for comparison between effects

Step summary

The loglinear Step Summary confirmed the previous findings from the parameter estimates, partial associations and K-way & higher-order effects. Namely, the backward elimination of interaction terms from the model, beginning with the highest order 4-way interaction and proceeding on down, did not reach significance to terminate the elimination process, until deleting the two-way interactions of Speed*Turn-Strategy [X^2 (2) =8.41, p=.015] and Cue*Turn-Strategy [X^2(2) =16.47, p=.000] (Table 10)

Table 10



Step Summary 0-1, 9-10 of the Effects of Backward Elimination Beginning with the Highest Order Interaction for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

Step[a]			Effects	Chi-Square[c]	df	Sig.	Number of Iterations
0	Generating Class[b]		Age*Speed*Cue*Turn_Strategy	.000	0	.	
	Deleted Effect	1	Age*Speed*Cue*Turn_Strategy	1.624	2	.444	3
1	Generating Class[b]		Age*Speed*Cue, Age*Speed*Turn_Strategy, Age*Cue*Turn_Strategy, Speed*Cue*Turn_Strategy	1.624	2	.444	
	Deleted Effect	1	Age*Speed*Cue	.211	1	.646	2
		2	Age*Speed*Turn_Strategy	.410	2	.815	3
		3	Age*Cue*Turn_Strategy	1.133	2	.567	3
		4	Speed*Cue*Turn_Strategy	2.465	2	.291	3
9	Generating Class[b]		Speed*Cue, Speed*Turn_Strategy, Cue*Turn_Strategy	6.659	14	.947	
	Deleted Effect	1	Speed*Cue	.307	1	.580	2
		2	Speed*Turn_Strategy	8.407	2	.015	2
		3	Cue*Turn_Strategy	16.472	2	.000	2
10	Generating Class[b]		Speed*Turn_Strategy, Cue*Turn_Strategy	6.966	15	.959	

a. At each step, the effect with the largest significance level for the Likelihood Ratio Change is deleted, provided the significance level is larger than .050.

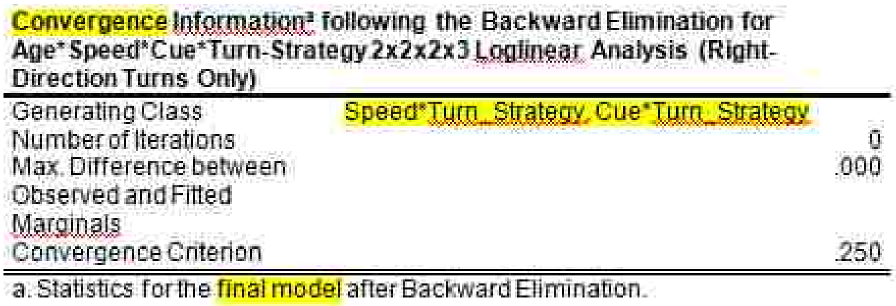
b. Statistics are displayed for the best model at each step after step 0.

c. For 'Deleted Effect', this is the change in the Chi-Square after the effect is deleted from the model.

Convergence and Goodness-of-fit

The Convergence information table indicated the final model generated from the backward elimination process comprised just the two-way interactions, Speed*Turn-strategy and Cue*Turn-Strategy, as both significantly contributed to predicting the observed count data (Table 11).

Table 11



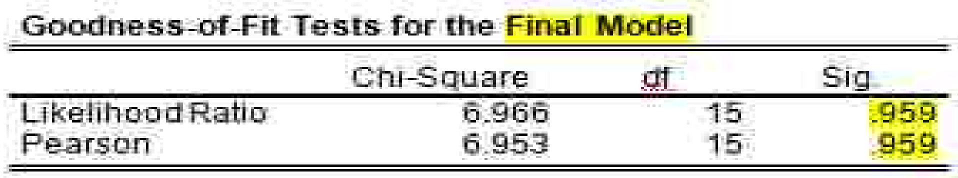
Convergence Information[a] following the Backward Elimination for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Right-Direction Turns Only)

Generating Class	Speed*Turn_Strategy, Cue*Turn_Strategy	
Number of Iterations		0
Max. Difference between Observed and Fitted Marginals		.000
Convergence Criterion		.250

a. Statistics for the final model after Backward Elimination.

The Goodness-of-Fit Tests, which indexed how well the data predicted by the final model actually corresponded to actual data observed (Field, 2009, p.718, 786), indicated the expected counts predicted by the final model were not significantly different than the observed counts. This was concluded since the likelihood ratio for the final model of Speed*Turn-Strategy, Cue*Turn-Strategy was non-significant [X^2 (15) =6.97, p=.959] (Table 12).

Table 12



Goodness-of-Fit Tests for the Final Model

	Chi-Square	df	Sig.
Likelihood Ratio	6.966	15	.959
Pearson	6.953	15	.959

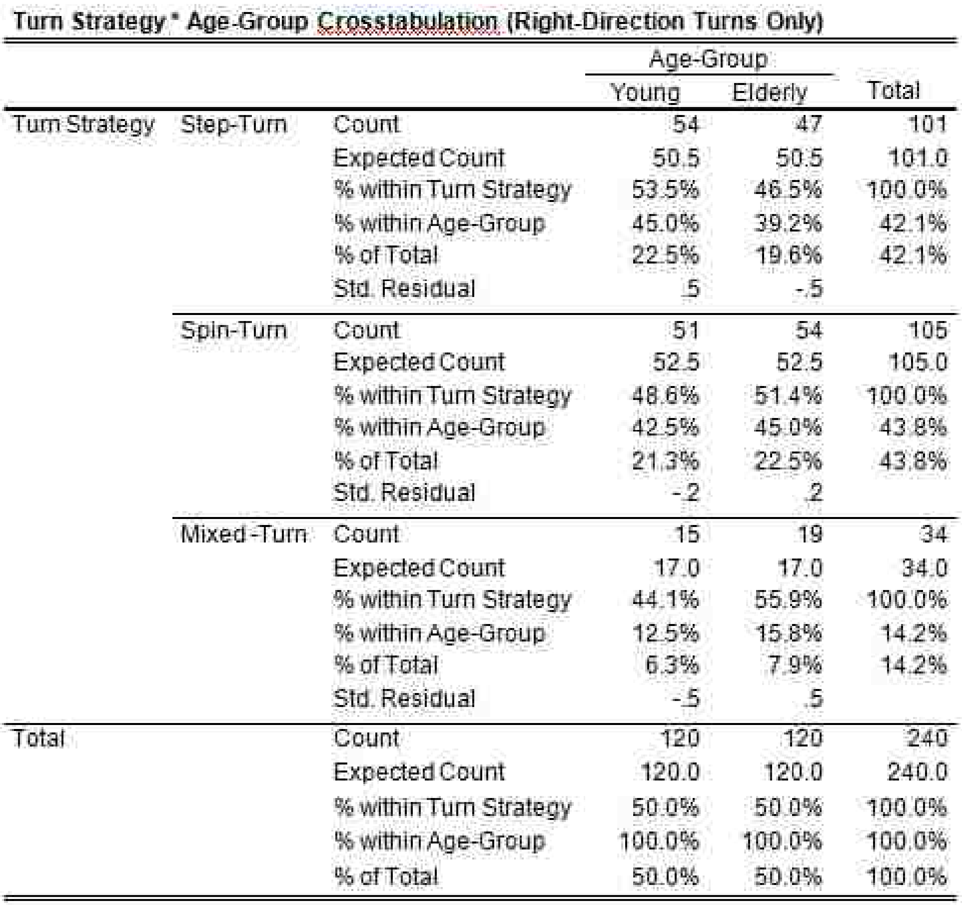
Results of Chi-square Analyses to Examine Lower-Order Strength of Associations for Turn-Strategy Preferences

The three separate Chi-square test of independence were carried out not only to confirm the two-way interaction findings as reported in the loglinear analysis, but of greater importance, to more closely examine the strength of the relationship in each of the significant two-way interactions, Cue*Turn-Strategy & Speed*Turn-Strategy. Given the Turn-Strategy factor had greater than 2 categories (step-turn, spin-turn, mixed-turn), each 2 x 3 significant interaction was broken down into two separate 2x2 contingency tables to then conduct two separate Chi-square analyses, which facilitated appropriate interpretation of these associations (Field, 2009, p.720).

2 x 3 Chi-square analysis for Age-Group*Turn-Strategy

First, a 2 x 3 cross-tabulation table of Age-Group*Turn-Strategy, for right-direction turns only, shows the assumption for Chi-square was met as each cell had an expected count >5, and the lowest expected count was 17 for mixed-turns in both age-groups (Table 13). All standardized residuals were small ≤ +/- 0.5. A clustered bar chart of the Age*Turn-Strategy relationship shows parity between age-groups across the three strategies (Figure 10.).

Table 13



Turn Strategy * Age-Group Crosstabulation (Right-Direction Turns Only)

			Age-Group		
			Young	Elderly	Total
Turn Strategy	Step-Turn	Count	54	47	101
		Expected Count	50.5	50.5	101.0
		% within Turn Strategy	53.5%	46.5%	100.0%
		% within Age-Group	45.0%	39.2%	42.1%
		% of Total	22.5%	19.6%	42.1%
		Std. Residual	.5	-.5	
	Spin-Turn	Count	51	54	105
		Expected Count	52.5	52.5	105.0
		% within Turn Strategy	48.6%	51.4%	100.0%
		% within Age-Group	42.5%	45.0%	43.8%
		% of Total	21.3%	22.5%	43.8%
		Std. Residual	-.2	.2	
	Mixed -Turn	Count	15	19	34
		Expected Count	17.0	17.0	34.0
		% within Turn Strategy	44.1%	55.9%	100.0%
		% within Age-Group	12.5%	15.8%	14.2%
		% of Total	6.3%	7.9%	14.2%
		Std. Residual	-.5	.5	
Total		Count	120	120	240
		Expected Count	120.0	120.0	240.0
		% within Turn Strategy	50.0%	50.0%	100.0%
		% within Age-Group	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

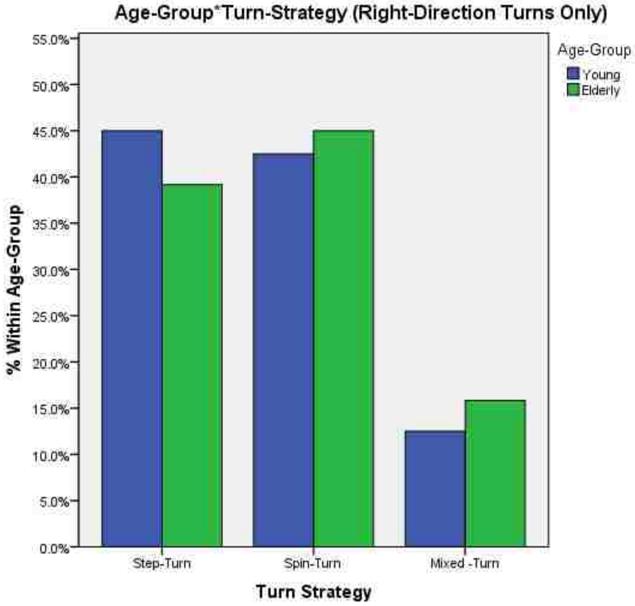
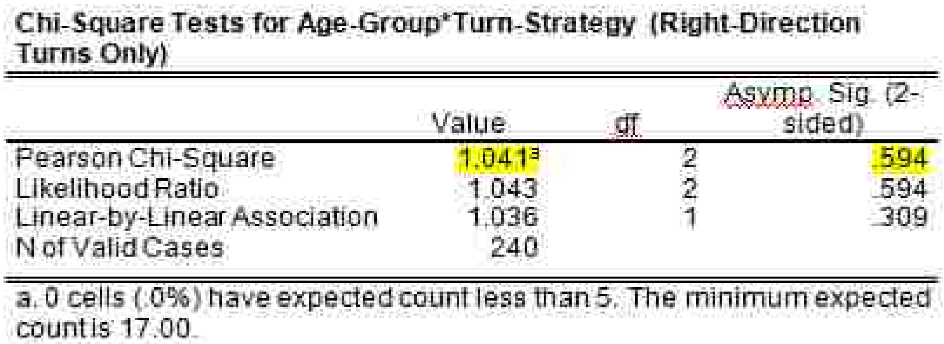


Figure 10. Age*Turn-Strategy (Right Direction Turns Only).

The 2 x 3 Chi-square test of independence confirmed the loglinear finding of no relationship between Age-Group*Turn-Strategy preference [X^2 (2) = 1.04, *p* = 0.59] (Table 14). The strength of the 2 x 3 association as determined by Cramer's V (which is recommended when a variables has greater than two-levels, Field, 2009, p.698) was non-significant [Cramer's V = .066, p = .59] (Prajapati et al., 2010), and not surprisingly post-hoc power was low [post-hoc power = 0.14] (Table 15).

Table 14

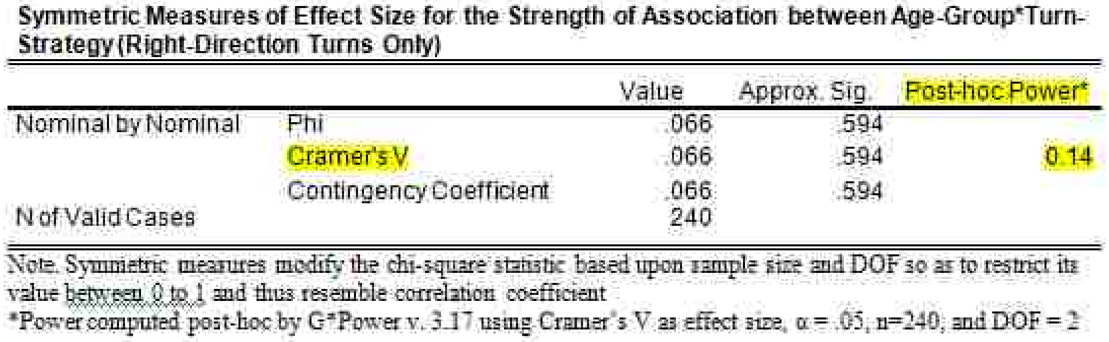


Chi-Square Tests for Age-Group*Turn-Strategy (Right-Direction Turns Only)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.041^a	2	.594
Likelihood Ratio	1.043	2	.594
Linear-by-Linear Association	1.036	1	.309
N of Valid Cases	240		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.00.

Table 15



Symmetric Measures of Effect Size for the Strength of Association between Age-Group*Turn-Strategy (Right-Direction Turns Only)

		Value	Approx. Sig.	Post-hoc Power*
Nominal by Nominal	Phi	.066	.594	
	Cramer's V	.066	.594	0.14
	Contingency Coefficient	.066	.594	
N of Valid Cases		240		

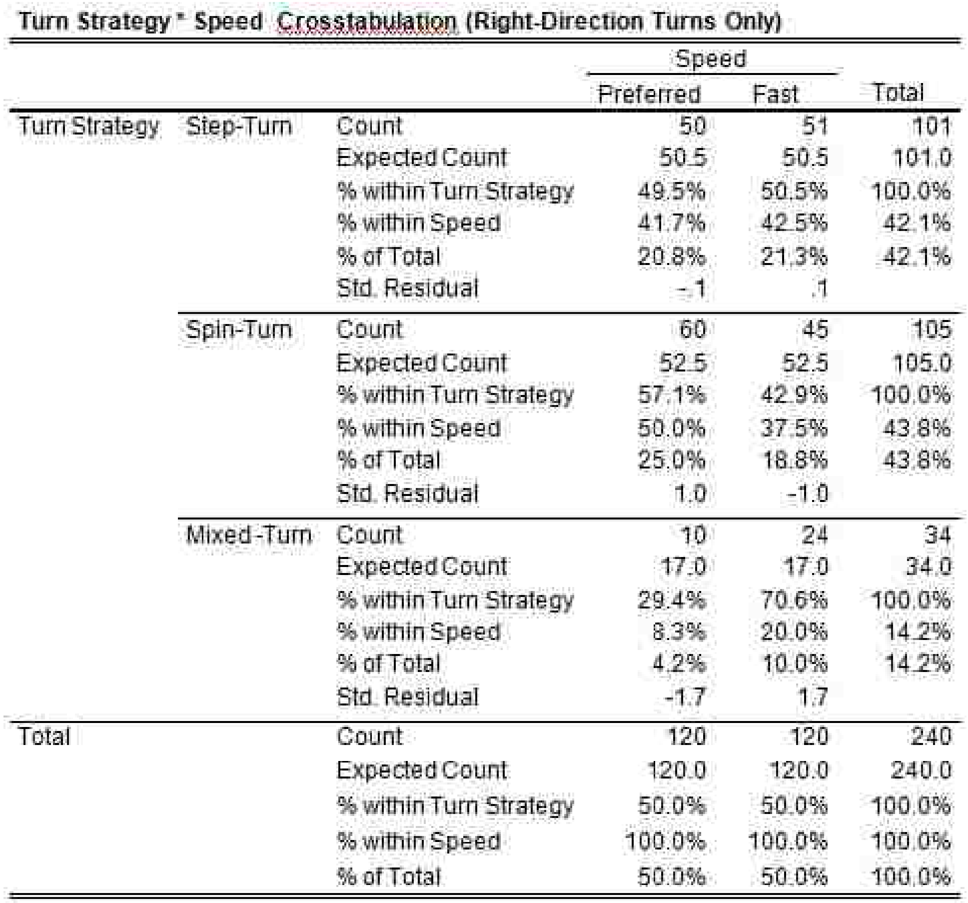
Note. Symmetric measures modify the chi-square statistic based upon sample size and DOF so as to restrict its value between 0 to 1 and thus resemble correlation coefficient

*Power computed post-hoc by G*Power v. 3.17 using Cramer's V as effect size, α = .05, n=240, and DOF = 2

2 x 3 Chi-square analysis for Speed*Turn-Strategy

Second, a 2 x 3 cross-tabulation table of Speed*Turn-Strategy, for right-direction turns only, shows the assumption for Chi-square was met as each cell had an expected count >5, and again the lowest expected count was 17 for mixed-turns at both speeds (Table 16). Standardized residuals were under +/-1.96 with values for mixed-turns being largest at +/- 1.7, followed by spin-turns at +/- 1.0, and those for step-turns smallest at +/- 0.1. A clustered bar chart of the Speed*Turn-Strategy relationship appears to show that when walking fast, relative to the increase seen in mixed-turns, spin-turns decreased whereas step-turns where relatively unchanged. (Figure 11.).

Table 16



Turn Strategy * Speed Crosstabulation (Right-Direction Turns Only)

			Speed		Total
			Preferred	Fast	
Turn Strategy	Step-Turn	Count	50	51	101
		Expected Count	50.5	50.5	101.0
		% within Turn Strategy	49.5%	50.5%	100.0%
		% within Speed	41.7%	42.5%	42.1%
		% of Total	20.8%	21.3%	42.1%
		Std. Residual	-.1	.1	
	Spin-Turn	Count	60	45	105
		Expected Count	52.5	52.5	105.0
		% within Turn Strategy	57.1%	42.9%	100.0%
		% within Speed	50.0%	37.5%	43.8%
		% of Total	25.0%	18.8%	43.8%
		Std. Residual	1.0	-1.0	
	Mixed-Turn	Count	10	24	34
		Expected Count	17.0	17.0	34.0
		% within Turn Strategy	29.4%	70.6%	100.0%
		% within Speed	8.3%	20.0%	14.2%
		% of Total	4.2%	10.0%	14.2%
		Std. Residual	-1.7	1.7	
Total		Count	120	120	240
		Expected Count	120.0	120.0	240.0
		% within Turn Strategy	50.0%	50.0%	100.0%
		% within Speed	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

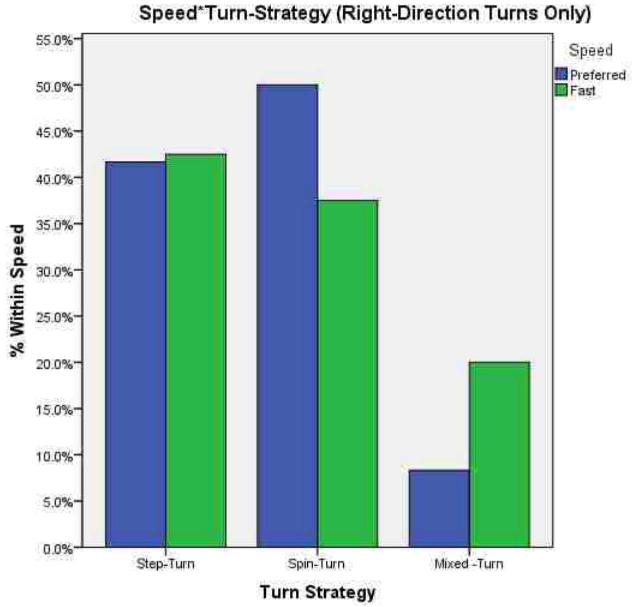
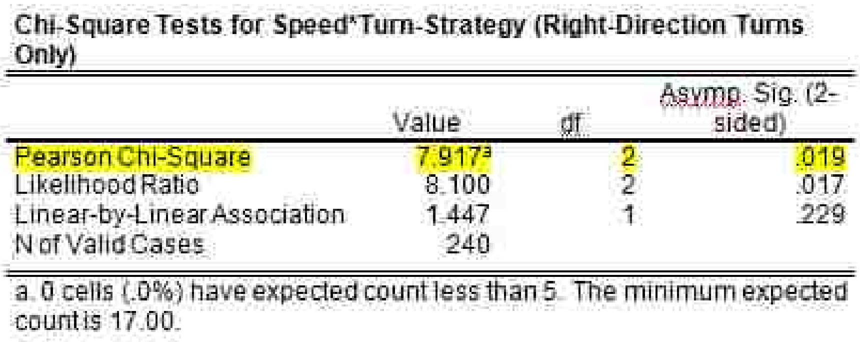


Figure 11. Speed*Turn-Strategy (Right Direction Turns Only)

The 2 x 3 Chi-square test of independence confirmed the loglinear finding of a significant relationship between Speed*Turn-Strategy preference [X^2 (2) = 7.92, p = 0.019] (Table 17). The strength of the 2 x 3 association as determined by Cramer's V was small yet significant [Cramer's V = .182, p = .019] (Prajapati et al., 2010), with post-hoc power = 0.71] (Table 18).

Table 17

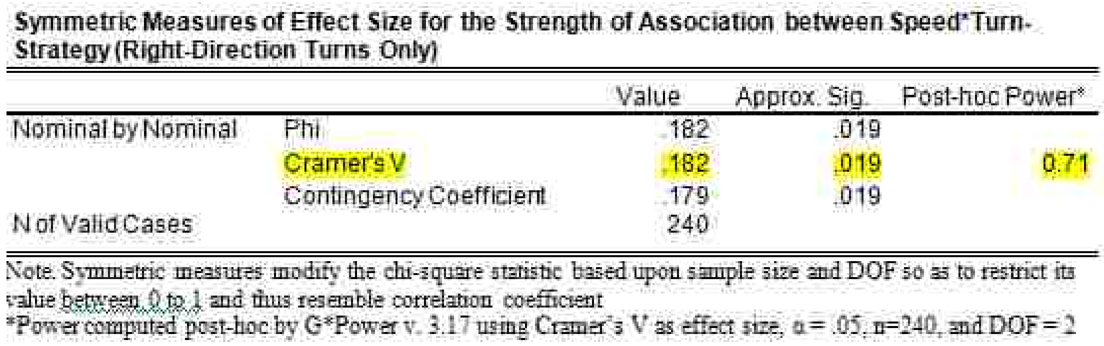


Chi-Square Tests for Speed*Turn-Strategy (Right-Direction Turns Only)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.917[a]	2	.019
Likelihood Ratio	8.100	2	.017
Linear-by-Linear Association	1.447	1	.229
N of Valid Cases	240		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.00.

Table 18



Symmetric Measures of Effect Size for the Strength of Association between Speed*Turn-Strategy (Right-Direction Turns Only)

		Value	Approx. Sig.	Post-hoc Power*
Nominal by Nominal	Phi	.182	.019	
	Cramer's V	.182	.019	0.71
	Contingency Coefficient	.179	.019	
N of Valid Cases		240		

Note. Symmetric measures modify the chi-square statistic based upon sample size and DOF so as to restrict its value between 0 to 1 and thus resemble correlation coefficient

*Power computed post-hoc by G*Power v. 3.17 using Cramer's V as effect size, α = .05, n=240, and DOF = 2

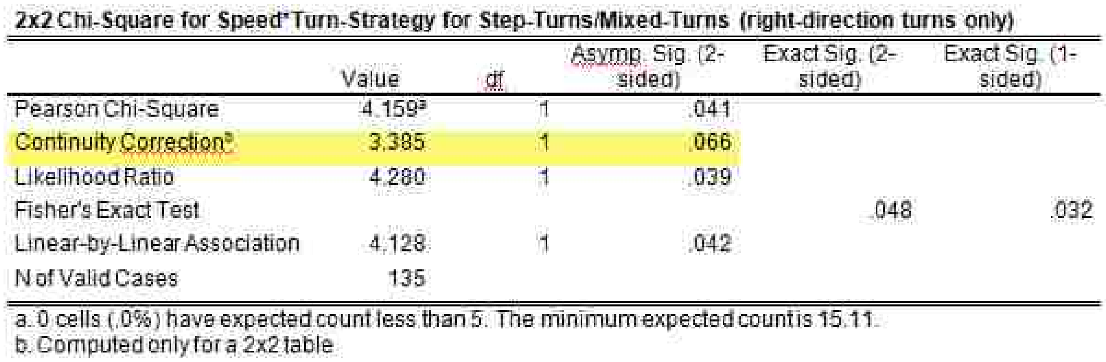
*Splitting the 2 x 3 analysis for Speed*Turn-Strategy into two separate 2 x 2 Chi-square tests*

The significant 2 x 3 Speed*Turn-Strategy two-way interaction was broken-down into two separate 2 x 2 Chi-square tests of independence using the 3rd turn-strategy category, mixed-turn, as the reference in order to further examine the location & strength of the relationship.

*2 x 2 Chi-square test for Speed*Turn-Strategy for step-turns/mixed-turns*

The 2 x 2 Chi-square for Speed*Turn-Strategy for step-turns/mixed-turns yielded $X^2(1) = 4.16$, p =.041; Yates's Continuity Correction=3.39, p=.066 (Table 19); small Cramer's V = 0.176, p =.041 (Table 20); and the odds (95% CI) of a step-turn (relative to mixed-turn) was 2.33 (1.01, 5.42) x lower when walking fast as opposed to when walking at preferred speed (Appendix 0). In view of Yates's continuity correction being non-significant, and the lower limit of the 95% confidence interval contain the null value of 1.0, the observed reduction in step-turn preference (relative to mixed-turns) at fast speed is not statistically significant at $p < 0.05$ and could have occurred by chance alone (Portney & Watkins, 2009, p. 669; Field, 2009, p. 289).

Table 19

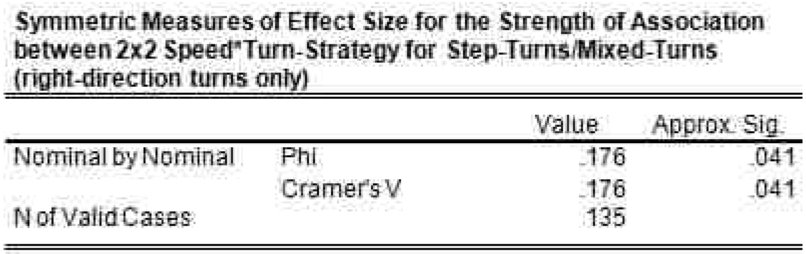


2x2 Chi-Square for Speed*Turn-Strategy for Step-Turns/Mixed-Turns (right-direction turns only)

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.159[a]	1	.041		
Continuity Correction[b]	3.385	1	.066		
Likelihood Ratio	4.280	1	.039		
Fisher's Exact Test				.048	.032
Linear-by-Linear Association	4.128	1	.042		
N of Valid Cases	135				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 15.11.
b. Computed only for a 2x2 table

Table 20



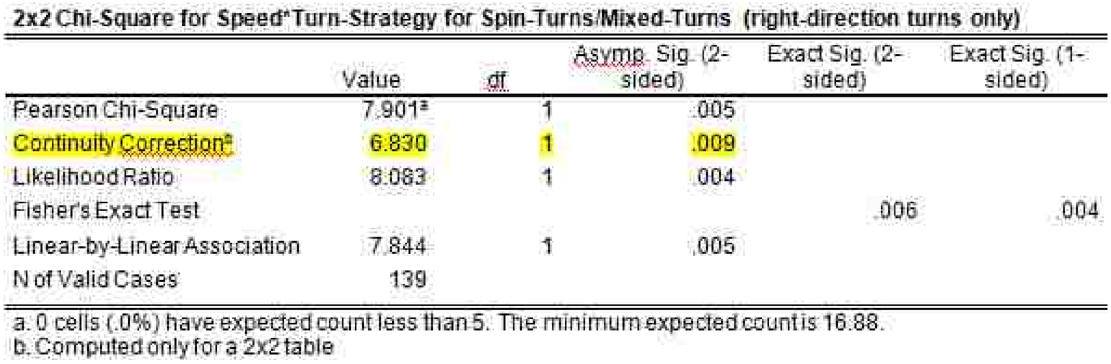
Symmetric Measures of Effect Size for the Strength of Association between 2x2 Speed*Turn-Strategy for Step-Turns/Mixed-Turns (right-direction turns only)

		Value	Approx. Sig.
Nominal by Nominal	Phi	.176	.041
	Cramer's V	.176	.041
N of Valid Cases		135	

*2 x 2 Chi-square test for Speed*Turn-Strategy for spin-turns/mixed-turns*

The 2 x 2 Chi-square for Speed*Turn-Strategy for spin-turns/mixed-turns yielded $X^2(1) = 7.90$, p =.005; Yates's Continuity Correction=6.83, p=.009 (Table 21); small/medium Cramer's V = 0.238, p =.005 (Table 22); and the odds (95% CI) of a spin-turn (relative to mixed-turn) was 3.23 (1.39, 7.46) x lower when walking fast as opposed to when walking at preferred speed (Appendix 0). In view of Yates's continuity correction being significant, and the null value of 1.0 not residing within the interval, the observed reduction in spin-turn preference (relative to mixed-turns) at fast speed is statistically significant and we could be 95% confident ($p < 0.05$) the reduction observed is true in the population (Field, 2009, p. 289; Portney & Watkins, 2009, p. 669).

Table 21

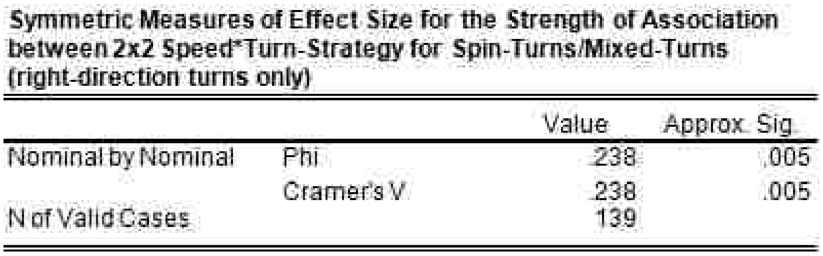


2x2 Chi-Square for Speed*Turn-Strategy for Spin-Turns/Mixed-Turns (right-direction turns only)

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.901[a]	1	.005		
Continuity Correction[b]	6.830	1	.009		
Likelihood Ratio	8.083	1	.004		
Fisher's Exact Test				.006	.004
Linear-by-Linear Association	7.844	1	.005		
N of Valid Cases	139				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 16.88.
b. Computed only for a 2x2 table

Table 22



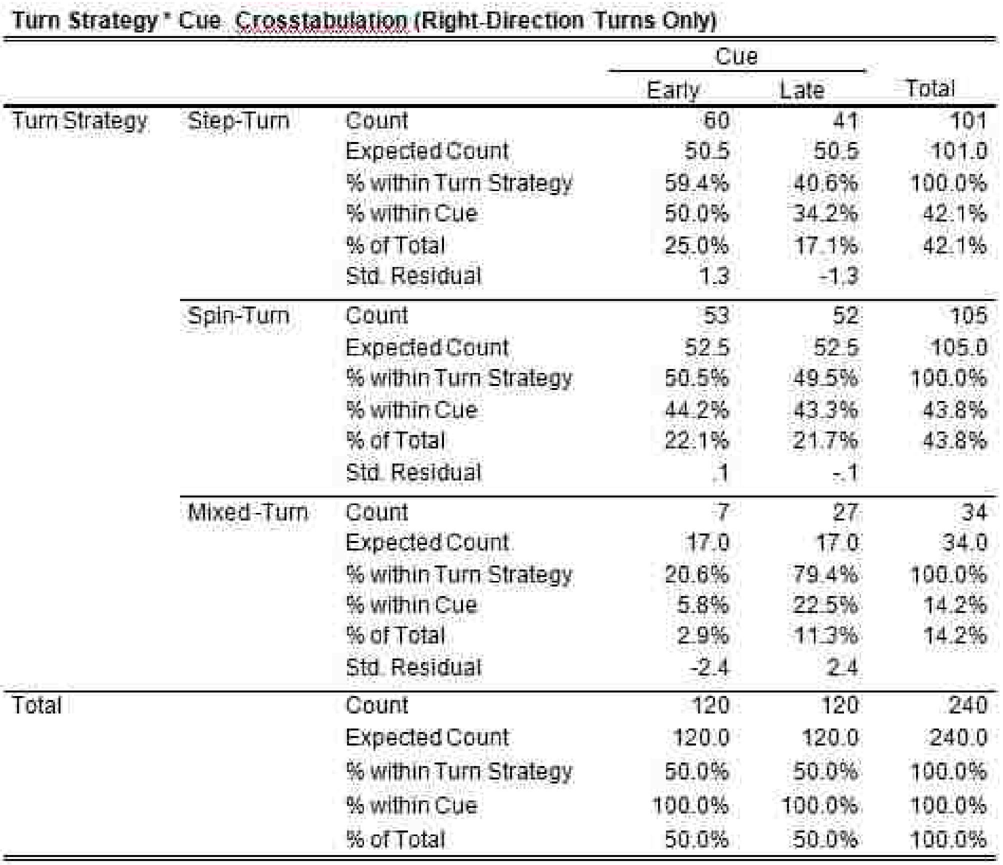
Symmetric Measures of Effect Size for the Strength of Association between 2x2 Speed*Turn-Strategy for Spin-Turns/Mixed-Turns (right-direction turns only)

		Value	Approx. Sig.
Nominal by Nominal	Phi	.238	.005
	Cramer's V	.238	.005
N of Valid Cases		139	

2 x 3 Chi-square analysis for Cue*Turn-Strategy

Third, a 2 x 3 cross-tabulation table of Cue*Turn-Strategy, for right-direction turns only, shows the assumption for Chi-square was met as each cell had an expected count >5, and yet again the lowest expected count was 17 for mixed-turns at both cues (Table 16). Standardized residuals were greatest and actually beyond +/-1.96 for mixed-turns at +/- 2.4, yet below that cut-off for step-turns at +/- 1.3, and least spin-turns at +/- 0.1. A clustered bar chart of the Cue*Turn-Strategy relationship appears to show that when cued-late, relative to the statistically significant increase seen in mixed-turns (standardized residuals beyond +/-1.96, $p < 0.05$, Field, 2009, p. 699), step-turns decreased whereas spin-turns where relatively unchanged. (Figure 12.).

Table 23



Turn Strategy * Cue Crosstabulation (Right-Direction Turns Only)

			Cue		
			Early	Late	Total
Turn Strategy	Step-Turn	Count	60	41	101
		Expected Count	50.5	50.5	101.0
		% within Turn Strategy	59.4%	40.6%	100.0%
		% within Cue	50.0%	34.2%	42.1%
		% of Total	25.0%	17.1%	42.1%
		Std. Residual	1.3	-1.3	
	Spin-Turn	Count	53	52	105
		Expected Count	52.5	52.5	105.0
		% within Turn Strategy	50.5%	49.5%	100.0%
		% within Cue	44.2%	43.3%	43.8%
		% of Total	22.1%	21.7%	43.8%
		Std. Residual	.1	-.1	
	Mixed-Turn	Count	7	27	34
		Expected Count	17.0	17.0	34.0
		% within Turn Strategy	20.6%	79.4%	100.0%
		% within Cue	5.8%	22.5%	14.2%
		% of Total	2.9%	11.3%	14.2%
		Std. Residual	-2.4	2.4	
Total		Count	120	120	240
		Expected Count	120.0	120.0	240.0
		% within Turn Strategy	50.0%	50.0%	100.0%
		% within Cue	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

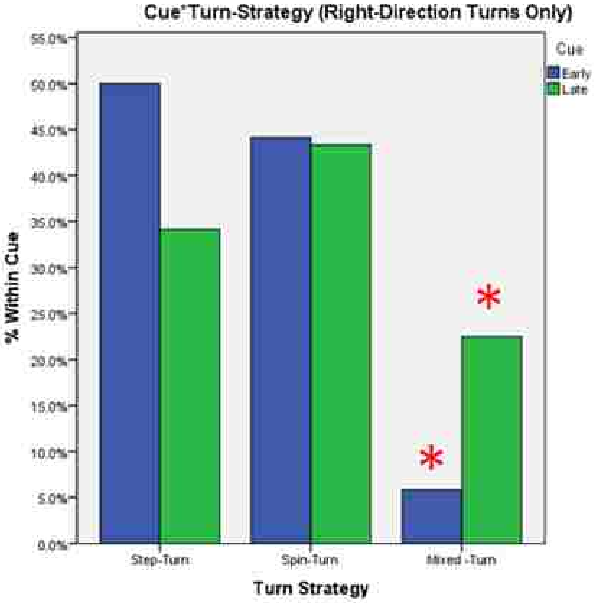
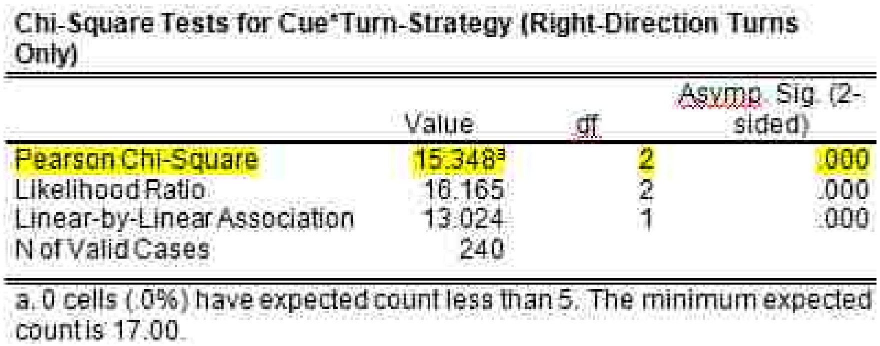


Figure 12. Cue*Turn-Strategy (Right Direction Turns Only). Note, the red asterisk indicates the standardized residual was beyond +/- 1.96 (*p* < 0.05).

The 2 x 3 Chi-square test of independence confirmed the loglinear finding of a significant relationship between Cue*Turn-Strategy preference [X^2 (2) = 15.35, *p* = 0.000] (Table 24). The strength of the 2 x 3 association as determined by Cramer's V was small/medium and significant [Cramer's V = .253, p = .000] (Prajapati et al., 2010), with post-hoc power = 0.95] (Table 25).

Table 24

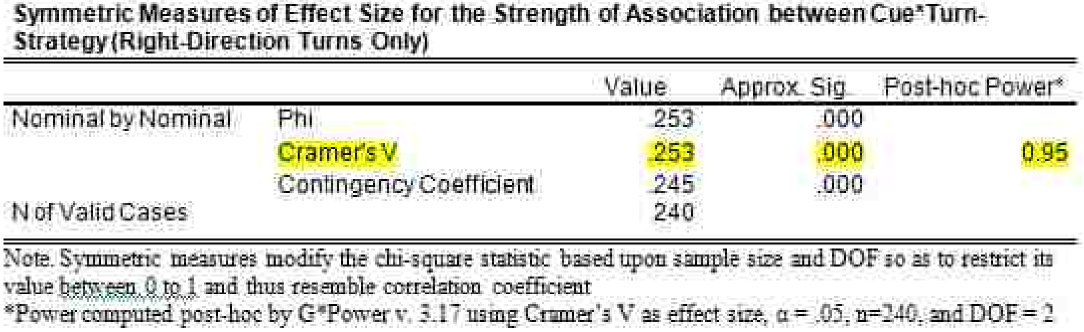


Chi-Square Tests for Cue*Turn-Strategy (Right-Direction Turns Only)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.348[a]	2	.000
Likelihood Ratio	16.165	2	.000
Linear-by-Linear Association	13.024	1	.000
N of Valid Cases	240		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.00.

Table 25



Symmetric Measures of Effect Size for the Strength of Association between Cue*Turn-Strategy (Right-Direction Turns Only)

		Value	Approx. Sig.	Post-hoc Power*
Nominal by Nominal	Phi	.253	.000	
	Cramer's V	.253	.000	0.95
	Contingency Coefficient	.245	.000	
N of Valid Cases		240		

Note. Symmetric measures modify the chi-square statistic based upon sample size and DOF so as to restrict its value between 0 to 1 and thus resemble correlation coefficient

*Power computed post-hoc by G*Power v. 3.17 using Cramer's V as effect size, α = .05, n=240, and DOF = 2

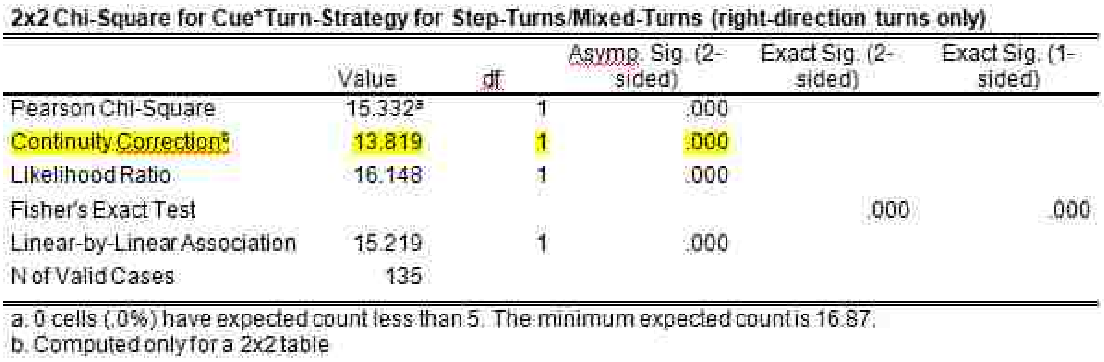
*Splitting the 2 x 3 analysis for Cue*Turn-Strategy into two separate 2 x 2 Chi-square tests*

The significant 2 x 3 Cue*Turn-Strategy two-way interaction was broken-down into two 2 x 2 Chi-square tests of independence using the 3rd turn-strategy category, mixed-turn, as the reference in order to further examine the location & strength of the relationship.

*2 x 2 Chi-square test for Cue*Turn-Strategy for step-turns/mixed-turns*

The 2 x 2 Chi-square for Cue*Turn-Strategy for step-turns/mixed-turns yielded $X^2(1) = 15.33$, p =.000; Yates's Continuity Correction=13.82, p=.000 (Table 26); medium Cramer's V = 0.337, p =.000 (Table 27); and the odds (95% CI) of a step-turn (relative to mixed-turn) was 5.56 (2.23, 14.01) x lower when cued-late as opposed to when cued-early (Appendix 0). In view of Yates's continuity correction being significant, and the null value of 1.0 not residing within the interval, the observed reduction in step-turn preference (relative to mixed-turns) when cued-late is statistically significant and we could be 95% confident ($p < 0.05$) the reduction observed is true in the population.

Table 26

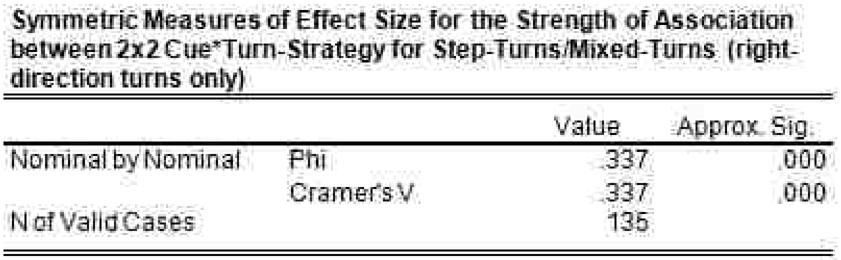


2x2 Chi-Square for Cue*Turn-Strategy for Step-Turns/Mixed-Turns (right-direction turns only)

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	15.332[a]	1	.000		
Continuity Correction[b]	13.819	1	.000		
Likelihood Ratio	16.148	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	15.219	1	.000		
N of Valid Cases	135				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 16.87.
b. Computed only for a 2x2 table

Table 27



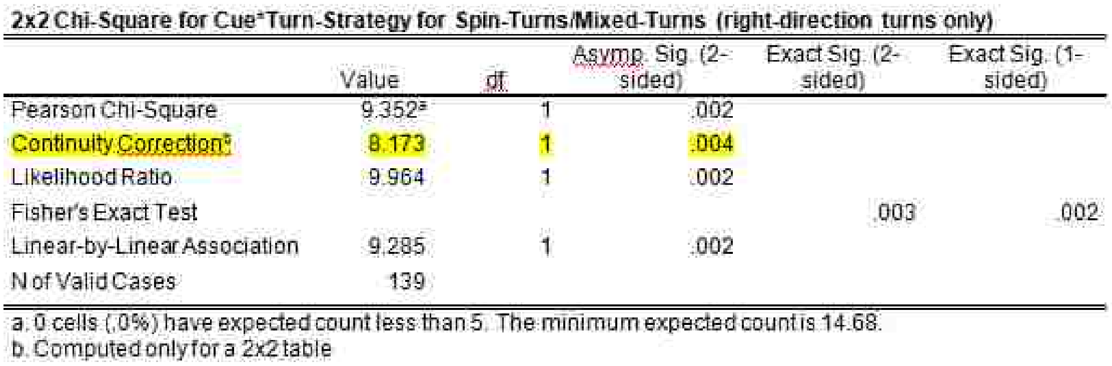
Symmetric Measures of Effect Size for the Strength of Association between 2x2 Cue*Turn-Strategy for Step-Turns/Mixed-Turns (right-direction turns only)

		Value	Approx. Sig.
Nominal by Nominal	Phi	.337	.000
	Cramer's V	.337	.000
N of Valid Cases		135	

*2 x 2 Chi-square test for Cue*Turn-Strategy for spin-turns/mixed-turns*

The 2 x 2 Chi-square for Cue*Turn-Strategy for spin-turns/mixed-turns yielded $X^2(1) = 9.35$, $p = .002$; Yates's Continuity Correction=8.17, $p=.004$ (Table 28); small/medium Cramer's V = 0.259, $p = .002$ (Table 29); and the odds (95% CI) of a spin-turn (relative to mixed-turn) was 4.00 (1.60, 10.07) x lower when cued-late as opposed to when cued-early (Appendix 0). In view of Yates's continuity correction being significant, and the null value of 1.0 not residing within the interval, the observed reduction in spin-turn preference (relative to mixed-turn) when cued-late is statistically significant and we could be 95% confident ($p < 0.05$) the reduction observed is true in the population.

Table 28

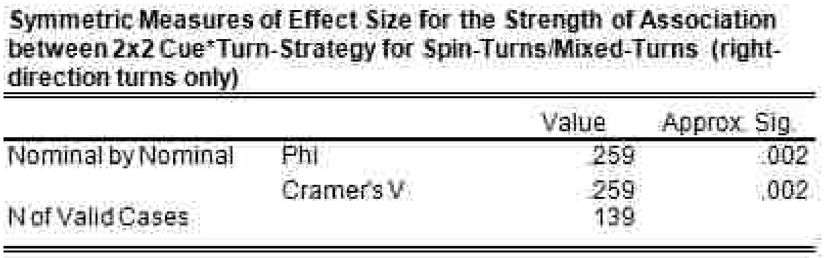


2x2 Chi-Square for Cue*Turn-Strategy for Spin-Turns/Mixed-Turns (right-direction turns only)

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.352^a	1	.002		
Continuity Correction^b	8.173	1	.004		
Likelihood Ratio	9.964	1	.002		
Fisher's Exact Test				.003	.002
Linear-by-Linear Association	9.285	1	.002		
N of Valid Cases	139				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 14.68.
b. Computed only for a 2x2 table

Table 29



Symmetric Measures of Effect Size for the Strength of Association between 2x2 Cue*Turn-Strategy for Spin-Turns/Mixed-Turns (right-direction turns only)

		Value	Approx. Sig.
Nominal by Nominal	Phi	.259	.002
	Cramer's V	.259	.002
N of Valid Cases		139	

Results of Mixed-Design ANOVA for Spatial-Temporal Gait Adaptations across the Four Final Recorded Approach Footfalls (Straight and Right Turns Only)

The four-way mixed-design ANOVA to assess age-group differences in spatial-temporal gait modifications across the final-four recorded approach footfalls from the interaction of the within-categorical independent variables of test-speed, cue-time constraint, and direction (straight v. right-turns only) analyzed n= 480 cases given each of the 20 participants contributed 24 trials (12 straight, 12 right-direction turns). The results of four separate 2x2x2x2 mixed-design ANOVAs, beginning in each instance with a brief review of assumptions testing, for the four dependent gait variables of interest are presented below including: normalized speed, normalized right/left combined stride-length, normalized right heel-to-heel base of support, & normalized left heel-to-heel base of support BOS. All age-related significant differences or trends, and all significant interactions will be reported here in the results section. When the interaction is found to be “ordinal” [i.e. the relative ranking of the levels of one factor is consistent across levels of the second factor (Portney & Watkins, 2009, p. 466)], as the significant main effects will be integrated into the interpretation, the main effect(s) will be omitted here in results section but instead presented in the appendix (although all significant effects are highlighted in the Mixed-Design ANOVA table for each dependent variable). However, when the interaction is “disordinal” [i.e. the relative ranking of the levels of one factor reverses across levels of the second factor

(Portney & Watkins, 2009, p. 466)], though the significant main effects are omitted when interpreting the finding, the main effect(s) will nonetheless still be reported in the results section to better facilitate an appreciation of the “disordinal” interaction.

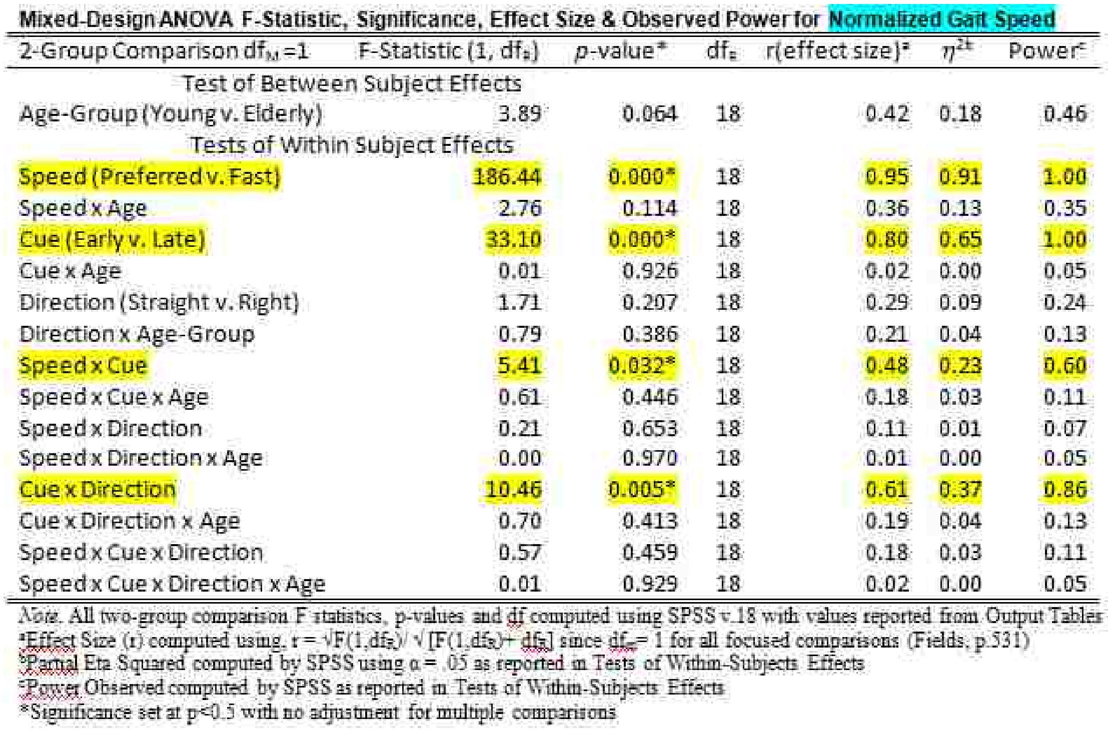
Dependent variable of normalized gait speed (leg-length/second)

Exploration of assumptions of the 2x2x2x2 mixed-design ANOVA for the dependent variable normalized gait speed (LL/s), for straight & right turns only, revealed that normality was violated in 1 of the 16 conditions [elderly late right preferred: significant Shapiro-Wilk test as W(10) = 0.832 with *p* = .036; but non-significant Kolmogorov-Smirnov test as D(10) = 0.208 with *p* = .20]. However, the assumption of homogeneity of variance was met as the Levene’s test was non-significant for all 8 conditions. (Appendix P). Despite the violation of normality, when group sizes are identical as in the present study (young n=10, elderly n=10), ANOVA is believed to be reasonably robust to violations both of normality and homogeneity of variance (Field, 2009). Finally, for all 2x2x2x2 mixed-design ANOVAs in the present study, sphericity was not an issue since each repeated measures variable had only 2 levels, and the assumption of sphericity is automatically met (Field, 2009).

The mixed-design ANOVA for the dependent variable Normalized Gait Speed (LL/s), for straight & right turns only, revealed the following significant findings: a main effect for Speed, a main effect for Cue, a two-way

Speed*Cue interaction, and a two-way Cue*Direction interaction. The F-statistic, significance level, effect size (both as Pearson's correlation coefficient, r, & eta squared, η^2), and observed power for all 15 comparisons are shown in Table 30 below. As interaction effects are of greater interest in this study, when both significant interaction & main effects are present, for the sake of clarity, graphical plots & any relevant details for main effects will be placed in the appendix. Hence, as interactions will be reported below, further information on the main effects for the normalized gait speed can be found in Appendix R.

Table 30



Mixed-Design ANOVA F-Statistic, Significance, Effect Size & Observed Power for Normalized Gait Speed

2-Group Comparison $df_M = 1$	F-Statistic (1, df_R)	*p*-value*	df_R	r(effect size)[a]	η^{2b}	Power[c]
Test of Between Subject Effects						
Age-Group (Young v. Elderly)	3.89	0.064	18	0.42	0.18	0.46
Tests of Within Subject Effects						
Speed (Preferred v. Fast)	186.44	0.000*	18	0.95	0.91	1.00
Speed x Age	2.76	0.114	18	0.36	0.13	0.35
Cue (Early v. Late)	33.10	0.000*	18	0.80	0.65	1.00
Cue x Age	0.01	0.926	18	0.02	0.00	0.05
Direction (Straight v. Right)	1.71	0.207	18	0.29	0.09	0.24
Direction x Age-Group	0.79	0.386	18	0.21	0.04	0.13
Speed x Cue	5.41	0.032*	18	0.48	0.23	0.60
Speed x Cue x Age	0.61	0.446	18	0.18	0.03	0.11
Speed x Direction	0.21	0.653	18	0.11	0.01	0.07
Speed x Direction x Age	0.00	0.970	18	0.01	0.00	0.05
Cue x Direction	10.46	0.005*	18	0.61	0.37	0.86
Cue x Direction x Age	0.70	0.413	18	0.19	0.04	0.13
Speed x Cue x Direction	0.57	0.459	18	0.18	0.03	0.11
Speed x Cue x Direction x Age	0.01	0.929	18	0.02	0.00	0.05

Note. All two-group comparison F statistics, p-values and df computed using SPSS v.18 with values reported from Output Tables

[a] Effect Size (r) computed using, $r = \sqrt{F(1, df_R)} / \sqrt{[F(1, df_R) + df_R]}$ since $df_M = 1$ for all focused comparisons (Fields, p.531)

[b] Partial Eta Squared computed by SPSS using $\alpha = .05$ as reported in Tests of Within-Subjects Effects

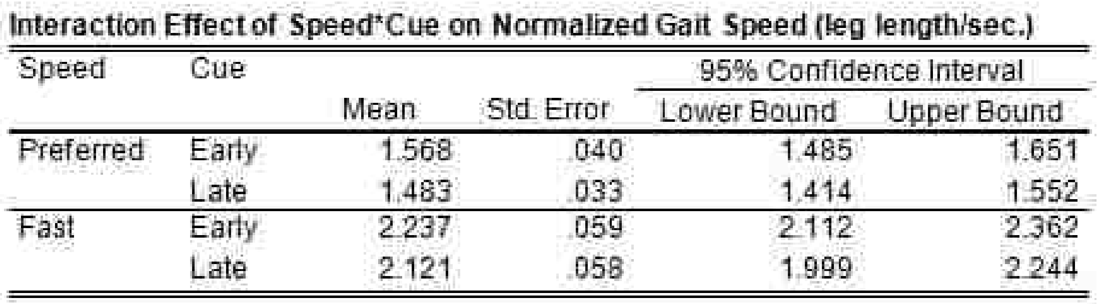
[c] Power Observed computed by SPSS as reported in Tests of Within-Subjects Effects

*Significance set at $p<0.5$ with no adjustment for multiple comparisons

With regards to higher order effects, the mixed-design ANOVA for the dependent variable Normalized Gait Speed (LL/s),for straight & right turns only, yielded a significant two-way Speed*Cue interaction [F(1,18) = 5.41, *p*=0.03, r=0.48 (medium/large), η^2 =0.23, power =0.60]. Based upon inspection of the estimated marginal means (Table 31) and the steepness in the slopes of the fast & preferred speed lines in the interaction plot (*Figure* 13.), this interaction is interpreted as suggesting that while participants walked faster during the fast-speed block of trials at both levels of cuing, they slowed down gait to a greater extent when cued late while walking at a fast speed, as opposed to at preferred speed. Moreover, given age-related differences are the focus of this study, this Speed*Cue interaction was similar in both age-groups [F(1,18) = 0.61, *p*=0.45] (*Figure* 14.). Finally, despite Field, (2009) advocating for the use of interaction plots/examination of estimated marginal means when interpreting significant interactions as reported in the Tests of Within-Subjects Contrasts, and Portney & Watkins (2009) noting standard post-hoc multiple comparison procedures are not routinely employed for repeated measures analyses (given post-hoc comparisons are formulated from overall group differences and not within-subject comparisons), an attempt was made nonetheless to also manually compute Tukey’s HSD. This was done in order to determine if the minimum significant difference (MSD) threshold in assessing pairwise comparisons collaborated with the significant findings reported in the SPSS Tests of Within

Subjects Contrasts & visual inspection of the interaction plot. In so doing, Tukey's HSD was manually computed using the known formula, MSD = q√(MS$_e$/n) (Portney & Watkins, 209), with the mean square error term used corresponding to the error for that specific interaction [i.e. in this case the mean square error reported for Error(Speed*Cue) =.002]. However, manual computation using Tukey's HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects the interpretation by the principal investigator of the interaction plot. Instead, the Tukey indicated all comparisons were significantly different (Appendix Q).

Table 31



Interaction Effect of Speed*Cue on Normalized Gait Speed (leg length/sec.)

Speed	Cue	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Preferred	Early	1.568	.040	1.485	1.651
	Late	1.483	.033	1.414	1.552
Fast	Early	2.237	.059	2.112	2.362
	Late	2.121	.058	1.999	2.244

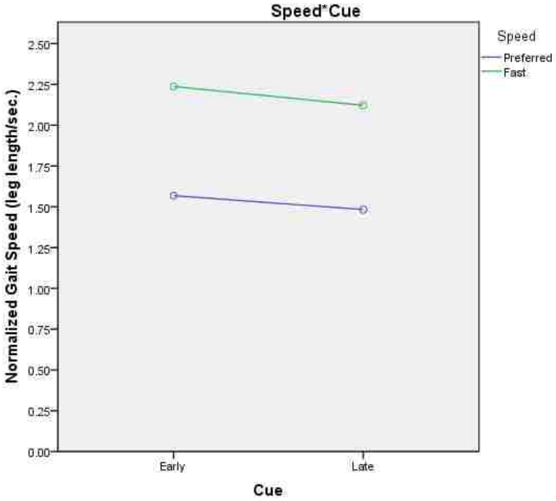


Figure 13. Speed*Cue Interaction on Normalized Gait Speed (Straight & Right Turns Only).

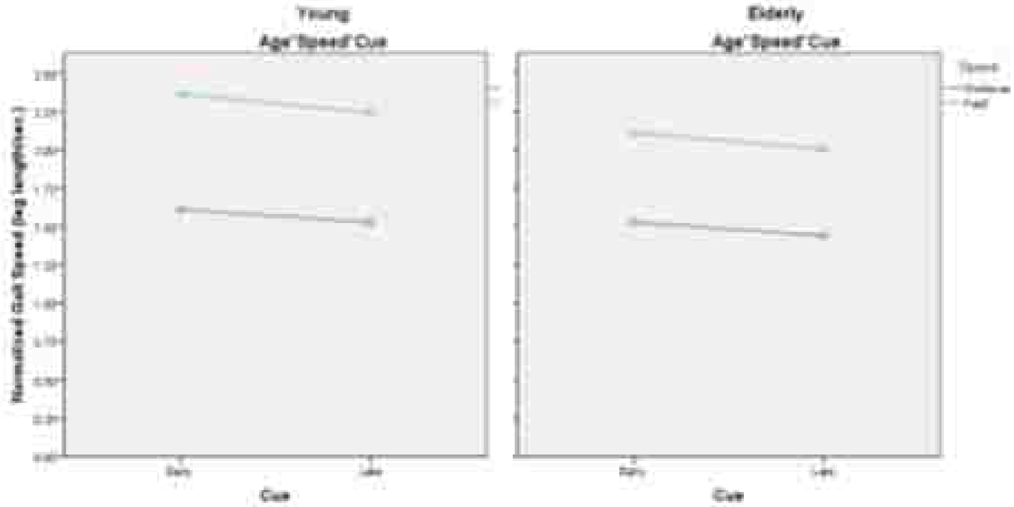
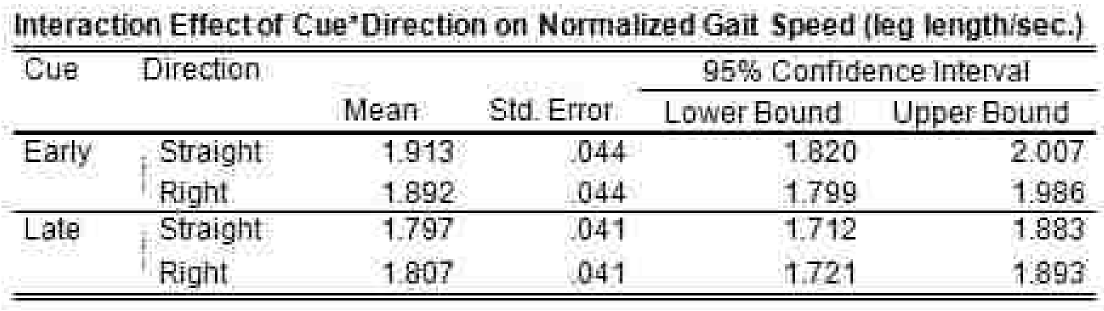


Figure 14. Speed*Cue Interaction on Normalized Gait Speed (Straight & Right Turns Only) Similar in Both Age-Groups

Additionally, the mixed-design ANOVA for the dependent variable Normalized Gait Speed (LL/s), for straight & right turns only, also yielded a significant two-way interaction for Cue*Direction [F(1,18) = 10.46 *p*=0.01, r=0.61 (large), η^2 =0.37, power =0.86]. Based upon inspection of the estimated marginal means (Table 32) and the steepness in the slopes of the early & late cue lines in the interaction plot (*Figure* 15.), this interaction is interpreted as suggesting that while participants walked slower when cued late at both levels of direction, it is only when cued early that speed decreased when turning right as opposed to continuing straight. This Cue*Direction interaction was similar in both age-groups [F(1,18) = 0.70, *p*=0.41] (*Figure* 16.). Finally, manual computation using Tukey's HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects nor the interpretation by the principal investigator of the interaction plot. Instead, the Tukey indicated no Cue*Direction interaction, and just revealed the main effect for cue i.e. early faster than late (Appendix Q).

Table 32



Interaction Effect of Cue*Direction on Normalized Gait Speed (leg length/sec.)

Cue	Direction	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Early	Straight	1.913	.044	1.820	2.007
	Right	1.892	.044	1.799	1.986
Late	Straight	1.797	.041	1.712	1.883
	Right	1.807	.041	1.721	1.893

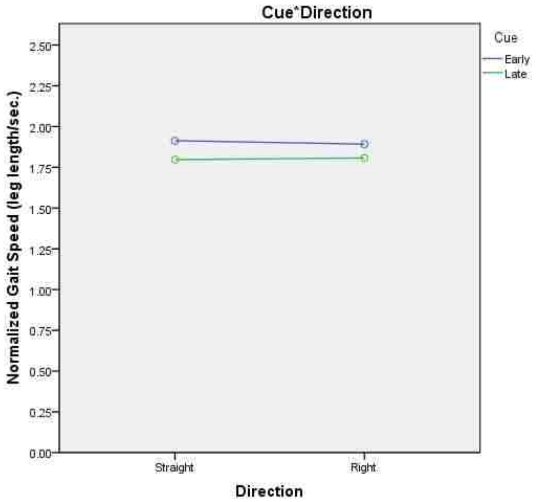


Figure 15. Cue*Direction Interaction on Normalized Gait Speed (Straight & Right Turns Only).

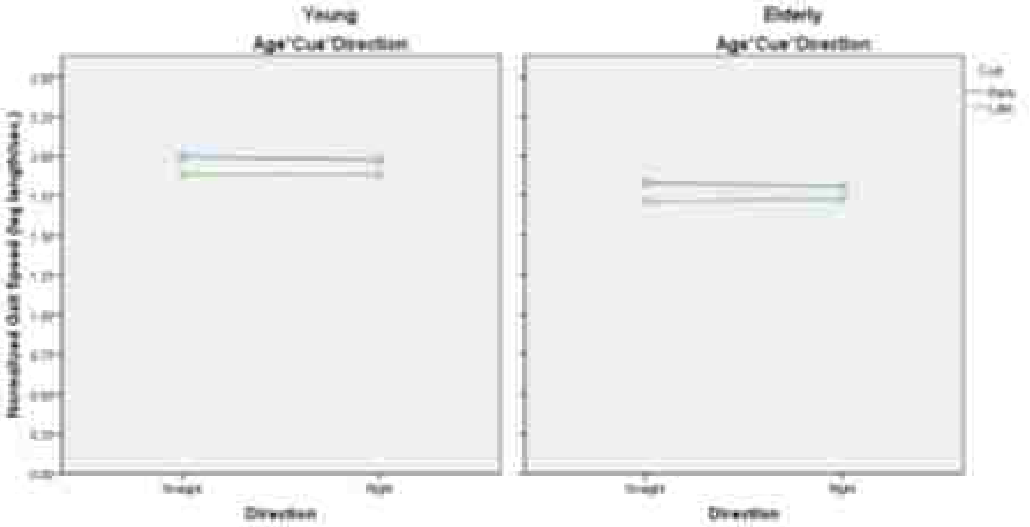


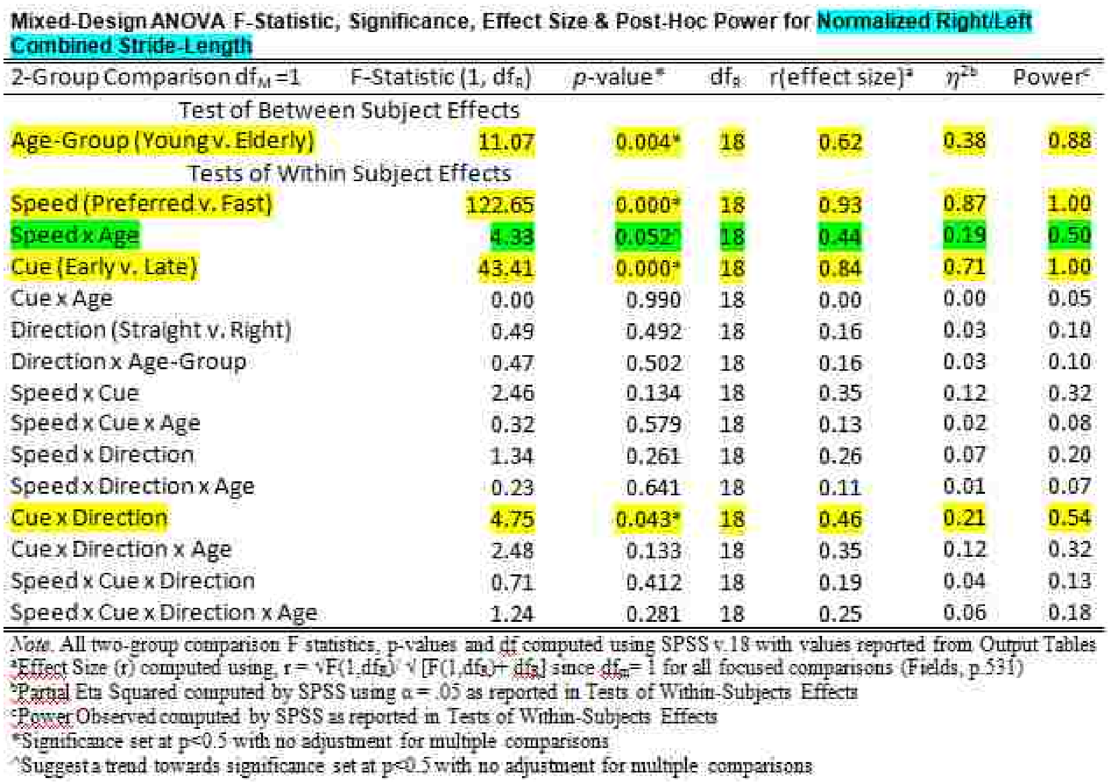
Figure 16. Cue*Direction Interaction on Normalized Gait Speed (Straight & Right Turns Only) Similar in Both Age-Groups.

Dependent variable of normalized right/left combined stride-length (leg-length)

Exploration of assumptions of the 2x2x2x2 mixed-design ANOVA for the dependent variable right/left combined stride-length, for straight & right turns only, revealed that normality was violated in 4 of the 16 conditions [1) elderly late straight preferred: significant Kolmogorov-Smirnov test as D(10) = 0.263, *p* = .048, but non-significant Shapiro-Wilk test as W(10) = 0.853 with *p* = .063; 2) elderly late right preferred: significant Kolmogorov-Smirnov test as D(10) = 0.269 with *p* = .039, but non-significant Shapiro-Wilk test as W(10) = 0.879 with *p* = .129; 3) young early straight fast: significant Shapiro-Wilk test as W(10) = 0.770 with *p* = .006, but non-significant Kolmogorov-Smirnov test as D(10) = 0.243 with *p* = .097; and 4) young late straight fast significant Kolmogorov-Smirnov test as D(10) = 0.263 with *p* = .048, but non-significant Shapiro-Wilk test as W(10) = 0.850 with *p* = .057]. However, the assumption of homogeneity of variance was met as the Levene's test was non-significant for all 8 conditions, although approached significance for early straight fast as F(1,18) = 4.187 with *p* = .056. (Appendix S). As mentioned above, despite the violations of normality, given group sizes were equal (young n=10, elderly n=10), ANOVA is believed to be quite robust to either violations of normality or homogeneity of variance (Field, 2009). Lastly, as also stated above, sphericity was not of concern as each repeated measures variable had only 2 levels, and the assumption of sphericity is automatically met (Field, 2009).

The mixed-design ANOVA for the dependent variable Normalized Right/Left Combined Stride-Length (LL), for straight & right turns only, revealed the following significant findings: a main effect for Age-Group, a main effect for Speed, a main effect for Cue, a two-way Cue*Direction interaction, and a “trend” toward an Age*Speed interaction. The F-statistic, significance level, effect size (both as Pearson's correlation coefficient, r, & eta squared, η^2), and observed power for all 15 comparisons are shown in Table 36 below. As interactions will be reported below, further information on the main effects for normalized right/left combined stride-length can be found in Appendix U.

Table 33



Mixed-Design ANOVA F-Statistic, Significance, Effect Size & Post-Hoc Power for Normalized Right/Left Combined Stride-Length

2-Group Comparison $df_M = 1$	F-Statistic (1, df_R)	*p*-value*	df_R	r(effect size)^a	η^{2b}	Power^c
Test of Between Subject Effects						
Age-Group (Young v. Elderly)	11.07	0.004*	18	0.62	0.38	0.88
Tests of Within Subject Effects						
Speed (Preferred v. Fast)	122.65	0.000*	18	0.93	0.87	1.00
Speed x Age	4.33	0.052^	18	0.44	0.19	0.50
Cue (Early v. Late)	43.41	0.000*	18	0.84	0.71	1.00
Cue x Age	0.00	0.990	18	0.00	0.00	0.05
Direction (Straight v. Right)	0.49	0.492	18	0.16	0.03	0.10
Direction x Age-Group	0.47	0.502	18	0.16	0.03	0.10
Speed x Cue	2.46	0.134	18	0.35	0.12	0.32
Speed x Cue x Age	0.32	0.579	18	0.13	0.02	0.08
Speed x Direction	1.34	0.261	18	0.26	0.07	0.20
Speed x Direction x Age	0.23	0.641	18	0.11	0.01	0.07
Cue x Direction	4.75	0.043*	18	0.46	0.21	0.54
Cue x Direction x Age	2.48	0.133	18	0.35	0.12	0.32
Speed x Cue x Direction	0.71	0.412	18	0.19	0.04	0.13
Speed x Cue x Direction x Age	1.24	0.281	18	0.25	0.06	0.18

Note. All two-group comparison F statistics, p-values and df computed using SPSS v.18 with values reported from Output Tables

^{a}Effect Size (r) computed using, $r = \sqrt{F(1, df_R)} / \sqrt{[F(1, df_R) + df_R]}$ since $df_m = 1$ for all focused comparisons (Fields, p.531)

^{b}Partial Eta Squared computed by SPSS using α = .05 as reported in Tests of Within-Subjects Effects

^{c}Power Observed computed by SPSS as reported in Tests of Within-Subjects Effects

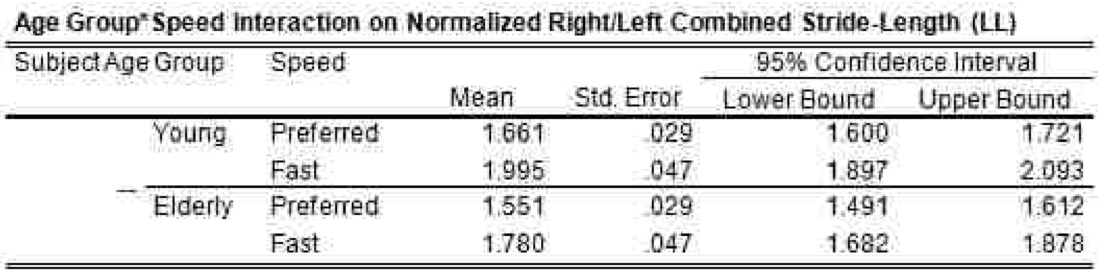
*Significance set at $p<0.5$ with no adjustment for multiple comparisons

^Suggest a trend towards significance set at $p<0.5$ with no adjustment for multiple comparisons

With regards to higher order effects, the mixed-design ANOVA for the dependent variable Normalized Right/Left Combined Stride-Length (LL),for straight & right turns only, yielded a "trend" towards significance for an Age*Speed interaction [F(1,18) = 4.33, *p*=0.052, r=0.44 (medium to large), η^2 =0.19 power =0.50]. Based upon inspection of the estimated marginal means

(Table 34) and the steepness in the slopes of the young & elderly lines in the interaction plot (*Figure* 17.), this interaction is interpreted as suggesting that while the elderly took shorter strides at both levels of walking speed, the elderly had less of an increase in stride length when walking fast as opposed to at preferred speed. Finally, manual computation using Tukey's HSD to assess between which pair of means the significance resided could not be performed as mean square error for between*within interactions (i.e. Age-Group*Speed) are not provided in Test of Within Subject Contrast table, unlike the error term provided for within*within interactions. (Appendix T).

Table 34



Age Group*Speed Interaction on Normalized Right/Left Combined Stride-Length (LL)

Subject Age Group	Speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Young	Preferred	1.661	.029	1.600	1.721
	Fast	1.995	.047	1.897	2.093
Elderly	Preferred	1.551	.029	1.491	1.612
	Fast	1.780	.047	1.682	1.878

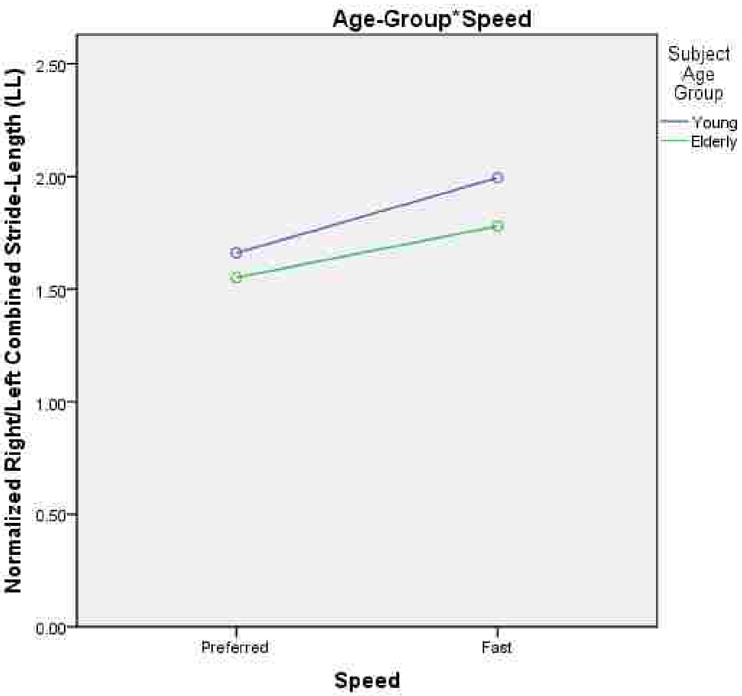
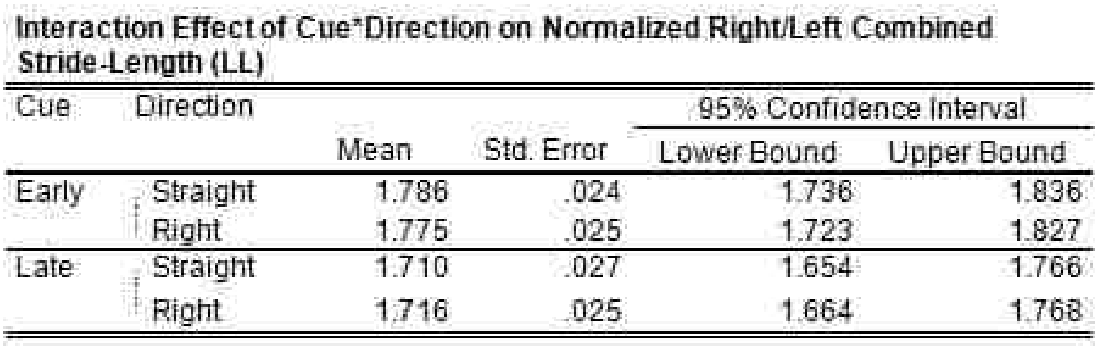


Figure 17. Age*Speed Interaction on Normalized Right/Left Combined Stride-Length (Straight & Right Turns Only)

Additionally, the mixed-design ANOVA for the dependent variable Normalized Right/Left Combined Stride-Length (LL), for straight & right turns only, also yielded a significant two-way interaction for Cue*Direction [F(1,18) = 4.75 *p*=0.043, r=0.46 (medium/large), η^2 =0.21, power =0.54]. Based upon inspection of the estimated marginal means (Table 35) and the steepness in the slopes of the early & late cue lines in the interaction plot (*Figure* 18.), this interaction is interpreted as suggesting that while participants took shorter strides when cued late at both levels of direction, it is only when cued early that stride-length decreased when turning right as opposed to continuing straight. This Cue*Direction interaction was similar in both age-groups [F(1,18) = 2.48, *p*=0.13] (*Figure* 18.). Finally, manual computation using

Tukey's HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects nor the interpretation by the principal investigator of the interaction plot. Instead, the Tukey indicated no Cue*Direction interaction, and just revealed the main effect for cue i.e. early longer than late (Appendix Q).

Table 35



Interaction Effect of Cue*Direction on Normalized Right/Left Combined Stride-Length (LL)

Cue	Direction	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Early	Straight	1.786	.024	1.736	1.836
	Right	1.775	.025	1.723	1.827
Late	Straight	1.710	.027	1.654	1.766
	Right	1.716	.025	1.664	1.768

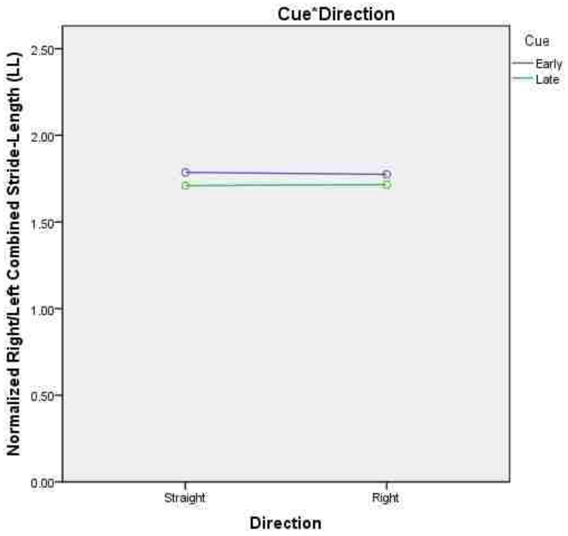


Figure 18. Cue*Direction Interaction on Normalized Right/Left Combined Stride-Length (Straight & Right Turns Only)

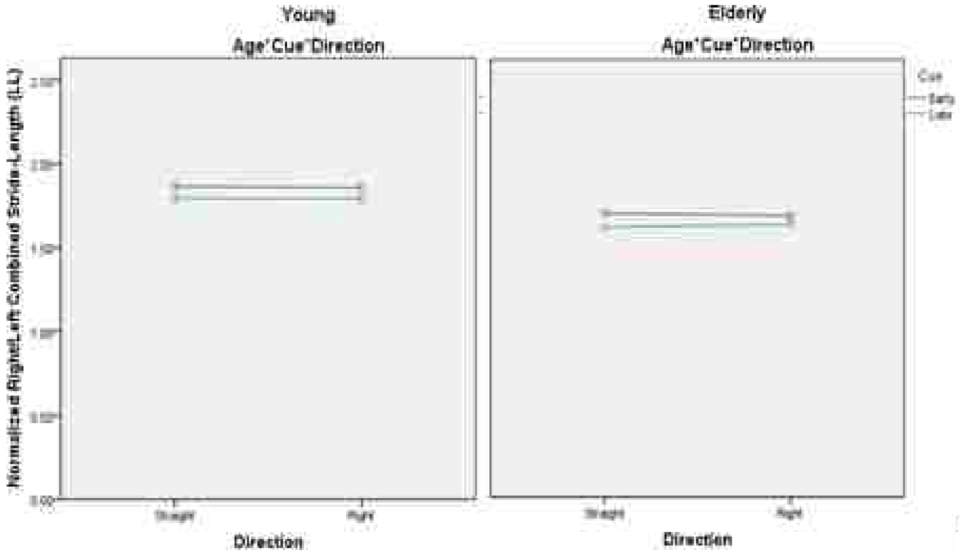


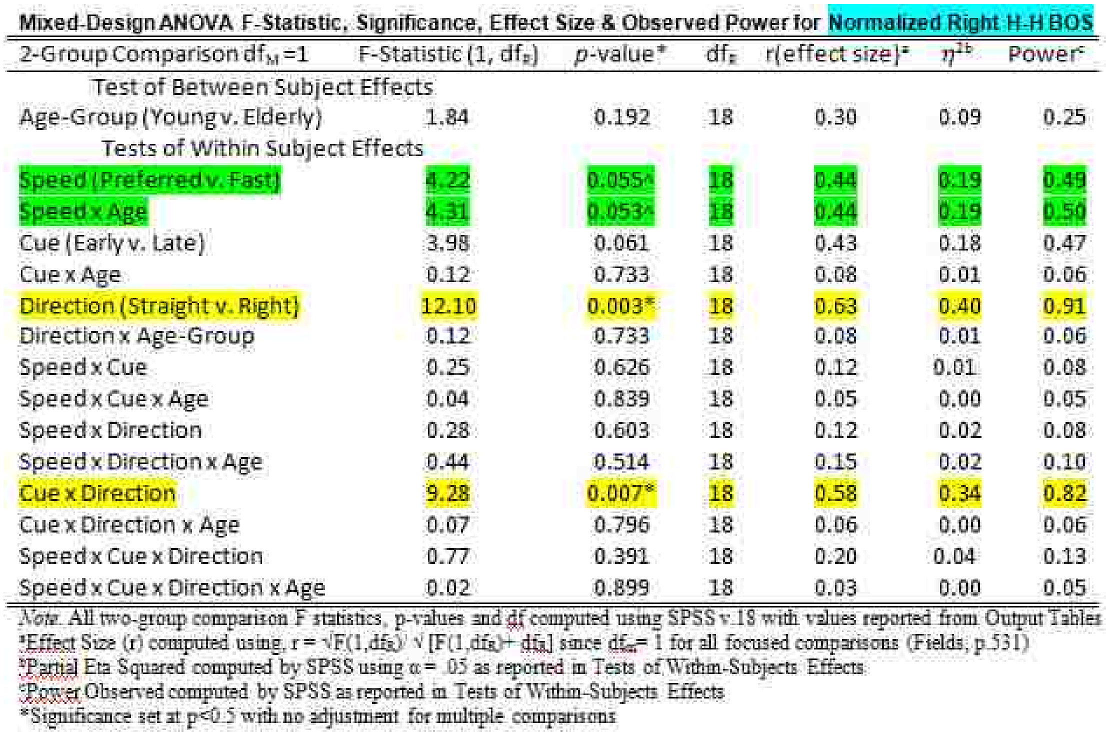
Figure 19. Cue*Direction Interaction on Normalized Right/Left Combined Stride-Length (Straight & Right Turns Only) Similar in Both Age-Groups

Dependent variable of normalized right heel-to-heel base of support (leg-length)

Exploration of assumptions of the 2x2x2x2 mixed-design ANOVA for the dependent variable normalized right heel-to-heel base of support, for straight & right turns only, revealed that normality was violated in 1 of the 16 conditions [elderly late straight fast: significant Shapiro-Wilk test as W(10) = 0.825 with *p* = .029, but non-significant Kolmogorov-Smirnov test as D(10) = 0.250 with *p* = .077]. However, the assumption of homogeneity of variance was met as the Levene’s test was non-significant for all 8 conditions. (Appendix V). As stated above, despite the violations of normality, given group sizes were equal (young n=10, elderly n=10), ANOVA is believed to be pretty robust to either violations of normality or homogeneity of variance (Field, 2009, p. 360). Lastly, as also noted above, sphericity was not of concern as each repeated measures variable had only 2 levels, and the assumption of sphericity is automatically met (Field, 2009).

The mixed-design ANOVA for the dependent variable Normalized Right Heel-to-Heel Base of Support (LL), for straight & right turns only, revealed the following significant findings: a main effect for Direction, a “trend” toward a main effect for Speed, a two-way Cue*Direction interaction, and a “trend” toward an Age*Speed interaction. The F-statistic, significance level, effect size (both as Pearson’s correlation coefficient, r, & eta squared, η^2), and observed power for all 15 comparisons are shown in Table 33 below. As interactions will be reported below, further information on the main effects for normalized right heel-to-heel base of support can be found in Appendix X.

Table 36



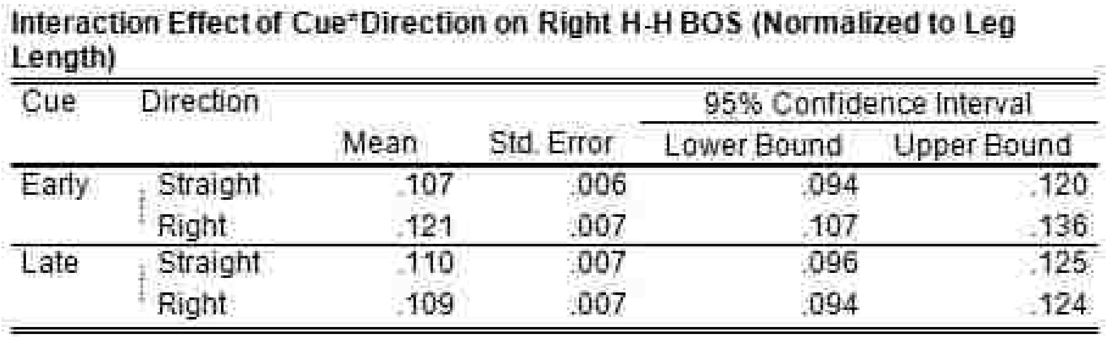
Mixed-Design ANOVA F-Statistic, Significance, Effect Size & Observed Power for Normalized Right H-H BOS

2-Group Comparison df_M =1	F-Statistic (1, df_E)	*p*-value*	df_E	r(effect size)^a	η^{2b}	Power^c
Test of Between Subject Effects						
Age-Group (Young v. Elderly)	1.84	0.192	18	0.30	0.09	0.25
Tests of Within Subject Effects						
Speed (Preferred v. Fast)	4.22	0.055^	18	0.44	0.19	0.49
Speed x Age	4.31	0.053^	18	0.44	0.19	0.50
Cue (Early v. Late)	3.98	0.061	18	0.43	0.18	0.47
Cue x Age	0.12	0.733	18	0.08	0.01	0.06
Direction (Straight v. Right)	12.10	0.003*	18	0.63	0.40	0.91
Direction x Age-Group	0.12	0.733	18	0.08	0.01	0.06
Speed x Cue	0.25	0.626	18	0.12	0.01	0.08
Speed x Cue x Age	0.04	0.839	18	0.05	0.00	0.05
Speed x Direction	0.28	0.603	18	0.12	0.02	0.08
Speed x Direction x Age	0.44	0.514	18	0.15	0.02	0.10
Cue x Direction	9.28	0.007*	18	0.58	0.34	0.82
Cue x Direction x Age	0.07	0.796	18	0.06	0.00	0.06
Speed x Cue x Direction	0.77	0.391	18	0.20	0.04	0.13
Speed x Cue x Direction x Age	0.02	0.899	18	0.03	0.00	0.05

Note. All two-group comparison F statistics, p-values and df computed using SPSS v.18 with values reported from Output Tables
^{a}Effect Size (r) computed using, r = $\sqrt{F(1,df_E)}$/ $\sqrt{[F(1,df_E)+ df_E]}$ since df_M= 1 for all focused comparisons (Fields, p.531)
^{b}Partial Eta Squared computed by SPSS using α = .05 as reported in Tests of Within-Subjects Effects
^{c}Power Observed computed by SPSS as reported in Tests of Within-Subjects Effects
*Significance set at p<0.5 with no adjustment for multiple comparisons

With regards to higher order effects, the mixed-design ANOVA for the dependent variable Normalized Right Heel-to-Heel Base of Support/ (LL) ,for straight & right turns only, yielded significant two-way Cue*Direction interaction [F(1,18) = 9.28, *p*=0.007, r=0.58 (large), η^2 =0.34 power =0.82]. Based upon inspection of the estimated marginal means (Table 37) and the steepness in the slopes of the early & late lines in the interaction plot (*Figure* 20.), this interaction is interpreted as suggesting that while participates used a similar right H-H BOS when walking straight at both levels of cuing, they increased right H-H BOS (made it wider) when turning right only when cued early as opposed to late. This Cue*Direction interaction was similar in both age-groups [F(1,18) = 0.07, *p*=0.80] (*Figure* 21). Finally, manual computation using Tukey's HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects nor the interpretation by the principal investigator of the interaction plot. Instead, the Tukey indicated no differences between comparisons were significant i.e. no interaction or main effect. (Appendix W).

Table 37



Interaction Effect of Cue*Direction on Right H-H BOS (Normalized to Leg Length)

Cue	Direction	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Early	Straight	.107	.006	.094	.120
	Right	.121	.007	.107	.136
Late	Straight	.110	.007	.096	.125
	Right	.109	.007	.094	.124

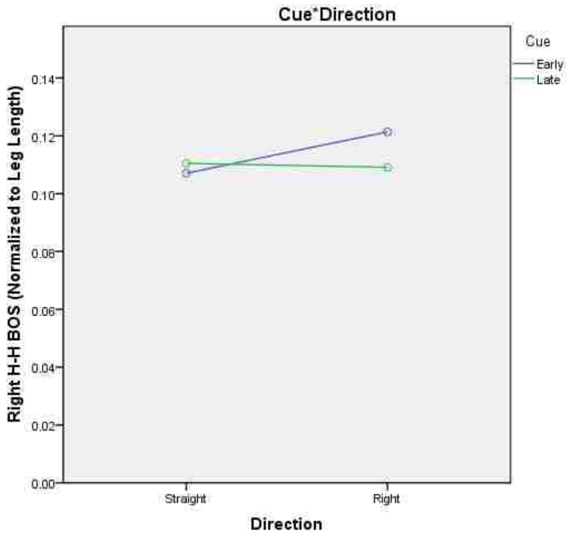


Figure 20. Cue*Direction Interaction on Normalized Right Heel-to-Heel Base of Support (Straight & Right Turns Only)

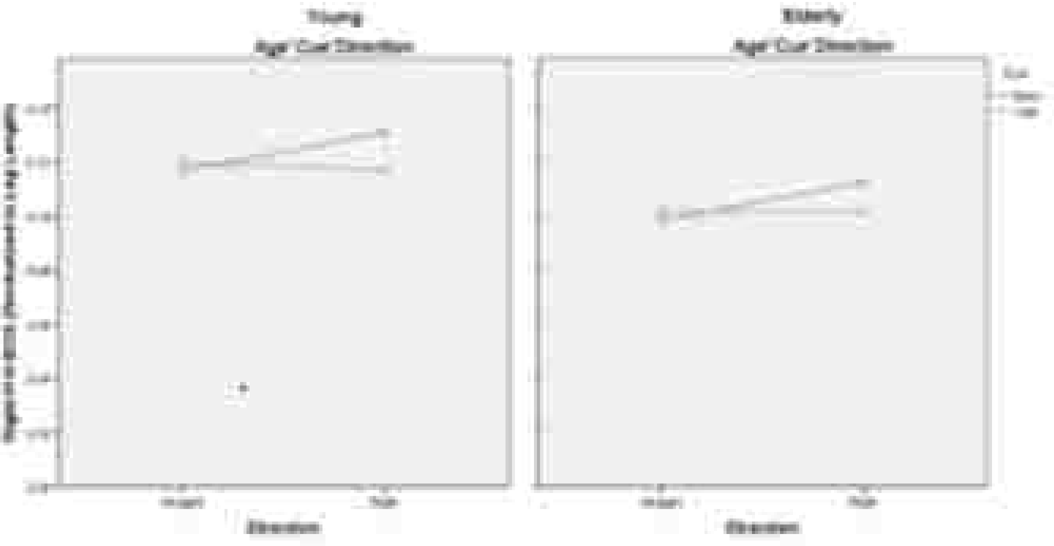
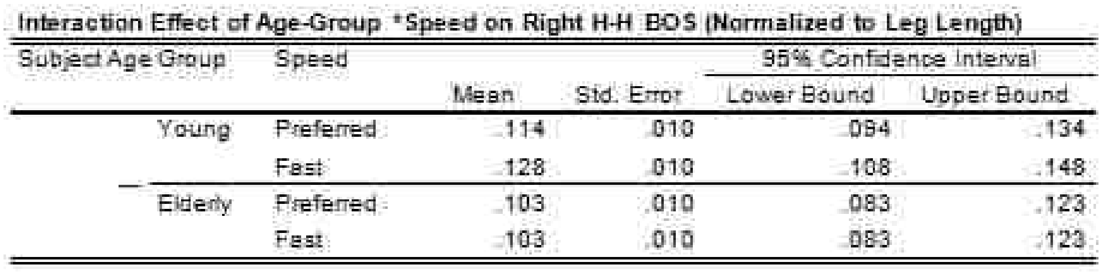


Figure 21. Cue*Direction Interaction on Normalized Right Heel-to-Heel Base of Support (Straight & Right Turns Only) Similar in Both Age-Groups

Additionally, the mixed-design ANOVA for the dependent variable Normalized Right Heel-to-Heel Base of Support (LL), for straight & right turns only, also yielded a “trend” toward a significant Age*Speed two-way interaction [F(1,18) = 4.31 *p*=0.053, r=0.44 (medium/large), η^2 =0.19, power =0.50]. Based upon inspection of the estimated marginal means (Table 38) and the steepness in the slopes of the young & elderly lines in the interaction plot (*Figure* 22.), this interaction is interpreted as suggesting that while both age-groups had statistically similar right H-H BOS at preferred speed, only young adults increased (widened) right H-H BOS at fast speed as it was unchanged in the elderly. Finally, as previously indicated, manual computation using Tukey’s HSD to assess between which pair of means the significance resided could not be performed as mean square error for between*within interactions (i.e. Age-Group*Speed) are not provided in Test of Within Subject Contrast table, unlike the error term provided for within*within interactions. (Appendix W).

Table 38



Interaction Effect of Age-Group *Speed on Right H-H BOS (Normalized to Leg Length)

Subject Age Group	Speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Young	Preferred	.114	.010	.094	.134
	Fast	.128	.010	.108	.148
Elderly	Preferred	.103	.010	.083	.123
	Fast	.103	.010	.083	.123

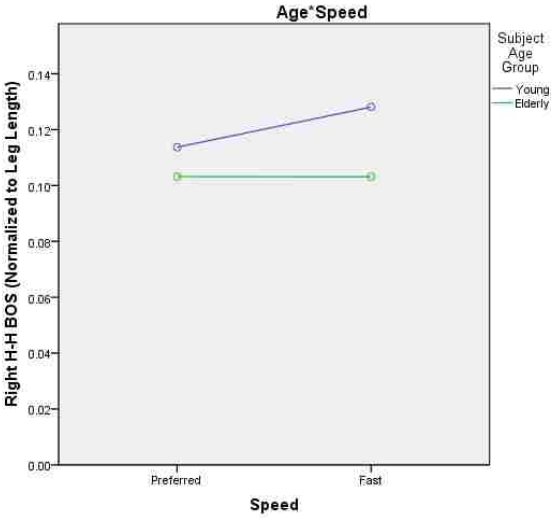


Figure 22. Age-Group*Speed Interaction on Normalized Right Heel-to-Heel Base of Support (Straight & Right Turns Only)

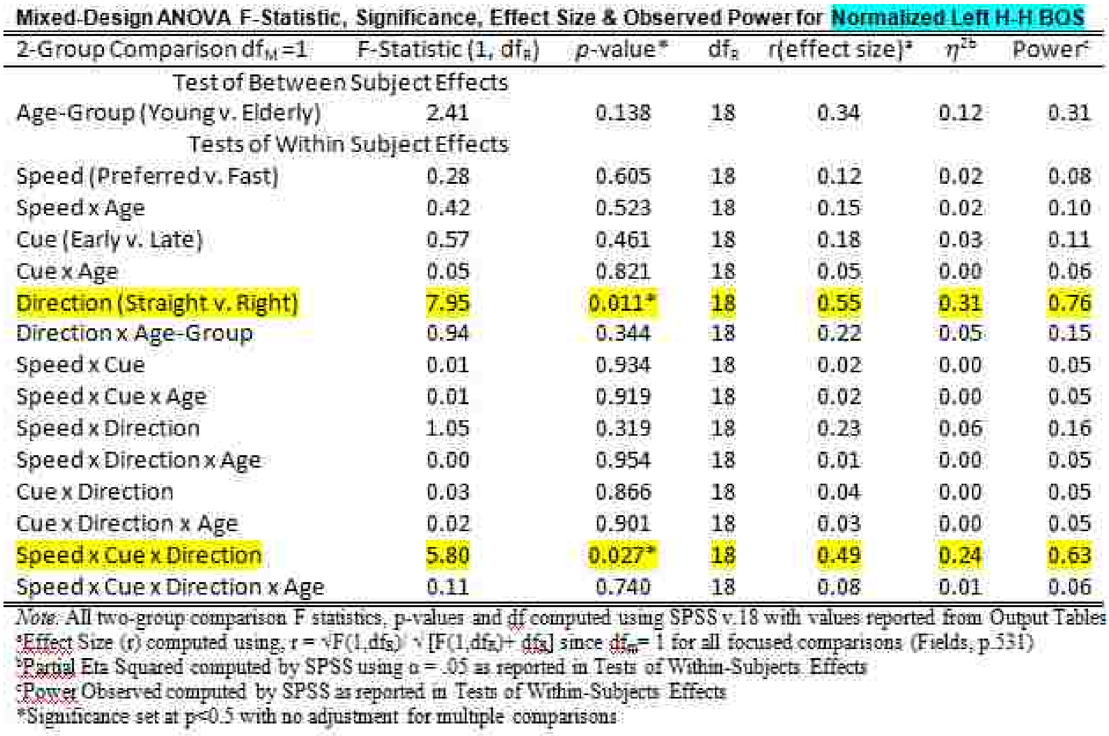
Dependent variable of normalized left heel-to-heel base of support (leg-length)

Exploration of assumptions of the 2x2x2x2 mixed-design ANOVA for the dependent variable normalized left heel-to-heel base of support, for straight & right turns only, revealed that normality was violated in 2 of the 16 conditions [1) elderly late right preferred: significant Kolmogorov-Smirnov test as D(10) =

0.269 with *p* = .039, but non-significant Shapiro-Wilk test as W(10) = 0.895 with *p* = .192; 2) young early straight fast: significant Kolmogorov-Smirnov test as D(10) = 0.288 with *p* = .018, but non-significant Shapiro-Wilk test as W(10) = 0.876 with *p* = .118]. However, the assumption of homogeneity of variance was met as the Levene's test was non-significant for all 8 conditions. (Appendix Y). As stated above, despite the violations of normality, given group sizes were equal (young n=10, elderly n=10), ANOVA is believed to be pretty robust to either violations of normality or homogeneity of variance (Field, 2009). Lastly, as also noted previously, sphericity was not of concern as each repeated measures variable had only 2 levels, and the assumption of sphericity is automatically met (Field, 2009).

The mixed-design ANOVA for the dependent variable Normalized Left Heel-to-Heel Base of Support (LL), for straight & right turns only, revealed the following significant findings: a main effect for Direction, and a three-way Speed*Cue*Direction interaction. The F-statistic, significance level, effect size (both as Pearson's correlation coefficient, r, & eta squared, η^2), and observed power for all 15 comparisons are shown in Table 39 below. In light of only two significant findings, and to facilitate interpretation of the three-way interaction, both main & interaction effects will be presented here.

Table 39



Mixed-Design ANOVA F-Statistic, Significance, Effect Size & Observed Power for Normalized Left H-H BOS

2-Group Comparison df_M=1	F-Statistic (1, df_R)	*p*-value*	df_R	r(effect size)^a	η^{2b}	Power^c
Test of Between Subject Effects						
Age-Group (Young v. Elderly)	2.41	0.138	18	0.34	0.12	0.31
Tests of Within Subject Effects						
Speed (Preferred v. Fast)	0.28	0.605	18	0.12	0.02	0.08
Speed x Age	0.42	0.523	18	0.15	0.02	0.10
Cue (Early v. Late)	0.57	0.461	18	0.18	0.03	0.11
Cue x Age	0.05	0.821	18	0.05	0.00	0.06
Direction (Straight v. Right)	7.95	0.011*	18	0.55	0.31	0.76
Direction x Age-Group	0.94	0.344	18	0.22	0.05	0.15
Speed x Cue	0.01	0.934	18	0.02	0.00	0.05
Speed x Cue x Age	0.01	0.919	18	0.02	0.00	0.05
Speed x Direction	1.05	0.319	18	0.23	0.06	0.16
Speed x Direction x Age	0.00	0.954	18	0.01	0.00	0.05
Cue x Direction	0.03	0.866	18	0.04	0.00	0.05
Cue x Direction x Age	0.02	0.901	18	0.03	0.00	0.05
Speed x Cue x Direction	5.80	0.027*	18	0.49	0.24	0.63
Speed x Cue x Direction x Age	0.11	0.740	18	0.08	0.01	0.06

Note: All two-group comparison F statistics, p-values and df computed using SPSS v.18 with values reported from Output Tables

^{a}Effect Size (r) computed using, $r = \sqrt{F(1,df_R)} / \sqrt{[F(1,df_R)+ df_R]}$ since df_m= 1 for all focused comparisons (Fields, p.531)

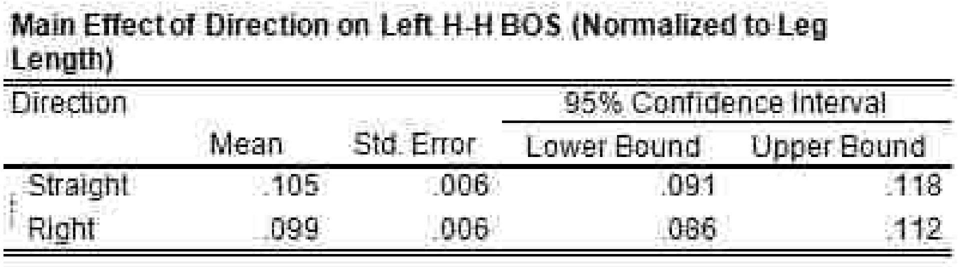
^{b}Partial Eta Squared computed by SPSS using α = .05 as reported in Tests of Within-Subjects Effects

^{c}Power Observed computed by SPSS as reported in Tests of Within-Subjects Effects

*Significance set at p<0.5 with no adjustment for multiple comparisons

As mentioned, the mixed-design ANOVA for the dependent variable Normalized Left Heel-to-Heel Base of Support/ (LL), for straight & right turns only, yielded a significant main effect for Direction [F(1,18) = 7.95, *p*=0.011, r=0.55 (large), η^2 =0.31 power =0.76]. Based upon inspection of the estimated marginal means (Table 40) and the slope of the Direction plot (*Figure* 23.), left heel-to-heel base of support deceased when approaching to turn right as opposed to continue walking straight. This main effect for Direction was statistically similar in both age-groups [F(1,18) = 0.94, *p*=0.344] (*Figure* 24).

Table 40



Main Effect of Direction on Left H-H BOS (Normalized to Leg Length)

Direction	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Straight	.105	.006	.091	.118
Right	.099	.006	.086	.112

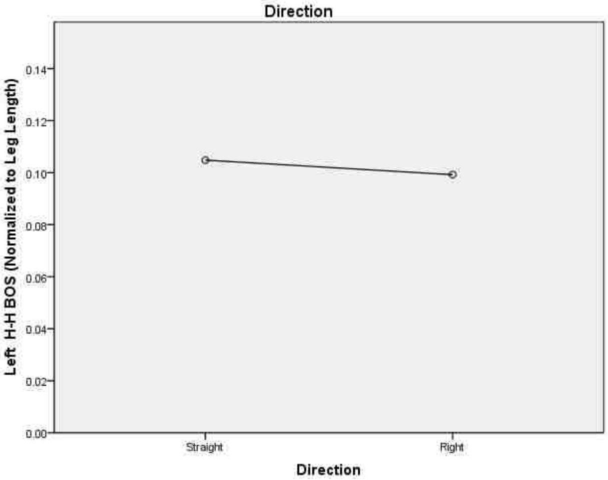


Figure 23. Main Effect of Direction on Normalized Left Heel-to-Heel Base of Support (Straight & Right Turns Only)

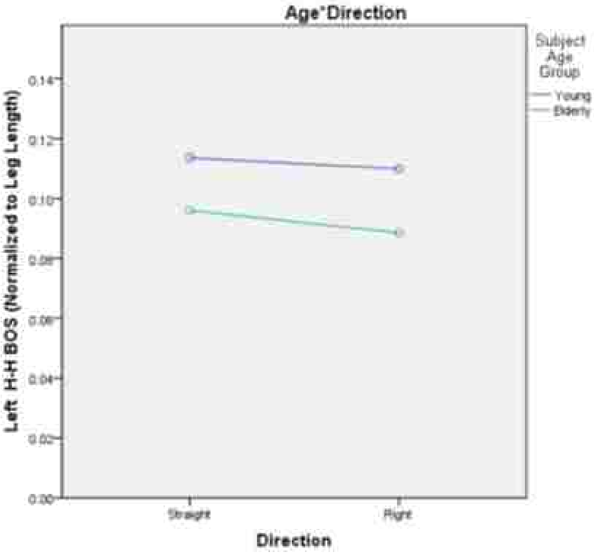


Figure 24. Main Effect of Direction on Normalized Left Heel-to-Heel Base of Support (Straight & Right Turns Only) Similar in Both Age-Groups

With regards to the higher order effect, the mixed-design ANOVA for the dependent variable Normalized Left Heel-to-Heel Base of Support/ (LL) ,for straight & right turns only, yielded a significant three-way Speed*Cue*Direction interaction [F(1,18) = 5.80, *p*=0.027, r=0.49 (medium/large), η^2 =0.24 power =0.63]. Based upon inspection of the estimated marginal means (Table 41) and the steepness in the slopes of the early & late lines in the interaction plots (*Figure* 25.), this interaction is interpreted as suggesting that a decrease (narrowing) in left heel-to-heel base of support when approaching to turn right (as opposed to continue straight) was seen when cued-early walking fast, but when cued-late walking at preferred speed. This Speed*Cue*Direction interaction was statistically similar in both age-groups [F(1,18) = 0.11, *p*=0.74] (*Figure* 26). Finally, manual computation using Tukey's HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects nor the interpretation by the principal investigator of the interaction plot. Instead, the Tukey indicated no differences between comparisons were significant i.e. no interactions or main effects. (Appendix Z).

Table 41

Interaction Effect of Speed*Cue*Direction on Left H-H BOS (Normalized to Leg Length)

Speed	Cue	Direction	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Preferred	Early	Straight	.099	.007	.084	.114
		Right	.101	.005	.090	.112
	Late	Straight	.106	.007	.092	.121
		Right	.097	.007	.082	.112
Fast	Early	Straight	.109	.007	.094	.124
		Right	.095	.009	.077	.113
	Late	Straight	.105	.007	.089	.120
		Right	.103	.007	.089	.117

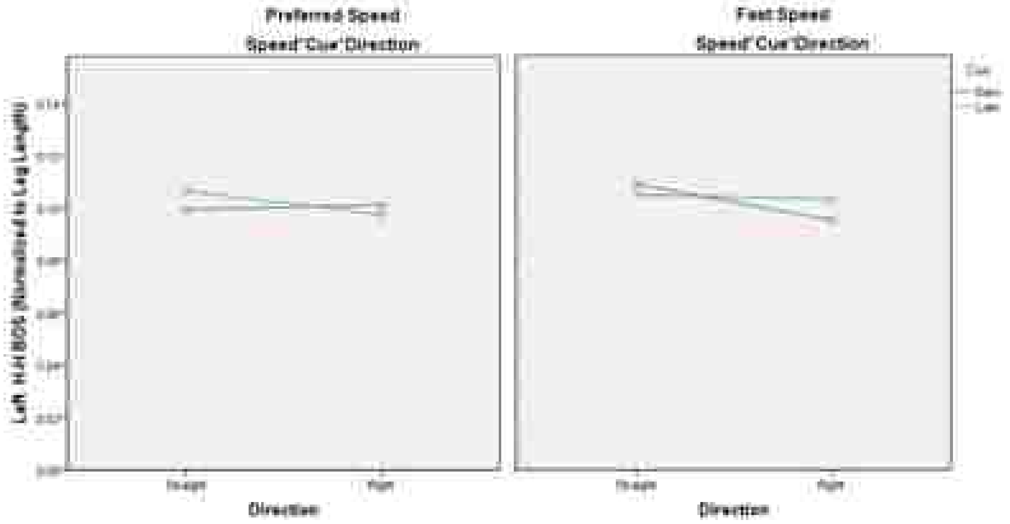


Figure 25. Speed*Cue*Direction Interaction on Normalized Left Heel-to-Heel Base of Support (Straight & Right Turns Only)

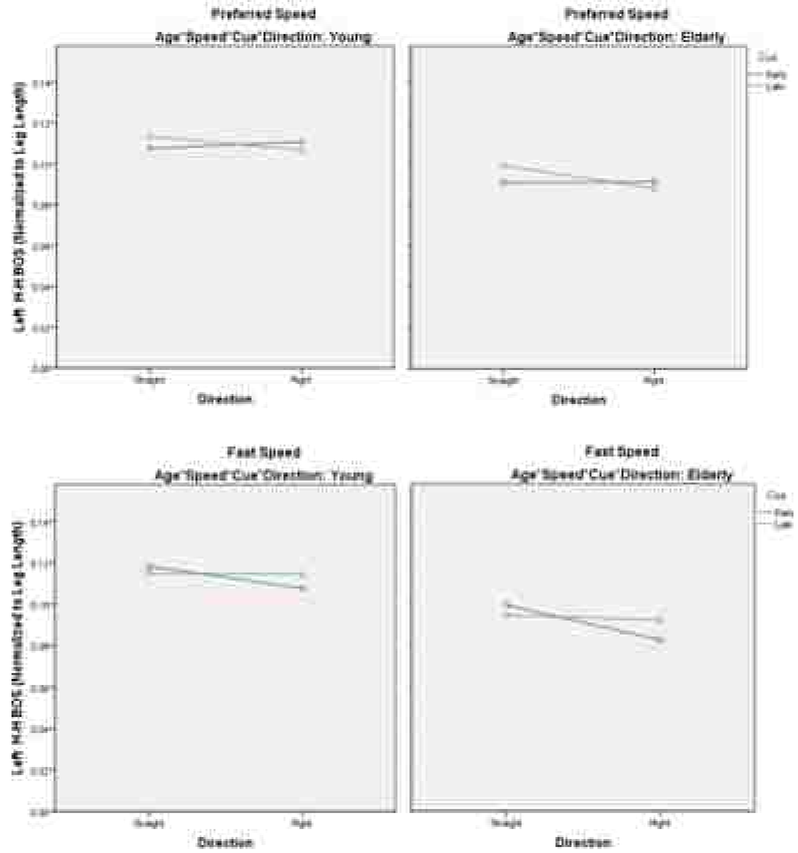


Figure 26. Speed*Cue*Direction Interaction on Normalized Left Heel-to-Heel Base of Support (Straight & Right Turns Only) Similar in Both Age-Groups

Discussion of Participant Demographics

Except for age, overall parity was seen in the groups with each being comprised of an equal proportion of females & males. The independent t-tests and Man-Whitney U comparisons on participant demographics indicated both age-groups were similar for the extraneous and potentially confounding variables of weight, body mass index, height, leg-length, cognitive impairment (MMSE), and psychological balance confidence. However, the elderly did score lower for functional balance (DGI), yet above the cut-off for fall-risk, demonstrating more subtle functional gait-related changes in response to changing tasks demands: i.e. greater observable reduction in speed & step-length, and sway in upright trunk posture when ambulating and requested to: simultaneously move their head up/down or sideways, stop & pivot 180^0, step-over a shoe-box, and weave through cones. Although the elderly sample in the present study were a very active group as a whole, this is not surprising as slower sensory-motor processing (Woollacott and Shumway-Cook, 2002) and decreased ML postural stability (Kavanaugh et al., 2005) have been reported in older adults.

Discussion of Loglinear and Chi-Square Analysis of Turn-Strategy Preferences

The findings of the loglinear & Chi-square analyses indicated that two separate non-age-related factors had a significant relationship with turn-strategy preference (Speed*Turn-Strategy and Cue*Turn-Strategy), and thus both two-way interactions significantly contributed to predicting the observed frequency data. In light of the present study including three categories of turn strategies (i.e. mixed-turns in addition to step-turns & spin-turns), comparison of the findings with previous research which manipulated similar control variables of speed or cue-time-constraint, but lacked a mixed-turn category, comes with limitations. Clearly, the present study shows that based upon the operant definitions employed, with regards to two-way relationships, although no age-group*turn-strategy, speed*turn-strategy, or cue*turn-strategy differences were seen in the preference between step-turns relative to spin-turns, across all these same two-way interactions there existed a preference for either step-turns or spin-turns relative to mixed-turns. However, that preference for either step-turns or spin-turns relative to mixed-turns was significantly reduced or modulated based upon the interaction with the categorical control variables of walking-speed & direction-cue-time-constraints.

Discussion of two-way interaction for Speed*Turn-Strategy Preference: relative to mixed-turns preference for spin-turns decreased at fast speed

The present findings suggest that in both age-groups, when walking fast relative to natural (preferred) speed and using mixed-turns as the reference, the preference for spin-turns decreased 3-fold but the preference for step-turns was unchanged. This likely reflects the greater biomechanical challenge inherent in spin-turns (Patla et al. 1991; Hase & Stein, 1999; Taylor et al., 2005; Xu et al, 2006). Akram et al. (2010) calculated odds ratios for step-turns relative to spin-turns, and reported the interaction of fast-walking*90^0 (large) angle turning resulted in a step-turn preference such that the odds-ratio for a step-turn was 3.2 x higher (95% CI: 1.08, 9.49). Akram et al. (2010) suggested the step-turn turn preference at fast*90^0 turn angles, which was not evident for the interaction of fast-walking*30^0 (small) angle turning, was biomechanical in nature given spin-turns require greater pivot limb hip abductor/ankle invertor moments, greater transverse plane motion, and offer less toe-to-toe clearance.

There is also some indication in the literature that when approaching turns at faster speeds, the challenge to modulation of GRFs at the penultimate footfall are greater in spin-turns than step-turns. Xu, Carlton, & Rosengren (2004) measured GRF changes in the penultimate footfall in young adults who were early-cued to perform 45^0 & 90^0 right step-turns & spin- turns at both a preferred & fast walking speed. Xu et al. (2004) noted that for the striking phase of the penultimate footfall, both the medial-lateral & anterior-posterior impulses increased with speed; and when comparing strategies, spin-turns (to the right with a right pivot foot) produced a greater medial-lateral impulse at the penultimate footfall as opposed to step-turns (to the right with a left pivot foot). However, with regards to the propulsive phase of the penultimate footfall, although only the anterior-posterior (AP) impulse was higher during turns as opposed to straight gait, both the ML & AP impulses decreased with speed. Moreover, when again comparing strategies, spin-turns (to the right with a right pivot foot) produced greater anterior-posterior & medial-lateral propulsive impulses at the penultimate footfall as opposed to step-turns (to the right with a left pivot foot).

While the primary investigator of the present study is unaware of literature assessing GRF changes across speeds at the ultimate pivot footfall when turning off a straight path, there is indication that in both spin-turns & step-turns as speed increases, so does the required coefficient of friction (RCOF) at push-off (Fino, et al., 2014), and the centripetal force requirement & degree of body leaning into the turn direction (Orenduff et al., 2006; Xu et al., 2004; Fino et al., 2015). Orenduff, Segal, Berge, Flick, Spanier, & Klute (2006) measured ML GRF impulses in young adults walking clockwise around a 270^0 1 m radius circular path at constant speeds ranging between 0.6 -1.3 m/s. Orenduff et al (2006) reported that as walking speeds increased, both the laterally applied impulse of the outer limb and the medially applied impulse of the inner limb also increased. Orenduff et al. (2006) attributed the increase in ML impulses with speed to the need for greater counter (centripetal) force towards the center of the turn. However, as lateral trunk lean into the turn direction was observed only during faster speed circular path turning, Orenduff et al (2006) believed trunk lean was primarily responsible for altering ML impulse and the COM trajectory. Xu, Carlton, & Rosengren (2004) early-cued young adults for 0^0, 45^0 & 90^0 right step & spin turns at normal & fast walking speeds. Xu et al. (2004) observed lateral leaning of the body into the direction of the turn during the prior step (penultimate FF) before turning on the upcoming ultimate pivot foot, which they believed served to bring about the required disequilibrium to alter direction. Accordingly, Xu et al. (2004) reported the distance between the COP and COM at both the penultimate and ultimate footfalls was significantly affected by both turn angle and speed. As actual COP-COM distances were only provided for mid stance of the ultimate footfall during these right turns, and limiting the discussion to speed, given the COM displaced right-ward into the right turn direction, the COP-COM distance decreased for a right pivot foot spin-turn (or actually becoming negative when further right-ward than the right pivot foot): [preferred speed straight .060m, right 90^0 .008m; fast speed straight .050m, right 90^0 -.040m], but the COP-COM distance increased for a left pivot foot step-turn: [preferred speed straight .055m, right 90^0 .085m; fast speed straight .050m, right 90^0 .150m]. It is should be noted that Xu et al (2004) attributed these changes in COP-COM distance primarily to trunk leaning (i.e. a trunk/hip strategy) and not M/L displacements of the penultimate & ultimate footfalls (i.e. a foot strategy).

Given the COM is outside the BOS for a longer duration of stance in spin-turns compared to step-turns (Taylor et al. (2009; Xu et al., 2006), despite indication the magnitude of the RCOF at push-off is similar in both strategies even at fast speed, the increase at fast speed could pose a greater challenge for spin-turns. Fino & Lochhart (2014) used motion analysis and force plates to compute ground reaction forces and the required coefficient of friction (RCOF) needed during push-off to prevent slippage as young adults (n=10, mean age = 25.3 years) performed early-cued 90^0 step-turns & spin-turns around pylons of various heights at their preferred, slow and fast walking speeds. While GRFs were not reported, a positive relationship is known to exist between horizontal GRF and the RCOF, given the RCOF is computed using the quotient of horizontal GRF/instantaneous vertical (normal) force (Christina & Cavanagh, 2002). Fino & Lockhart.(2014) reported that when turning 90^0, peak RCOF occurred at push-off, with regression analysis indicating peak RCOF at push-off increased with speed [slow .38(.10); preferred .45(.11); and fast .54(10)]. However, type of turn strategy had no effect on peak RCOF at push-off [step-turn .48(.11); spin-turn .47(.13)]. Despite the lack of a difference in the peak RCOF at push-off between strategies, Fino & Lockhart (2014) nonetheless suggested that a turning slip during push-off may be more problematic for a spin-turn since prior research has shown that, unlike for a step-turns where the COM is confined within the BOS for practically all of stance (defined by the right & left ankles), during spin-turns the COM is displaced lateral to the BOS for the majority of stance except at push-off. Hence, although the increase in RCOF at fast speed is seen in both strategies, a slip during push-off would allow the COM to persist outside the BOS during a spin-turn, and possibly contribute to a lower spin-turn preference at fast speed.

Despite the finding of Fino & Lockhart (2014) of similar peak RCOF at push-off between step-turns v. spin-turns, there is indication that across the first-half of stance the magnitude of RCOF & body lean as speed increases is less in spin-turns; yet, of equal importance as speed increases, the turn curvature of spin-turns becomes greater than that of step-turns (Fino et al., 2015). Fino, Lochhart & Fino (2015) had young adults perform early-cued left direction 90^0 step-turns v. spin-turn across different obstacle heights and walking speeds. Fino et al. (2015) pointed-out that based upon the formula for centripetal force, $F_C=mv^2/r= mvk$, turning either at a faster walking speed or a larger/sharper curvature (k) in the COM trajectory (which is the same as a smaller radius, given curvature k = 1/r) would necessitate a greater centripetal force towards the center of the turn. Accordingly, similar to Ordenduff et al. (2006), Fino et al. (2015) likewise reported the faster the walking speed, the greater the amount of body leaning (i.e. trunk/pelvic/lower-limb inclination) into the turn as measured using the ML COM-COP angle (θ_{ML}) [θ_{ML} in degrees: slow-speed 4.4 $(6.0)^0$, preferred-speed $6.8(6.1)^0$, fast-speed $12.7(7.0)^0$]. Fino et al. (2015) also found that the faster the walking speed, the less-sharp the turn curvature (k) of the COM trajectory, taken as the second derivative of the curve function, and considered to be a good indicator of turn radius [curvature (k) =1/radius, when combining the data for step-turn & spin-turns together: slow-speed 8.7, preferred-speed 6.9, and fast-speed 6.5]. Fino et al. (2015) suggested the greater anticipatory leaning when walking fast and turning 90^0, though beneficial in adding to the centripetal force, further displaced the COM beyond BOS (and likewise resulted in less ML body COM clearance relative to the obstacle). Moreover, noting that centripetal force necessitates friction when turning, Fino et al. (2015) also found the RCOF at weight acceptance of the pivot foot to be larger when turning fast as opposed to at preferred speed [RCOF: fast 0.41(.08) v. preferred 0.30(.07)]. But most intriguing, when comparing 90^0 step-turns v. spin-turns across speeds for the first-half of stance of the ultimate pivot foot, the only speed*strategy interaction reported was that relative to step-turns, spin-turns were performed with less curvature in the COM trajectory at slow speed (not preferred speed), yet greater curvature relative to step-turns at fast speed. Besides this interaction, when collapsing for speed, across the first-half of stance the main effects for strategy included spin-turns were performed with a lower RCOF to prevent foot slippage [RCOF spin-turns 0.33(.09) v. step-turns 0.35(.09)]; and spin-turns were performed with less leaning into the turn direction i.e. a lower ML COM-COP angle (θ_{ML}) [θ_{ML} in degrees: spin-turns 3.4 $(4.4)^0$ v. step-turns $14.6(5.0)^0$]. Thus, based upon the speed*strategy interaction reported by Fino et al. (2015), the greater spin-turn curvature requirement at fast speed may also possibly contribute to the reduction in spin-turn preference seen in the present study.

Finally, it is worth considering the greater challenge of performing the turning task at a rapid uncharacteristic walking speed may have triggered participants to use a less stressful strategy. To this end it is worth recalling that Lenoir, Overschelde, De Rucke, & Musch (2006) reported a left direction turn bias (equated with use of a step-turn by Taylor et al., 2006) which was significantly higher when running (left turn bias: running 71.4% v. walk 59.3%), reduced when initiated from stationary asymmetric standing with the left foot forward (left turn bias: left foot forward 9.9% v. feet together 59.7%), but remained high when combining running & asymmetric limb positioning at the instant of whistle cuing to turn (left bias: right foot forward at whistle 70.8% v. left foot forward at whistle 69.4%). Lenoir et al. (2006) suggested the increase in the preferred pattern of a left direction bias (i.e. left step-turn) when running may have increased as a consequence of the greater task complexity and/or metabolic demand necessitating a more efficient-comfortable strategy. Thus, when stressed at a fast speed, step-turns may be the more comfortable strategy to execute.

Discussion of two-way interaction for Cue*Turn-Strategy Preference: relative to mixed-turns preference for step-turns & spin-turns decreased at fast speed

The present findings suggest that in both age-groups, when cued-late relative to early and using mixed-turns as the reference, the preference for step-turns decreased 5-fold and the preference for spin-turns decreased 4-fold. Given the odds ratio for both strategies were reduced relative to mixed-turns, this may reflect difficulty in arresting the forward momentum within the available response-time. As previously mentioned, Cao et al. (1997) cued-late for direction & location for 90^0 turns using available response times ranging between 375-750 ms prior to crossing one-of-eight (4 on right, 4 on left) turning gate locations marked by ten poles (five each side) spaced 1 m apart. Although Cao et al (1997) did no distinguish between step-turns v. spin-turns, across all subjects & late-cue conditions, of the 3,300 attempted trials, failure was scored in 1,174 trials (about 36% of trials), and of these turning failures, 99% were attributed to an inability to arrest the forward momentum of the COM within the available response time. It is worth noting the work of Cao et al., (1997) stands out from other studies in that the turn-zone environment was spatially constrained as was the turn-zone in the present study.

From a biomechanical perspective, a late-cue would also present a challenge to both step-turns and spin-turns as the ability to generate ML GRF impulse is hampered by lower peak amplitude & prolonged time to peak, and the hip moment requirements are increased. Kim et al. (2014) reported that young male “middle-school” soccer players who performed unanticipated (late-cued at 90% stride-length) 45^0 side and cross-cutting maneuvers generated smaller peak vertical & ML GRF amplitudes for both strategies; had longer times to peak vertical & ML GRF; however, hip abductor moments were increased during step-turns, while hip adductor moments were increased during spin-turns. In agreement with the findings of the present study for a reduction in preference for both step-turns and spin-turns relative to mixed-turns when cued-late, Kim et al (2014) suggested that direction-cue time constraints rather than choice of turn strategy appears to have a greater impact on kinematic and kinetic variables.

Another possible explanation for the decrease in preference for both strategies when cued-late was the lab set-up as the central placement of the direction-cue signal lights at the end of the straight path may have prolonged forward gaze. Patla et al. (1999) likewise centrally placed the visual cue signal-lights eye level at the end of the straight walking path, similar to present study. When participants were cued-early, Patla et al. (1999) found an axial re-orientation sequence which was initiated with head yaw; however, when cued-late, trunk roll preceded head yaw. In commenting on the change in onset early v. late cue onset sequence as reported by Patla et al. (1999), Hollands et al., (2001) suggested the central location of the visual cue signals just beyond the straight walkway (rather than an individual signal light at the end of each separate path) may have prolonged attention & forward gaze in order to ascertain direction, which could have afforded participants little time to process the indirect information of the late-cue in order to align gaze & the head wth the corresponding new heading. Courtine & Schieppati (2003) have suggested that during curved path walking, asymmetric sensory feedback especially from cervical proprioceptors & the vestibular system may modulate CPG motor commands to adjust the relative coupling between centers on either side of the spinal cord, which during straight gait are otherwise driven 180^0 out-of-phase by descending tonic supra-spinal influence.

Aligning gaze & head yaw with the new path is believed to be important for providing an allocentric reference frame upon which the rest of the body re-orients, and placement of the late-cue at the end of the straight path may have delayed acquiring the reference frames. Hollands, Patla & Vickers (2002), using 5 individual signal lights at the end of each possible travel path instead of one centrally located direction light as in the present study, reported that regardless of early v. late cuing, a longer percentage of the total duration of gaze fixation was spent on environmental features within the current heading/plane of progression than on environmental features eccentric to the current heading both before (early-cue 67%, late-cue 79% of the total gaze time) and after (early-cue 92%, late-cue 90% of the total gaze time) the late-cue or turn-execution stride for when early-cued. Moreover, Hollands et al. (2002) noted that prior to turning, regardless of cue condition, saccadic eye movements accompanied by head yaw, were performed to orient gaze with the end point of the designated path of travel. In so doing, participants fixated on the goal of the end point of the destination until the head had oriented as well. Hollands et al. (2002) suggested anticipatory eye and head re-orientation have key roles when changing direction; and proposed that synchronized eye & head movements provide an allocentric reference frame upon which the rest of the body reorients. Hollands et al. (2002) likewise noted the abundant vestibular and proprioceptive feedback accompanying head motion. Thus, in the present study, as a consequence of the lab being set up with one set of centrally located signal lights, rather than an individual indicator light for each direction path as in the as in the case of Hollands et al., (2002), the possibility exists that when late-cued to turn, prolonged forward gaze may have delayed coordinated saccadic eye gaze & head yaw to establish an allocentric reference frame needed when re-orienting limb placement (i.e. modulating the width of the turn-execution stride) in order to attain the thresholds defined for step-turns & spin-turns.

Another potential reason for the decrease in preference of both step-turns & spin-turns when cued-late may involve dual-task-costs (cognitive-motor-interference) from the visual-spatial attention allocated to process the late-cue signal. Although it is acknowledged the design and methods used in the present study design do not exemplify a classic dual-task-paradigm, the attentional resources directed towards the late-cue signal cannot be ignored and represents a more practical & realistic scenario, than for example a secondary serial-threes-subtraction-task.

Appreciation for the visual-spatial attention spent on processing late-cue lights and its affect on motor performance exists in the literature in terms of limb-obstacle clearance and obstacle avoidance success rates during step-over task. Hence, in light of the spatial-temporal gait changes which occur upon approach of turns (Patla et al., 1999; Paquette et al., 2008; Hollands et al., 2001; Paquette & Vallis, 2010; Mak et al., 2008) the possibility for dual-task-cost from attention directed to the late-cue signal and its affect on turn strategy preferences in both age-groups must be considered. Lo, Donkelaar & Chou (2015) had young adults perform a secondary visuo-spatial attention task when approaching to step-over an obstacle of 10% subject height. The visuo-spatial task involved a square 26 x 34” image projected on the path 2-3 steps ahead for duration of 200 ms with the obstacle placed either one-step in front or one-step behind the floor image projection. The image contained a letter C in each corner (in particular, 1 red "C" and 3 orange-red "C"s with various orientations), and participants had to immediately verbally respond as to the direction in which the red C opened. Lo et al. (2015) noted that relative to single-task obstacle-crossing, when subjects performed the secondary visual-attention task (of verbally identifying the direction of "C" opening shown in the 26" x 34" square image projected on the floor) one-step before the obstacle, the amount of trail-limb toe-obstacle clearance decreased although gait speed was unchanged [trial toe-clearance: 15.3(0.8) v. 13.2(0.7) cm]; and when the image was one-step after the obstacle a trend was seen for a reduction in toe-clearance for both limbs. Lo et al., (2015) concluded that performing a secondary visual-spatial attentional task when approaching a cluttered environment decreases toe-obstacle clearance in young adults, and may increase the risk for tripping when attentional resources are compromised. In a related study, Chen, Schultz, Ashton-Miller, Giordani, Alexander & Guire (1996) had both young and older adults walk at preferred speed along an 8m x 1.2m wide path to perform a stepping task over a virtual obstacle display with and without divided attention to a simultaneous secondary visual-verbal reaction task. The virtual obstacle was displayed 1 step prior (with an available response time of 350-450 ms) at random locations along the path while walking. The secondary attention-dividing task used an LED display mounted on a 12 cm circular panel centrally placed slight above the ground 0.5m beyond the end of the walking path. The display contained multiple diodes of red, green and yellow colors. The secondary reaction time task required subjects to say “ah” immediately upon seeing the red lights lit. Chen et al. (1996) reported that relative to the single obstacle-crossing task, when the secondary visual-verbal response task was added, mean obstacle avoidance success rates significantly decreased in both age-groups although the elderly were more affected. Chen et al (1996) suggested that given older adults exhibit the ability to avoid obstacles when time is constrained, their greater risk for tripping may stem more from limitations in attentional resources than biomechanical ability.

One of the proposed effects of allocating attentional resources away from the primary motor task to a secondary cognitive task is increased swing-limb stiffness (co-contraction) which has been suggested as a strategy to guard against perturbed off-target foot placement; however, such swing-limb stiffness may potentially minimize step-width changes when executing step-turns & spin-turns. Weerdesteyn, Schillings, Galen, & Duysens (2003) unexpectedly dropped an obstacle prior to left limb contact as young adults walked on a treadmill while performing a secondary verbal-response task, and attributed a decrease in swing-limb velocity at crossing to greater limb stiffness as a consequence of dual-task cost. In greater detail, Weerdesteyn, et al. (2003) used motion analysis on these young participants to assess contact avoidance strategies as a 40 x 30 x 1.5 cm obstacle was unexpectedly dropped ahead of the left limb across three different points in the left step-cycle: left mid-swing which facilitated a pre-crossing short-step-strategy (SSS); left early-mid-stance which facilitated a crossing-step long-step- strategy (LSS); and left late-stance which could have either facilitated a pre-crossing SSS or crossing LLS. The treadmill avoidance stepping task was performed both as a single-task, and accompanied by a secondary auditory Stroop task of verbally responding after being cued with the word “High” or “Low” randomly spoken in a contradictory tone. Weerdesteyn et al. (2003) reported greater dual-task failure-rates (i.e. obstacle contact rates) at an available response time of ≤ 300 ms as when the obstacle was dropped in left mid-swing (single-task 9.5 v. dual-task 20.3%) with contact in all instances the result of inadequate step-shortening. However, the more important finding was related to kinematics as despite no difference in toe-height, relative to the single-task condition, horizontal swing velocity at crossing was reduced during the dual-task step-response both when the object was dropped at left mid-swing and left early-mid stance. The decrease in horizontal stride-velocity at crossing when the obstacle was dropped late at left mid-swing during the dual-task was the result of a slight decrease in normalized stride-length at crossing and slight increase in swing duration at crossing, whereas the decrease in horizontal stride-velocity at crossing when the obstacle was dropped sooner at left early-mid-stance during the dual-task was the result solely of an increase in swing duration. Moreover, when normalizing swing heel trajectories for both stride-length and swing-duration, and then comparing the % of swing trajectory length covered at three distinct moments (20%, 50% & 80% swing duration), although no difference in trajectory length at either of the three moments was seen between the single v. dual-task condition when the object was dropped late at left mid-swing, when the obstacle was dropped sooner at left early-mid-stance, less total trajectory was covered over the final 20% of the swing duration. Weerdesteyn et al. (2003) attributed the decrease in dual-task horizontal left swing-velocity at crossing (both when the obstacle was dropped late at left mid-swing, & a little sooner at left early-mid-stance) to reallocation of attentional resources from the primary motor task to the secondary cognitive task. Weerdesteyn et al. (2003) advanced that when availability of attentional resources to a the primary motor task are diminished, this may make the swing-crossing-limb more vulnerable to unanticipated perturbations, and increased swing-limb stiffness (possibly as a consequence of co-contraction of agonist & antagonist muscles) may be a strategy to minimize the potential for unwanted deflection of the swing-limb from its target location. Interestingly, Weerdesteyn et al. (2003) suggested the finding that a lower percentage of the total normalized trajectory distance was covered across the last 20% of swing duration during the dual-task when the obstacle was dropped at left early-mid-stance, may indicate the crossing swing trajectory was not just scaled-down but may have been altered online as attentional demands may be heighten immediately before ground contact when executing the long-stride avoidance strategy. Thus, the need for online attention when changing direction may be at its highest when actually executing the turn step.

It is important to note that Weerdesteyn et al. (2003) did not perform EMG analysis in suggesting co-contraction contributed to limb stiffness as a consequence of dual-task-cost. Although the primary research of the present study is unaware of turn-related dual-task studies using EMG analysis, greater lower extremity co-contraction & EMG activity when turning has been reported in the elderly as compared to young adults. I-Hsuan Chen et al. (2013) found that during circular path (0.8 m radius) walking (with no secondary cognitive task), relative to straight gait, only young adults showed a decrease in outer leg for 1st peak knee flexion displacement at loading, and had less co-activation of rectus femoris & biceps femoris, as the elderly persisted with a similar outside limb co-activation pattern relative to straight walking. I-Hsuan Chen et al. (2013) suggested a similar co-activation pattern relative to straight walking may aid stability. In another turn-related study without dual-tasking, Kuo, Hong & Liau (2014) reported that when executing early-cued 180^0 turns, the elderly showed greater extensor synergy muscle activity of the erector spinae, bicpes femoris and gastrocnemius during stance of the ultimate pivot limb. Kuo et al. (2003) suggested that the greater extensor synergy muscle activity displayed by the elderly in the pivot limb likely represents an age-related decline in muscle efficiency. Thus, although there is indication the elderly turn using greater lower extremity co-contraction & extensor muscle activity when direction is known in advance without needing to allocate attention elsewhere, whether dual-task-cost further increases lower limb muscle contraction in the elderly (stiffness) to affect turn-strategy preferences, or increases lower extremity stiffness in young adults when turning as reported for a step-over task by Weerdesteyn et al. (2003), remains an open question.

In addition to the allocation of attentional resources for visual-processing of the late-cue signal, in view of the entrance of turn-zone environment being ML spatially constrained and somewhat “cluttered” by the use of physical objects (red plastic flexible hazard cones) placed bilaterally at each front & back corner of the turn-zone i.e. depth or length of the turn zone at foot-level was 95 cm in the AP, but the ML width of the turn-zone entrance at foot-level was between 70-73 cm (27.5-29”) [and also constrained from the combination of the plastic flexible cones on each side of the Gaitrite’s edge and its last sensor pad], attentional resources may have also been allocated for visual-motor control of foot placement when both approaching and executing the turn. The Americans with Disabilities Act of 1990 (Office of Compliance, US Congress & Legislative Branch, 2008) requires public entities have door widths of at least 32 inches and route widths to all offices of at least 36”. Thus the 27.5-29” ML width entrance to the turn-zone environment was narrower at the ground level of the feet than would otherwise be encountered in publicly funded buildings. The width of the entrance to the turn zone is particularly relevant in light of the increase in step-width reported when both approaching (Paquette et al., 2008; Hollands et al., 2001; Mak et al., 2008) and executing turns (Patla et al., 1999; Conradsson et al., 2017; Hollands et al., 2001; Huxham et al., 2006; Huxham et al., 2008; Strike & Taylor, 2009; Taylor et al., 2005; Mari et al., 2012).

In is worth noting that although we live in cluttered environments, relative to the present study, most previous turn-related research has been carried out in lab settings which have not placed physical objects bilaterally at the entrance to the turn zone, nor an object at each back corner border. Indeed, most prior research has offered little in the way of physical objects to demarcate borders of a turning area or spatially constrain its entrance, and have instead used either force-plates or floor markings & mats (Patla et al., 1991; Patla et al. 1999; Hase & Stein, 1999; Hollands et al., 2001;Thigpen et al., 2001; Taylor et al., 2005; Hollands et al., 2010; Hollands et al., 2014; Xu et al., 2004, 2006; Fuller et al., 2007; Paquette et al., 2008; Strike & Taylor, 2009; Akram et al., 2010; Mari et al., 2012; Mak et al., 2008; Lenoir et al., 2006); a unilateral physical object such as a pole or pylon just at one-corner with floor markings (Huxham et al., 2006, 2008; Glaister et al., 2008; Fino et al, 2014, 2015); or one centrally located obstacle to circumvent with clearance on either side (Paquette & Vallis, 2010; Vallis & McFadyen, 2003). Similar to the present study, Conradsson et al., (2017) is one of the few studies which placed physical objects bilaterally in the form floor cones on either side of the entrance to the turn zone, but the space between both cones was 1 m and a little wider than the 73 cm of the present study. As previously mentioned, Cao et al., (1997) stands-out in that although the walk path had a width of 1 m, the series of perpendicularly situated off-path turn-gates were each spatially constrained to a ML width of just 80 cm using bilateral poles on either side, however, Cao et al did not assess turn-strategy preferences or spatial-temporal gait parameters upon approach.

In light of the above prelude, the dual-task-cost for either feed-forward (early-cue) or online (late-cue) visual-motor processing & control needed for accurate foot placement to both avoid potentially hazardous physical (foot) contact with the bilaterally placed red hazard cones, yet execute the turn, needs consideration as to any affect such attention allocation may have on turn strategy preferences. To this point, the literature supports the use of feedforward visual control when environments are non-threatening but cautions for greater online control when hazards exist. Patla & Vickers (2003) found that when negotiating across a 10 m cluttered environment containing 17 flat (non hazardous) footprint targets, young adults used travel gaze fixation (≤ 300 ms) for 60% of the travel duration (characterized by the eyes being stationary at a constant angle and focused in front on the travel path while being carried along with the rest of the body), and footprint/landing-target gaze fixation (≤ 300 ms) about 15% of the travel duration (gaze actively shifted to the location of a footprint target averaging 2 steps ahead of foot placement i.e. 800-1,000 ms, which was believed to afford time to appropriately adapt the stepping pattern). However, as the percentage of trials in which footprint gaze fixation was used to a target 0 steps ahead was very small (i.e. online footprint gaze fixation to an immediately imminent target while in swing), Patla & Vickers (2003) suggested young adults primarily used feed-forward (rather than online) visual-motor preplanning when negotiating footprint targets. Patla & Vickers (2003) proposed a minimum time of 2 steps is needed in order to extract information regarding target location in relation to current body & limb position, and then calculate needed adjustments in step-length & width for accurate foot placement. Patla & Vickers (2003) did advise that if the environment is hazardous or the task threatens stability, as may have been the case in the present study with the bilateral cones at the entrance of the turn zone posing a potential risk of tripping, participants may switch from feedforward (gaze fixated ≥ 2 steps ahead) to online (gaze fixated < 2 steps ahead) visual-motor control to guide foot placement. Patla & Vickers (2003) suggested the possibility of the nervous system being watchful of balance with each step, and eliciting online footprint gaze fixation (gaze fixated < 2 steps ahead) when stability is in decline. Thus, with regards to dual-task-cost related to visual motor control, based-upon the suggestion of Patla & Vickers (2003) of a minimum advance time/distance requirement of 2 steps for visual-motor preplanning, and as participants in the present study initiated the turn/pivot within 1 post-late-cue footfall about 54% of the time across all trials (1-post-late-cue-footfall 54%, 2-post-late-cue-footfalls 46%, see Appendix C), this may suggest that when cued-late, attentional resources may have often been allocated for online-feedback visual-motor control when approaching the turn-zone & executing the turn step (as opposed to anticipatory-feed forward visual-motor control processed/computed over the prior 2 steps) to guide limb-foot trajectory and avoid the cones bordering the turn zone.

When obstacle location is known in advance, such that here is adequate time/distance (i.e. 2 steps or greater) to utilize feed-forward visual motor control upon approach of a step-over task, research has shown that at least in young adults, the effects of dual-task cost exist only during the approach of visual processing but not at crossing. Brown, McKenzie & Doan (2005) had young & elderly participants step-over a 60 cm wide x 22.5 cm high x 15 cm deep foam block (sidewalk curb) placed at the midpoint of an 8m long path while walking at preferred speed, and engaging in a secondary dual-task of verbally responding to the sound of a buzzer by saying the word “top” as rapidly as possible. The audible cue was delivered during SLS across three-events: control (steady-state i.e. 4th stride) unobstructed gait; and two-phases of the step-over task including the final full stride before crossing (approach or pre-crossing), and the actual crossing. Brown et al (2005) reported that whereas young adults had longer reaction time scores for the secondary verbal response task only during pre-crossing as opposed to both crossing & unobstructed gait, in the elderly both pre-crossing & crossing had longer reaction times than unobstructed gait. Citing the prior work of Patla & Vickers (2005) reviewed above, Brown et al. (2005) suggested that when obstacle location is known in advance, relative to unobstructed walking, young adults have greater attentional need only upon approach, whereas in the elderly the attentional demand is greater not only when approaching but also while stepping over the obstacle. Brown et al. (2005) proposed that whereas young adults likely fixed their gaze ahead in approach of the obstacle using vision in a feed-forward manner to regulate the step-over, the elderly being more conservative so as to avoid contact may have additionally fixed their gaze on the obstacle at the crossing. Noting the attentional demands in young adults were similar between crossing and unobstructed gait, Brown et al., (2005) suggested advanced awareness of the obstacle’s location permitted pre-planning for gait adaptations upon approach; however, an unexpected step-over task (i.e. a late-cue) would impose greater dual-task cost during the crossing phase. It is important to note Brown et al., 2005) did not assess a late-cue condition, and as such did not state attentional resources were greater for online as opposed to feedback visual motor control. Rather, this a priori obstacle placement study of Brown et al., (2005) indicates that in young adults the processing & computing of visual information upon approach suffices for controlling foot placement when subsequently executing the crossing 2-steps later (i.e. feed-forward control), but that it does not suffice in the elderly who must still allocate attentional resources for on-line visual motor control at the crossing. It bears mention that although Brown et al., (2005) reported the attention allocated for visual-processing affected the secondary auditory-verbal-response task rather than the primary motor task in both groups as assessed using gait parameters across either phase of the obstacle step-over (i.e. no difference in stride-length, SLST or COM velocity), the potential effect of a late-cue necessitating attention resources for online visual-motor control when executing the turn (which if cued-early would have otherwise only required attentional resources for feedforward visual-motor control during approach) cannot be disregarded in interpreting turn performance as noted by the reduction in both step-turn & spin-turn preference when late-cued.

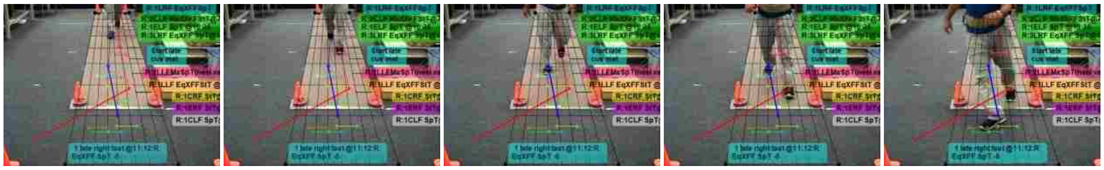
As this discussion of the Cue*Turn-Strategy interaction has thus far “lumped together” the decrease in step-turn & spin-turn preference when cued late (relative to mixed-turns), some consideration may need to be given to the decrease in step-turns being 5-fold while that for spin-turns only 4-fold (both relative to mixed-turns). On biomechanical level, a consideration as to why a late-cue may potentially be more problematic for step-turns is the finding that, although not consistently reported in the literature, a late cue may impair the ability to ML accelerate the COM from a reduction in both use of a foot strategy (absence of lateral pivot foot placement) & trunk strategy (absence of trunk lean into the turn direction) as a consequence to less pelvic-drop into the turn. Houck et al. (2006) early v. late cued young adults walking at a fast speed (2.0 m/s) for straight v. left 45^0 step-turns and noted an increase in lateral placement of the right ultimate pivot foot when early-cued for left step-turns, but no change was seen when late-cued. Moreover, when cued-late, even though trunk lean away from the turn increased (relative to the room), no change was seen in both lateral placement of the pivot foot & hip abductor moment relative to early-cued straight-gait, and the pivot hip abduction angle was the smallest of all conditions. Thus, Houck et al. (2006) attributed the greater trunk lean away, which did not translate into frontal plane limb rotation into the turn about the STJ to a smaller pelvic drop on the side of the turn as a consequence of the late-cue compromising neuromuscular hip control in its quest to preserve ML trunk alignment & balance stance of the pivot limb (MacKinnon & Winter, 1993). This suggestion of Houck et al.(2006) of a late-cue presenting a neuromuscular challenge to hip control (as observed during 45^0 step-turns), when taken together with the conclusion of both MacKinnon & Winter (1993) & Winter (1995) that ML foot placement at initial contact was most critical for COM acceleration (and controlled during swing by the hip abductors/adductors), may help explain how a constrained response time (late-cue) may render the use of both a foot & trunk strategy less effective thereby reducing step-turn preference.

Another potential explanation for the odds-ratio decline in step-turn preference being numerically (not statistically) higher than the odds-ratio decline in spin-turn preference, relative to mixed-turns, is the late-cue may have compromised anticipatory preservation of ML personal-space at the ground level between the turn-execution swing foot and the corner cone at the entrance to the turn-zone on the side of the turn. The is particularly relevant for step-turns as opposed to spin-turns, given the “step-out” of the swing-limb is space-consuming from the stand-point of increasing the width of the turn-execution stride by approximately 3 fold or greater (Huxham et al., 2006, 2008; Mari et al., 20120: Strike & Taylor,2009). Hackney & Cinelli (2013) had young and elderly adults choose their own direction when avoiding two (2.45 x 0.17 m) vertical obstacles whose separation distance varied between 0.6-1.8 m. Participants were free to walk straight between the obstacles or to the right/left in which the minimum clearance was at least 2m on either side. Hackney & Cinelli (2013) reported that although the elderly approached the obstacle at a slower speed (1.2 v. 1.5 m/s), no age-group difference was seen in the AP distance relative to the object before changing direction when normalizing for approach velocity, which for both groups corresponded to 2.4 seconds time-to-contact. Moreover, a consistent ML safety margin distance between the obstacle and the point of the shoulder at the crossing was also reported in both age-groups, although, this distance in the ML plane was wider in the elderly [(68.59(4.8) v. 31.38(2.9) cm]. Hackney

& Cinelli (2013) also found the elderly to have greater ML COM variability upon approach (an indication of trunk sway). Interestingly in both age-groups, a positive relationship was seen between ML COM variability and the ML safety margin distance at the instant of crossing. Given the finding of the ML COM variability upon approach having a positive association with the ML clearance distance at the instant of crossing, Hackney and Cinelli (2013) suggested the larger ML trunk excursions may enlarge the perception of body width (i.e. body width + ML COM variability) such that the altered perception drives the action of a large ML safety margin. Moreover, as the age-related difference of the AP proximity distance at the instant of direction change (elderly 2.41 v. young 3.86 m) was obviated when expressed in time-to-contact units rather than meters, Hackney and Cinelli (2013) cited previous research by one of the authors showing a similar path change distance in young adults (3.73m), in which it was believed this distance achieved the optimal image expansion threshold needed to trigger an obstacle avoidance response. Hackney and Cinelli (2013) expressed a similar belief and suggested the findings demonstrate how the visual system regulates the timing and amplitude of avoidance responses throughout the lifespan. Moreover, Hackney & Cinelli (2013) proposed the personal space safety envelop is systematically maintained to permit adequate response time to potential hazards, and can be generalized to numerous obstacle negotiation situations although the dimensions of the envelope may vary with environmental & task constraints. Applying this finding to the present study in which entrance to the turn-zone was spatially constrained by the physical presence of a cone at foot-level on either side, it is reasonable to speculate how preservation of a ML safety envelop with regards to the foot-cone distance may have been compromised by the late cue condition, and if so the effect would likely be greater for decreasing the preference for “space-consuming” step-turns than spin-turns in which the minimum distance separating the feet is smaller (Taylor et al., 2005). Interestingly, as Hackney & Cinelli (2013) have identified a consistent shoulder to object ML clearance distance in both age-groups when crossing obstacles(which appears greater in the elderly), and a typical vertical toe-clearance distance has been identified in the literature for a step-over task of approximately 10 cm for the elderly & 12.5 cm for young adults (McFadyen & Price, 2002), the principal investigator of the present study is unaware of prior research reporting a medial-lateral foot-to-object safety clearance distance at the ground-level when turning around objects. Furthermore, given Hackney & Cinelli (2013) found that ML COM variability (an indication of trunk sway) upon approach had a positive association with the ML shoulder-to-obstacle clearance distance at the instant of crossing (yet no association with variability in the ML safety margin itself), with the elderly showing both greater ML COM variability & a greater ML safety margin (68.59 v. 31.38 cm), questions regarding the potential for age-relate differences & variability in the ML foot-to-object safety clearance distance likewise seem intriguing.

Further support for the view that step-turns may be more susceptible to a preference decline than spin-turns when a late-cue precludes the ability to preserve the ML safety margin when turning around objects comes from the work of Fino, Lochhart & Fino (2015), who as previously described, had young adults perform early-cued left direction 90^0 step-turns v. spin-turn across different obstacle heights and walking speeds. When comparing early-cued 90^0 spin-turns v. step-turns, whereas a speed*strategy interaction revealed a larger curvature of the COM trajectory for spin-turns at fast -speed, other main effects for strategy showed that spin-turns were performed with both less ML distance separating the body's COM to the corner pylon & less radial distance separating the COP of the pivot foot to the same corner pylon. Thus, although spin-turns are more biomechanically challenging, (Patla et al., 1991; Hase & Stein, 1999; Taylor et al., 2006; Xu et al., 2006), spin-turns may be better suited for turning in “tight” environments, unlike step-turns which could potentially increase the risk of contact with near-by objects (i.e. cones, furniture) and tripping.

One final point regarding why execution of step-turns may be particularly challenging when a physical object is at each corner to spatially constrain entrance to the turn-zone, is that not only is the width of the turn-execution step enlarged, but when response time is constrained, lateral placement of the ultimate pivot foot opposite to the turn (i.e. use of a foot strategy) is used to assist the trunk in accelerating the COM into the turn. Hollands, Sorensen & Patla (2001) who late-cued young adults, and Mak, Patla, & Hui-Chan (2008) who late-cued healthy elderly controls in a Parkinson-related study both reported an increase in step-width (i.e. widening) of the ultimate pivot footfall during step-turns. Hollands et al (2001) and Mak et al. (2008) both suggested use of an utimate pivot foot strategy (lateral placement away from the turn) likely increases the COP-COM distance and hence enhances COM acceleration into the turn. Hence, although lateral placement of the pivot foot assists in displacing the COM when performing a late-cued step-turn, the increase in step-width not only across the turn-execution footfall, but also the preceding ultimate pivot footfall, could potentially be problematic for step-turns if the width of the entrance to the turn area is spatially constrained by a physical object on each end, as was the case in the present study (*Figure* 27.).



a. b. c. d. e.

Figure 27. Photo image sequence demonstrating how the spatially confined width at the turn zone entrance may have reduced step-turn preference when response-time was constrained (a. - e.). In this fast speed trial, the late-cue may have not permitted adequate time for preservation of a ML personal space safety margin for right-limb/foot clearance (relative to the corner cone on the participant's right) needed to "step-out" and execute a right step-turn (d.). Additionally, the final Gaitirite sensor pad located on the participant's left (just prior to the edge of the mat), may have constrained lateral placement of the left footfall needed to assist in accelerating into a right step-turn (e.).

Discussion of no age-group relationships for turn-strategy preference, or preference for one strategy over the other

The first obvious explanation as to why no age-group based relationships were recorded in the present study involves inadequate power (low n). Although a priori computation of power yielded 241 cases for a Chi-square test of independence, and 240 right-turn trials were included in the analysis, the small-medium effect size of 0.2 estimated in the a prior G*Power computation was inflated, as the post-hoc power achieved = 0.14 (Table 15). The second obvious explanation for the lack of an age-related effect for turn strategy preference resides in the elderly population being a very active group. Many of the elderly participants of the study were engaged in ongoing exercise programs at local fitness & community centers.

In the present study, not only were there no age-group relationships found with regards to turn-strategy preference across conditions, but neither was there a preference for step-turns over spin-turns across conditions which appears to be the general trend portrayed in the literature. As previously mentioned, the principal investigator of the present study is unaware of prior research comparing young v. elderly turn performance when late-cued in the same single study; however, Hackney & Cinelli (2013) reported that when electing to bypass the known (i.e. early-cued) location of two closely placed obstacles, rather than continue straight through the aperture between them, the elderly (as compared to young adults) showed a greater preference for using a step-wide strategy than young adults. Moreover, in late-cued studies confined to just one age group, Patla et al, (1991) and Hase & Stein (1999) reported a late-cue step-turn preference in populations in young to middle-aged adults; however, Conradsson et al. (2017) reported no early v. late cue difference in step-turn v. spin-turn preferences in healthy elderly serving as controls in a Parkinson-related study. Additionally, in a speed*turn-angle study in which direction was known in advance (i.e. early-cued) and no physical spatial constraints were used to define the turn zone (only a 50 cm diameter circle drawn on floor), Akram et al., (2010) found the elderly preferred spin-turns at slower or faster speed, however, an interaction was reported as step-turns were preferred when making large 90^0 angle turns at fast speed.

In contrasting these studies, Conradsson et al. (2007) stands-out as the only one in which the environment was spatially constrained with a physical presence at each corner of the entrance to the turn zone (i.e. a floor cone), similar to the present work. This observation highlights the need to interpret turn strategy preferences not only from the biomechanical perspective of constraints of response time and speed, but also from the perspective of physical boundaries at the foot level. Thus, the four hazard cones used in the resent study which spatially constrained the dimensions of the trapezoid-shaped turn zone primarily at its front entrance (i.e. front ML width 73 cm, back ML width 155 cm, AP depth 95 cm) may have acted as a ML "buffer" against any age-group based speed or cue-related preference for step-turns, which would otherwise be expected from a biomechanical perspective (Patla et al., 1991; Akram et al., 2010). Taylor et al., (2005) has shown that the minimum separation between toes is least for cross-over spin-turns relative to both step-turns & straight gait (cross-over spin-turn 100, straight 157, step-turn 298 mm during turn execution stride), suggesting the outside-swing-limb of spin-turns (which is further away from the turn corner in the ML plane) takes a more direct route than does the inside-swing-limb of step-turns; however, at the time time Taylor et al. (2005) also note that it is for this reason the risk for tripping-over-one's-own-two-feet may be greater for spin-turns. Additionally, the present study is in agreement with Akram et al (2010) in noting that elderly individuals still often use spin-turns despite the greater biomechanical challenge. In commenting on the elderly preference for spin-turns at slower & faster than preferred walking speeds, Akram et al., (2010) suggested the continued use of spin-turns across the life-span may add to their greater fall risk. However, to this the present study would suggest the that the spatially confined environments often encountered, especially in crowed & busy urban areas, may mandate that elderly individuals maintain proficiency in the use of both spin-turns & step-turns alike. Accordingly, rehabilitation programs on otherwise healthy elderly individuals would do well to include training in spin-turns as well, commensurate with the client's ability.

To this point it should be noted that Glaister et al.,(2007) used video analysis to do a field study of young adults negotiating real-life non-laboratory environments to assess the influence of architectural constraints on the frequency with which straight (linear) v. direction-altering (non-linear) steps were taken. Despite reporting the percentage of non-liner steps was at its highest of 50% when space in the environment was confined or cluttered (i.e. such as a busy cafeteria as opposed to exiting an office into a parking lot), Glaister et al. (2007) reportedly observed only step-turns as spin-turns were not used. However, in critique of this field study by Glaister et al., (2007), although course maps and general area dimensions for the different architectural environments were provided, the width at each turning point was not specified; but of even greater importance, participants were filmed using a posterior view; and spin-turns were very narrowly defined as "spinning" on the stance-foot. Taylor et al. (2005) had previously identified two sub-types of spin-turns in a sample of 10 young adults, namely, one involving limb-crossing (ipsilateral-crossover as seen in 6 of 10 individuals), and the other a pivot (ipsilateral-pivot seen in 4 of 10 individuals). In the present study, both the cross-over & pivot subtypes were considered one-and-the-same, as a “spin” did not have to be observed in order for the strategy to be scored as a spin-turn. Additionally, unlike the posterior film view used by Glaister et al. (2007), which may have hindered the observance of limb-crossing, the present study used an anterior video view. It also bears mention that Glaister et al., (2007) made no mention of mixed-turns. Hence, the lack of use of spin-turns as reported by Glaister et al. (2007) in young adults across architectural constraints, including those considered to be spatially “tight”, may need to be interpreted with caution and warrants further investigation.

It is worth mentioning that while the smaller toe-to-toe separation of spin-turns & narrower BOS may present a greater risk for tripping & ML biomechanical challenge (Taylor et al., 2005; Xu et al., 2004; Patla et al., 1991) yet possibly more ML space efficiency , there is some suggestion that both final approach step length & turn-execution stride length may be longer (Mari et al., 2012; Paquette & Vallis, 2010) allowing for a greater AP margin of stability yet with that less AP space efficiency. In particular, Mari et al. (2012) late-cued a 90^0 direction change in healthy elderly controls required to walk at a slower than preferred-speed [i.e. 0.81 (.14) as opposed to preferred speed of 1.15(.16) m/s so as to match velocity with their ataxic group peers] and found that when comparing spin-turn v. step-turn strategies across the turn-execution stride for just the healthy elderly control group, as expected spin-turns showed narrower turn execution stride-width [-14.6 (6.3) v. +33.1(4.1) cm or if normalized to mean walking stride-width -1.33(0.89) v. +3.00(1.24) with the negative indicating a cross-over]; however, conversely spin-turns also showed greater normalized turn-execution step length [i.e. step-length ending in placement of the turn execution footfall parallel to the new direction of progression: 0.59 (0.09) v. 0.30 (0.09) normalized to leg length]. Moreover, Paquette & Vallis (2010) reported that when late-cued for a circumvention task, step-length ending in ultimate pivot foot placement was significantly longer for a cross-over maneuver as opposed to a step-out maneuver, although the greater spin-turn step-length reached significance only for the elderly group (cross-over v. step-out step-length ending in ultimate pivot foot placement: elderly .51 v. .38 m; young: 0.60 v. 0.53 m). In the opinion of the principle investigator, when these findings of a longer step/stride-length when executing spin-turns over step-turns (Mari et al., 2012; Paquette & Vallis et al., 2010) are taken-together with the smaller spin-turn minimum toe-to-toe distance & its narrow BOS (Taylor et al., 2005; Patla et al., 1991) may suggest that while spin-turns offer less ML plane stability (Patla et al 1999; Hase & Stein, 1999; Taylor et. al. 2005; Xu et al., 2006; Akram et al., 2010) they may possibly be more ML space-efficient; given that a longer step/stride-length increases the AP stability margin (Hof, 2008; Hak et al., 2013; Suptitz et al., 2013; Chen et al., 1994), spin-turns may offer more AP plane stability given the longer turn execution step-length, yet may possibly be less AP space efficient. It is also of interest that with longer turn-execution stride-length with its potential for a longer spin-turn AP stability margin, relative to straight gait, A-P braking GRFs at the ultimate pivot foot have been reported to be greater for both strategies yet more so for step turns. However, the greater challenge to modulating ML GRFs during spin-turns (Patla et al., 1991) especially at fast speed (Xu et al., 2004) likely overshadows any benefit the the longer turn-execution stride-length has potential to provide to aid AP stability. Further research into ML v. AP space-efficiency v. stability margin for both strategies appears warranted as well as looking for any association between step/stride-length changes and turn strategy preferences.

Another possible explanation for the lack of an age-related difference in the present study, is that placement of the late-cue mat with its leading edge a sizeable120 cm from the Gaitrite edge, was not challenging enough in either group nor adequately constrain response time especially when walking at preferred speed. As already mentioned, Cao et al. (1997) found that 99% of turn-failures in both age-groups walking at a preferred speed were attributed to an inability to arrest the forward momentum of the COM within the available response time Yet younger subjects had greater success-rates at response times between 375-600 ms, while no difference was seen at a response time of 750 ms. Moreover, for the same 50% turn-success-rate, older adults required a longer response time (523 v. 408 ms) and distance (68 v. 53 cm).

As both age-groups in the study of Cao et al. (1997) walked at the same speed of about 1.33 m/s, the parity in turn success rates between the two groups at a response time of 750 ms (elderly 97 v. young 99%) implies a response distance at preferred speed of about 1 m. In the present study, the elderly late-cue preferred & fast non-normalized walking speeds were 1.30(.14) & 1.81(.25) m/s, respectively. Based upon the same response time of 750 ms in which parity was seen for turn success between age-groups in the study of Cao et al.(1997), when applied to the present study computes to a response distance in the elderly of 0.98 m & 1.36 m at preferred & fast speeds, respectively. Thus, given the start of the late cue mat was placed a distance of 1.20m before the turn-zone, based upon a response time of 750 ms and the average non-normalized elderly preferred & fast walking speeds recorded in the present study, the elderly appear to have had adequate response distance to support parity with young adults at the preferred speed, but the same cannot be said at the fast speed. Related to this point of placement of the late-cue mat not adequately constraining the response distance, it should be noted that for the right-turns, the late-cue was delivered upon penultimate footfall contact in 54% of late right-turn trials, and the antepenultimate foot contact in 46% of late right-turn trials (Appendix C). Moreover, little change was seen in all these percentages across age-groups and walking-speeds. Thus, in almost one-half of the late-cue right-turn trials, participants had a two-step warning response-time to execute the turn, unlike most other late-cue turn-strategy preference studies which allowed just a one-step response time (Patla e al., 1991; Hase & Stein, 1999; Conradsson et al., 2017; Mak et al., 2008; Mari et al., 2012; Gilchrist, 1998). Finally, other than having a separate preferred and fast categorical speed block of trials for each age-group, the numerical speed within each block was not controlled to match between age-groups. Thus, although not significantly different, young adults did walk about 5% faster during the preferred speed block of trials [1.30(.14) v 1.37(.10)], and about 12% faster during the fast speed block of trials [1.81(.25) v. 2.02(.24)]. Hence, possibly the 12% difference in attained speed between groups for the fast-block of trials acted as a slight buffer to an age-related difference in turn strategy preferences.

Discussion of increase in elderly mixed-turns for the fast*late-cue condition

Only 1 of the 24 cells in the 2x2x2x3 loglinear analysis crosstabulation achieved a significant standardized residual beyond +/-1.96, and that was the elderly*fast*late*mixed-turn cell with a value of +2.4. Indeed, inspection of Age*Speed*Cue*Turn-Strategy cell count & residual table (Table 6) and bar-chart (Figure 9) indicates that relative to both step-turns & spin-turns, less mixed-turns were performed by both age-groups across 3 of the 4 response-conditions, however, for the most time-constrained fast*late interaction, at least numerically-speaking, the elderly observed mixed-turn count out-numbered that for either step-turn or spin-turn (turn-strategy observed counts for fast*late condition: in the elderly step-turn 8, spin-turn 10, mixed-turn 12; in young adults step-turn 9, spin-turn 14, mixed-turn 7). Although the small counts for mixed-turns required the four Mixed-Turn subgroups (i.e. small amplitude step-turns, small amplitude spin-turns, extra footfall spin-turns, extra footfall step-turns) be combined in order to meet expected cell-count assumptions for the loglinear analysis, a break-down of all mixed-turn cells into its four sub-groups, reveals the age-group difference in count for the mixed-turn extra-footfall step-turn sub-group of the elderly*fast*late cell stands-out (observed count: elderly 7 v. young 1), and this one sub-group likely explains why this cell had a +2.4 standardized residual (Appendix AA).

The increase in the mixed-turn sub-group, elderly-extra-footfall-step-turns, is likely comprised of several explanations. First, this finding would be in agreement with Cao et al, (1997) who calculated that when late-cued to turn, in order to achieve the same 50% turn-success-rate as young participants, older adults required both a longer response distance (68 v. 53 cm) & a longer response time (523 v. 408 ms) prior to reaching the turn gate. Cao et al. (1998) suggested older adults need extra distance & time to decelerate their forward momentum during unexpected turning, primarily due to less of a reduction in time to achieve peak velocity following cuing (i.e. less of a reduction in the duration of stance-limb push-off once receiving the late-cue).

As already mentioned, outside of Cao et al, 1997, 1998) the principal investigator of the present study is unaware of prior research comparing young v. elderly turn performance when late-cued within the same study (i.e. under similar conditions) for a permanent direction change, let alone late-cue research on turn strategy preferences in healthy elderly. Nonetheless, this finding in the present study of healthy elderly requiring an extra step beyond the turning location used when cued-early (which operationally defined use of an extra-footfall) is in agreement from what can be gleaned from patient-related studies in which healthy elderly served as controls. Conradsson et al. (2017) late-cued healthy elderly controls in a Parkinson-related study. With regards to just the healthy elderly control group, a delay was noted in the onset of ML displacement for the 1st turn-execution step for the required 180^0 turn as a consequence of the late-cue, which corresponded to approximately 1 step beyond the location chosen to initiate the turn when cued-early (early-cue 0.09 s before the turn-point v. late-cue -0.45 s after the turn-point).

Moreover, the “stand-out” of the mixed-turn sub-group, “elderly extra-footfall-step-turns” (observed count of 7 elderly), relative to other mixed-turn sub-groups across all conditions, is also in agreement with prior research suggesting elderly difficulty with unexpected direction changes requiring limb-crossover as compared to a step-out. As mentioned in the literature review, Gilchrist (1998) late-cued young & healthy elderly females (mean 70 years of age) 100 ms post penultimate (prior step) footfall contact for random right v. left rapid lane change responses while walking straight at a preferred speed along the center lane. Glichrist (1998) reported that relative to young adults, the elderly were less capable of a rapid lane shift after just 1 post-late-cue center lane footfall (elderly 26% v. young 58% of trials), especially when the lane-shift necessitated a "cross-over" spin-turn maneuver as opposed to "side-step" step-turn maneuver (frequency of 1 post-late-cue center lane footfall: spin-turn maneuvers: elderly 1.5% v. young 31.2% of trials; step-turn maneuvers: elderly 51.6% v. young 84.9% of trials). Gilchrist (1998) suggested the greater threat to balance imposed by the crossing of limbs during the cross-over maneuver likely accounted for it not being the preferred first option strategy when needing to execute a rapid lane shift within just 1 post-late cue center lane footfall. Gilchrist (1998) proposed the greater overall frequency of the elderly needing to take more than 1 post-late-cue center lane footfall to shift lanes likely permitted a more incremental ML displacement of the COM; however, the prolonged distance of forward progression brought-about by the taking of an extra footfall could increase the risk of contact with nearby objects. Support for healthy elderly more often needing an extra step to avoid spin-turns as opposed to step-turns when late-cued again can be found in a patient-related study in which this time healthy middle-aged participants served as controls. Mari et al., (2012) audibly late-cued healthy middle-age controls (mean 48 years) for large 90^0 v. small 30^0 right spin-turns v. left step-turns in an Ataxia-related study. Again, limiting the discussion to just the healthy elderly control group, when comparing large 90^0 v. small 30^0 amplitude turning with regards to the percentage of healthy elderly controls needing > 2 steps to complete the late-cued direction change, a statistically higher percentage of > 2 steps was seen only for the larger amplitude spin-turn but no difference for the larger amplitude step-turn (% of middle-aged control participants needing > 2 steps i.e. choosing not to complete turn within the turn execution stride: for a right spin-turn: 5% at 30^0 v. 48% at 90^0; for a left step-turn: 20% at 30^0 v. 35% at 90^0). Preferring not to complete a right spin-turn within the 2 steps of the turn-execution stride once late-cued on the penultimate footfall implied taking an extra step so as to delay the response one footfall in order to execute a right step-turn instead; and on the flip-side, not completing a left step-turn within 2 steps but delaying the response one footfall to execute a left spin-turn instead. Thus, taken collectively, the work of Gilchrist (1998) and Mari et al., (2012) would appear to suggest that when the taking of an extra-footfall to avoid executing a spin-turn appears to be a late-cue strategy used by healthy elderly individuals, however, the additional stopping distance nonetheless has clinical implications for tripping.

To be fair, as the data of Gilchrist (1998) would suggest, late cue cross-over maneuvers can also be somewhat challenging even in the younger population. Thus, Hase & Stein (1999) reported that when a combination of young to middle-aged adults (26-57 years) were cued-late for 180^0 turns, 3 of 10 participants failed to execute the spin-turn following just 1 post late-cue footfall, as one extra footfall was taken to instead choose a step-turn despite the longer response distance & time. However, the ages of those participants who avoided late-cued spin-turns were not provided. Yet, despite this finding that even young to middle-aged adults find late-cued spin-turns challenging, the count for the mixed-turn extra-footfall step-turn sub-group of the young*fast*late cell in the present study amounted to 1 (observed count: elderly 7 v. young 1), while the count for the mixed-turn extra-footfall spin-turn sub-group of the young*fast*late cell amounted to 3 (observed count: elderly 2 v. young 3) (Appendix AA). Although, these mixed-turn counts are way too small to draw any conclusions, it is worth noting that the Counts and Residuals Table produced by the Final Model for Age*Speed*Cue*Turn-Strategy 2x2x2x3 Loglinear Analysis (Table 6) indicates that although not significant at the level of +/-1.96 for a standardized residual, the young*fast*early*step-turn cell had the 2nd largest value at +1.75, and the young*fast*late*mixed-turn cell had a standardized residual of -1.05, which represents a sizeable “swing” in young adult preference for step-turns when walking fast and cued early as opposed to late. Indeed this was integrated & reflected in the significant Cue*Turn-Strategy interaction as was previously discussed. It bears mention again that the turning task of Hase & Stein (1998), in which even young to middle aged individuals found a late-cue spin-turn more challenging in the taking of an extra footfall, was not spatially constrained as the present task.

In line with this discussion about the taking of extra-footfalls and additional response distance needed by the elderly, it is worth noting that in the present study, when collapsing for turn-strategy, the percentage of trials in which the elderly required a response distance of 2-post-late-cue-footfalls as opposed to just 1 post-late-cue-footfall was approximately 10% greater at both speeds; however, the difference in percentages between the two age-groups were not found to be significant based upon a separate three-way (age*speed*nth-post-late-cue-footfalls) loglinear analysis (Appendix C): at preferred speed: pivoted on 1st post-late-cue-FF Young 60% v. Elderly 46.7%; pivoted on 2nd post-late-cue-FF Young 40% v. Elderly 53.3%; at fast speed: pivoted on 1st post-late-cue-FF Young 60% v. Elderly 50%; pivoted on 2nd post-late-cue-FF Young 40% v. Elderly 50% (Appendix C). It is worth recalling that Patla et al. (1991) reported young subjects had high success ($\geq$ 70%) when cued-late one step prior to the turning point (i.e. allowed 1 post-late-cue-footfall to respond).

The +2.4 standardized residual found in the present study for the Elderly*Fast*Late*Mixed-Turn cell may also reflect the greater dual-task-cost from the additional allocation of attentional resources for online visual-motor control to supplement feed-forward control, which appears to be needed by the elderly to a greater extent than young adults (even when cued-early for a crossing task as was touched-upon in the discussion of the Cue*Turn-Strategy interaction). Paquette and Vallis (2010) late-cued young & elderly participants for direction 1 step prior to circumventing either right or left to avoid a 2 m high by 0.2 m wide cylindrical obstacle. The eye-gaze point of regard was computed for four areas-of-interest as a percentage of the time of the walking trial elapsed between receiving the visual cue (at the penultimate footfall) and crossing of the COM beyond the obstacle, based upon the total number of video frames. Although no age-related differences were found when comparing gaze-point-of regard preferences between the two circumvent strategies (step-out v. cross-over), young adults spent a greater percentage of the trial duration looking directly ahead at either the obstacle or wall at the end of the walk-way, whereas the elderly spent the largest percentage of the trial duration gazing towards the ground after the obstacle [four areas-of-interest % of walking trial: a) obstacle - young 36% v. elderly 28%, b) ground after the obstacle -young 19% v. elderly 45%, c) wall at end of walkway- young 34% v. elderly 20%, and d) random locations- young 11% v. elderly 7%). Paquette & Vallis (2010) suggested that when late-cued for a circumvent task, unlike young adults who appeared to use vision for foot placement in a feed-forward manner in being less dependent upon visual information from the ground beyond the obstacle, the elderly were more proactive in planning the placement of their footfalls both before and during the task in a feed-back manner by visually scanning the environment to ensure safe passage. While the purpose of Paquette & Vallis (2010) was never to directly assess the effect of any additional attentional resources that may have been needed by the elderly for online visual-motor processing, as opposed to the feedforward processing of the young participants, it is worth noting that in this same study by Paquette & Vallis, the elderly had a greater reduction in both speed & step-length, yet less of an increase in step-width corresponding to placement of the ultimate pivot footfall. Although Paquette & Vallis (2010) interpreted these findings purely from both a motor control perspective (elderly more cautious with regards to speed/step-length) & biomechanical perspective (COP-COM distance) with no regards to the potential for additional elderly attentional resources needed for the online visual-motor control, it is important to note that dual-tasking during straight gait has been shown to decrease both speed & stride-length (Al-Yahya, Dawes, Smith, Dennis, Howells & Cockburn, 2011), and either increase/decrease step-width (Nordina, Moe-Nilssen, Ramnemark & Lundi-Olsson, 2010).

Further support for an age-related increase in need for online visual motor control comes from indication the elderly may have greater difficulty using stored visual-spatial information to direct pending footfall placement. Yamada, Higuchi, Mori, Uemura, Nagai, Aoyama & Ichihashi (2012) found that when negotiating across 15 rows of footfall targets (each row containing 1 target & 2 distractors), older subjects tended to rely more upon online visual feedback information of imminent footfall targets when stepping (i.e. greater tendency to fixate their visual gaze closer to imminent footfall targets) whereas younger individuals showed a greater ability to fixate on footfall targets a couple of rows ahead while relying on “stored” visual-spatial information to place their feet on imminent footfall targets (gaze initiation times before stepping on the target with longer times indicating gaze initiation was more futuristic and less immediate (i.e. feed forward control): young 3.54, elderly 1.94 s). Thus, the elderly were less capable of using “stored” visual-spatial information to direct imminent footfall placement in a feed forward fashion. Yamada et al. (2010) also reported that in young adults the location of the gaze fixation was more frequently directed towards the target, and less frequently towards the immediate path as compared to the elderly (percentage of the total fixation duration towards the target: young 52%, elderly 28%; fixation duration towards the path: young 48%, elderly 72%). Although the duration of gaze fixation did not differ between groups (gaze duration: young 0.62 v. elderly 0.78 s) since the elderly directed their gaze to the path more frequently, Yamada et al. (2010) suggested older adults may have a greater need to fixate on the trajectory (i.e. path) of their footsteps rather than the target itself.

To the effect that attentional resources allocated for visual-motor processing can affect turn strategy preferences, particularly with regards to extra footfall spin-turns, there is suggestion dual-task-cost can trigger unnecessary use of a step-strategy in the elderly. Brown et al. (1999) compared the DTC effects of backward serial 3’s subtraction on balance recovery strategies (feet-in-place: ankle or hip, or stepping response) in young and elderly adults who were randomly perturbed either backward & forward (unanalyzed catch trials) with both feet atop two translating force plates. Brown et al. (1999) noted that postural responses were not automatic but necessitate attentional resources; and that during stationary standing the dual-task costs to recover balance for a step strategy are greater in the elderly. Brown et al. (1999) reported that although both age-groups initiated the stepping response with the COM further from the BOS limit during the dual-task condition, the elderly step strategy response came at a higher DTC (larger difference in serial subtraction pre-post counting-speed) and was used with greater frequency, which may indicate the elderly perceive postural disturbances as a larger threat to stability. Brown et al. (1999) suggested dual-tasking may promote unnecessary-attention-consuming-step-taking in the elderly, and if attention resources are too low to support safe stepping, a fall could ensue. Although the motor task in Brown et al. (1999) involved stationary standing, the finding of dual-task cost precipitating use of a step strategy despite no threat to balance, may still be applicable to gait. Tirosh & Sparrow (2004) noted older adults more frequently used a two-step stopping response to halt straight gait especially when cued late, yet 86% of elderly two-step responses were employed unnecessarily with the COM within the anterior-posterior stability boundaries (whereas for young adults this percentage was less at 36% of two step responses). Although the potential effect of DTC from visually attending to the late-cue or the DTC of the stepping response itself were not considered, given the extra step to stop was often employed unnecessarily, Tirosh & Sparrow (2004) suggested the two step responses may have been pre-planned with the additional step intended to aid medial-lateral stability. This suggestion that the taking an extra-step when late-cued to stop for straight-gait may have more of an intent to preserve ML rather than AP balance, may be particularly relevant when late-cued and needing to decelerate prior to turning. In agreement with Gilchrist (1998), Tirosh & Sparrow (2004) proposed that some elderly falls may be caused by object contact as a result of needing to take an extra step to stop.

Discussion of Mixed-Design ANOVA Spatial-Temporal Gait Adaptations across the Four Final Recorded Approach Footfalls

The findings of the mixed-design ANOVAs for the spatial-temporal analysis did not reveal any significant age-related differences although two age-related trends were seen, namely, the elderly had less of an increase in combined right/left stride-length when walking fast, and unlike young adults the elderly did not increase right H-H BOS when walking fast. However, despite few age-related differences, both groups when cued-late for direction walked slower (especially when walking fast as opposed to at preferred speed) & took shorter strides; and when cued-early both slowed-down and took shorter-strides to turn-right as compared to straight. Moreover, with regards to H-H BOS changes, both groups increased right H-H BOS when cued-early to turn right as compared to straight; and the only three-way interaction of the entire study revealed both decreased left H-H BOS when cued-early to turn right when walking fast but did same when cued-late to turn right at preferred speed.

Discussion of few age-related differences/trends

Similar to the discussion on turn strategy, the first obvious explanation as to why few age-related differences (only two trends) were found in the present study for the spatial-temporal variables involves inadequate power (low n). A priori computation of sample size for a 2 x2 Mixed Design repeated measures F test using G*Power v. 3.1.7 for the Between Factor yielded a total sample size (n) = 150, while the compromise power analysis using a total sample size (n) = 20 (as from the Chi square power analysis) yielded a low power (1-β error probability) = .35. Similarly, for the Within Factor & Within-Between Factor Interaction, a priori computation yielded a total sample size (n) = 52, while the compromise power analysis using a total sample size (n) = 20 again yielded low power (1-β error probability) = .55.

Another potential reason for the paucity in age-related differences for spatial-temporal variables in the present study is that, although as expected the elderly group scored lower on the DGI, many in the sample of seniors who participated were very active and recruited from local fitness centers. Moreover, the average age for the elderly group was just under 70 years (mean 69.7, range 66-75). The importance of this is there is indication in the literature that both young adults and seniors below 70 years of age prioritize a posture preserving strategy under dual-task conditions in attempting to avoid obstacle contact and the potential for tripping. Harley, Wilkie & Wann (2009) had young (20-29 years), elderly (60-69 years) and an older-elderly group (70-79 years) perform a secondary verbal fluency task for 1 minute (i.e. saying as many words as possible that originated with a specified letter) while continuously walking briskly around a 14.5 m figure-of-eight path (entire figure-of-eight-path fit into a rectangular area of 5.2m x 2.3 m) which required participants to step-over over a centrally-located rectangular obstacle, one large (15.2 x 7.6 x 30 cm) and one small (2.5 x7.6 x 10 cm), walking counter-clockwise and clockwise, respectively. Harley et al. (2009) found that while both elderly groups performed similarly during the single motor task, the young adults & young-elderly group showed greater resemblance during the dual-task. In particular, both the 20-29 year olds & 60-69 year olds decreased step-velocity at the crossing and increased lead & trial-limb toe-clearance during the dual-task thus demonstrating a ‘posture-protective ‘ strategy to minimize the risk of foot-obstacle contact at crossing. Concurrently, during the dual-task, these same two younger age-groups (the 20-29 year olds & 60-69 year olds) both displayed a small decrease in verbal fluency, thus suggesting the re-allocation of attentional resources for posture-preservation. However, while the 70-79 year olds stepped conservatively during the single-task, unlike the two younger groups, this older-elderly group inconsistently preserved dual-task step control, as despite reducing step-velocity at the crossing & increasing lead-toe clearance, when performing the secondary verbal fluency task, the older-elderly 70-79 year old group showed less trail-toe clearance and greater variability of the trail & lead-foot landing distances. Harley et al. (2009) proposed the increased lead-toe clearance, but decreased trail-toe clearance in the 70-79 year old group, suggest moderate attentional demands from the use of online visual feedback control when stepping over the obstacle with the lead-limb, as opposed to the greater attentional costs from the combined use of both feed-forward visual & online kinesthetic control when crossing with the trial-limb requiring. Interestingly, given the 70-79 year old group preserved verbal output across the single & dual-task conditions, Harley et al. (2009) suggested that this older-elderly group may have misallocated attentional resources needed for postural control to the secondary verbal task, and unlike the 20-29 year olds & 60-69 year olds, may be less consistent in utilizing a posture-preserving strategy under conditions of cognitive-motor interference. Thus, in applying the findings of Harley et al. (2007), although all age-groups, including the older-elderly, reduced step-velocity at the crossing (note- step-velocity upon approach was not assessed), both the young adults and elderly group (average-age under 70 yrs.) in the present study may have given similar priority to preserving foot clearance so as not to contact/trip over the hazard cones in the turn-zone, rather than persist in steady-state gait upon approach.

A further potential explanation for the exiguous number of age-related differences in spatial-temporal parameters is equipment/instrumentation limitations in that the last 55 cm of the Gaitrite carpet lacked sensors. Hence, data could not be recorded for the ultimate pivot footfall, and post late-cue footfalls were seldom recorded. Of the 240 right-turn trials, the final recorded footfall corresponded to the penultimate footfall in 76% of trials, and the ante-penultimate footfall in 24% of trials (Appendix B). Thus, the two strides (3 steps or 4 footfalls) of Gaitrite data recorded terminated one and at-times two steps before the actual pivot. Glaister et al. (2007, 2008) noted that in young adults who performed preferred speed early-cued 90^0 step-turns, the ML impulse of the ultimate footfall was twice the value of the preceding penultimate footfall, and the propulsion impulse was also greatest at the ultimate footfall. Moreover, with regards to post-late cue footfalls, very few were recorded especially for right-turns and at fast-speed (Appendix C) [1 post-late cue FF: right-turns 11% (15%preferred, 7% fast) & straight walks 22% (preferred 32%, fast 12%). Hence, due to instrumentation limitations, in the majority of the 240 late-cue trials (84% when collapsing for speed & direction), all 4 recorded footfalls were taken with no inkling of direction, and for the most part post-late-cue “reactive” feed-back gait changes & strategies went undetected. In comparison, when cued-early, all 4 recorded footfalls were pre-planned and placed with prior knowledge of direction, and as such the Gaitrite data represents anticipatory “proactive” feed-forward gait changes

& strategies. Interestingly, the percentage of trials containing 1-post-late-cue footfall in either direction was comparable in both age-groups regardless of speed (Appendix C): [collapsing for speed right-turn trials containing 1 post-late-cue footfall (young 6 trials at 10%, elderly 7 trials at 12%); and straight trials containing 1 post-late-cue footfall (young 12 trials at 20%, elderly 14 trials at 23%). Hence, in light of the elderly having slower sensory-motor processing (Woollacott & Shumway-Cook, 2002), lower turn success-rates at response times under 750 ms (Cao et al., 1997), and needing more time to decelerate during unexpected turning due to less of a reduction in the duration of stance-limb push-off once cued (Cao et al., 1998), the paucity of post-late cue spatial-temporal data may have also contributed to the sparsity in age-related differences. Additionally, the low percentage of post-late-cue footfalls also explains why, when comparing right turns v. straight gait, right & left heel-to-heel base of support changes were primarily seen when cued-early.

Discussion of Age*Speed trend which suggest less elderly increase in stride-length, and unlike young adults no increase in right BOS when fast approaching a crossroad irrespective of direction

Relative to young adults, the elderly showed a trend for less of an increase in stride-length, and unlike young adults no increase in right heel-to-heel base-of-support when approaching the turn-zone walking fast as opposed to at preferred speed irrespective of direction. However, to put this in perspective, although the increase in stride-length at fast speed was less in the elderly, both age-groups similarly reduced stride-length when turning right after an early-cue regardless of speed; and while the elderly showed no increase in right heel-to-heel base-of-support when walking fast, both age-groups similarly increased right H-H BOS when turning right after an early-cue regardless of speed. Thus, in all fairness, these age-related trends in the present study are not peculiar to right-turns only, but the trends for less of an elderly increase in stride-length & no increase in right heel-to-heel base-of-support when walking fast (as opposed to preferred speed) apply to straight gait as well. It is for this reason it is being stated these age-related trends were seen when approaching a crossroad such as the turn-zone, and not specifically when approaching to turn right. However, given the magnitude of change in step-width is known to be greater when approaching turns as opposed to straight gait (Paquette et al., 2008), the combined effect of these age-resulted trends may take-on greater clinical significance for direction-changes.

Each of these age-related trends is of interest in and of itself. First, in support of the present study’s finding of a trend for less of an elderly increase in stride-length (relative to young adults) at fast speed, Shkuratova et al. (2004) also reported that when walking fast as opposed to at preferred speed, the increase in elderly stride-length (& speed) was smaller relative to young adults, and believed less of an increase may aid stability when walking fast by minimizing perturbations acting on the body when accelerating. Thus, although older adults in the present study were able to significantly modulate & increase stride-length when walking fast, the use of smaller steps in the elderly (at least at preferred walking speeds) has been linked with falling. Lipsitz, Jonnson, Kelley & Koestner (1991) reported that when walking straight at preferred speed, elderly fallers took smaller steps than elderly non-fallers [0.22(.09) v. 0.31(.10) m], and when turning 360^0 required a greater number of steps to [17(8) v. 11(4) steps]. Thigpen et al. (2000) found greater prevalence for use of 3-4 steps during the 180^0 turn of the TUGS at preferred speed among elderly participants with self-described turning difficulty (elderly with turning difficulty 54%, elderly without turning difficulty 38%, young 0%). Moreover, the inability to adequately modulate stride-length when increasing speed as has been seen in multiple fallers. Callisaya, Blizzard, McGinley & Srikanth (2012) noted the risk for multiple falls was associated with a decrease in the preferred v. fast speed walk ratio (i.e. step length/cadence), as those with a history of multiple falls exhibited a smaller walk-ratio at fast speed with the increase in cadence being greater than the increase in step length.

In interpreting these age-related trends, it is worth recalling that the present study only assessed the final 2 recorded strides as participants negotiated the entire 459 cm length of the Gaitrite walkway. Moreover, with regards to stride-length, the data across the final 2 recorded strides (1 right stride & 1 left stride, but not necessarily in the order) was averaged, with each stride-length measure impacted by changes across 2-consecutive step-length measures; and each base of support measure was impacted by changes across 2-consecutive step-width measures. Hence, combined right/left stride-length represents the average across a “window” of 4 consecutive steps, and each right & left base-of-support represents the average across a window of 2 consecutive steps. As such, although the elderly showed less of an increase in stride-length & right heel-to-heel base-of-support when walking fast compared to preferred speed, a determination cannot be made for ether age-group as to whether the change in these dependent variables was gradual, proportional and spread-out across all steps taken along the Gaitrite, or whether the change was sudden, disproportional and focused at a specific location instead. Yet it may be helpful to note that at least with regards to turn trials, when early-cued for direction Paquette et al., (2008) found most gait adaptations prior to turning 40^0 took place across the final-three approach steps i.e. across the final two approach strides ending in either the penultimate or ultimate footfall.

This point of whether or not the smaller elderly increase in stride-length & no increase in right H-H BOS, when walking fast compared to preferred speed, was uniform from the outset across steps or the result of a later decline following an initial period of increase, is particularly warranted as research at preferred speed has already suggested a decrease in step-length prior to & during obstacle crossing may trigger a tripping episode particularly if attentional resources are challenged. McFadyen & Price (2002) had young & elderly [(n=10, 69.5(6.1) years] males step-over an 11.75 cm obstacle while walking at preferred speed. McFadyen & Price (2002) reported that relative to young males, the elderly males had less vertical lead-limb clearance over the obstacle, and moreover the lead limb was placed in closer horizontal proximity to the cleared obstacle. McFadyen & Price (2002) suggested shorter stride-length in the elderly could be one of several factors contributing to a greater risk for tripping from toe-obstacle contact. In a related study using a curb stepping task, Lythgo, Begg, & Best (2007) noted that when approaching to negotiate a 15 cm (6”) high curb at preferred speed, the elderly had almost twice the decrease in step-length relative to young adults in the last 4 steps & crossing when descending /and crossing step when ascending. Lythgo et al. (2007) suggested that a fall could ensue should a distraction or motor control error take place across the 4-5 approach steps when descending curbs.

When the decrease in step-length in approach of a step-over task is sudden & precipitous, particularly at a fast speed, there appears to be a greater risk for tripping as momentum may propel the body beyond the abbreviated placement of the forward foot. Chen, Aston-Miller, Alexander & Schults (1994) had young and elderly participants walk at a preferred speed along an instrumented 8m walkway to perform a virtual obstacle (narrow 3 cm band of light) step-over task at a fixed location 4 m away and across available response times (ART) prior to an anticipated footfall location ranging between less than 1 up to approximately 2 steps (300,350,400, 450 & 1000 ms). Chen et al. (1994) noted that as available-response-times (ART) in approach of a virtual obstacle became less, the elderly appeared to have greater difficulty utilizing a long-(crossing)-step-strategy (LSS) as opposed to a short-(pre-crossing)-step strategy (SSS). When ARTs were greater than 400ms, young & elderly participants both showed a preference for the long-(crossing)-step-strategy (LSS) ; however, when ARTs were under 400 ms, both age-groups employed the more risky short-(pre-crossing)-step strategy (SSS). Although no significant age-related difference was seen in LSS v. SSS preference, Chen et al. (1994) suggested indirect evidence the elderly had more difficulty executing the LSS as they used the SSS 8-10% more frequently than young adults when the ART was 450 ms or greater. Of particular interest to the discussion at-hand, Chen et al. (1994) reported 4 falls ensued as a result of attempting the step-over task. In each case the participant was walking at a faster-than-normal speed (with available response times between 200-450 ms); and 2 of the 4 falls were attributed to a sudden decrease in pre-crossing step-length, allowing momentum to carry the COM forward beyond the reduced BOS despite the attempt of an additional step. Chen et al. (1994) cautioned that although a short step-strategy may be less biomechanically demanding to employ at short ARTs, it poses a greater risk for tripping when combined with a hurried walking speed in and of itself, without needing to make physical contact with an object.

An extreme decrease in step-length in the aftermath of a medial perturbation when walking at fast speed has also been reported to be predictive of a future injurious fall as seen in a group composed of those with diabetic neuropathy & healthy elderly controls. Allet, Kim, Ashton-Miller, De Mott, & Richardson (2014) reported that across the 4 steps immediately following a medial-perturbation applied to elderly participants (a combined group of healthy controls & those with diabetic neuropathy) walking at a fast speed, based upon a 12-month prospective survey, prospective fallers who sustained injury had a significantly greater extreme (i.e. maximum) reduction in step-length than prospective fallers who did not sustain injury [percent maximum decrease in step-length for the combined group of healthy elderly controls & those with diabetic neuropathy: injured-fallers 18.5(9.2) v. non-injured-fallers 11.3(4.57) %, p=0.01. Significance was almost also reached when comparing fallers with non-fallers (% maximum decrease in step-length: fallers 16.41(8.42) v. non-fallers 11.0(4.95) %, p=0.06)]. Moreover, a relationship was found between preservation of step-length and the hip abductor/adductor rate of torque development and ankle proprioception (i.e. the greater the hip rate of torque development or ankle proprioception sensitivity, the less of a decrease in step-length following perturbation). Allet et al. (2014) proposed the inability to preserve step-length following a perturbation may possibly be used to predict prospective fallers & fall-relate injury. Allet et al. (2014) suggested that placing the swing limb down prematurely by taking a shorter step following a perturbation may be a strategy used, particularly by those with a decreased rate of hip abductor/adductor torque development, to avoid the destabilizing effect of an increase in step-width. In applying the findings of Allet et al., (2014) to the present study, if one were to equate a perturbation with ML acceleration of the COM as results from the use of a foot and/or trunk strategy (Patla et al., 1999; Hollands et al., 2001; Paquette et al., 2008), it is not unreasonable to speculate a large abrupt decrease in step-length when rapidly approaching turns may potentially forebode a greater risk for an injury-related fall.

Thus far, the discussion has primarily centered on the first age-related trend of the elderly having less of an increase in stride-length when approaching the turn-zone (irrespective of direction) walking fast as opposed to at preferred speed, but the second age-related trend of the elderly showing no increase in right heel-to-heel base of support when approaching the turn-zone walking fast (regardless of direction) may be of somewhat more importance. Again, the present study cannot say whether the young adults maintained a wider right BOS at the start of the walk, although this is unlikely. Morris et al. (2007) reported a -0.262 autocorrelation for H-H BOS across two successive strides in young adults such that a narrow stride 1 was immediately followed by a wide stride 2; whereas a wide stride 1 was immediately followed by a narrow stride 2. Morris et al (2007) referenced the inverted pendulum model of gait predicts such regression towards the mean given the rhythmical pattern of lower limb oscillation, and suggested the negative autocorrelation across two strides functions to preserve steady-state linear walking. Moreover, Collins & Kuo (2013) reported step-width varied step-to-step with a short-term correlation which was negative at a lag time of one-step, but positive at a lag time of two-steps (i.e. if a right step $_0$ were to be displaced laterally more than average, the left upcoming step $_1$ would be displaced slightly more medial than average, and the subsequent right step $_2$ would be placed very slightly more lateral than average). Thus in light of step-width varying from step-to-step, and in light of most BOS change at least with regards to approaching turns taking place in the strides ending with the penultimate & ultimate footfalls (Paquette et al., 2008), it is doubtful that young adults increased right heel-to-heel base of support at the start of the trial when walking fast (as opposed to at preferred speed) but instead did so in closer proximity to the turn zone.

Nonetheless, regardless of where along the Gaitrite young as opposed to older adults first increased right BOS when walking fast as compared to at preferred speed, given BOS to a certain degree reflects the amount of ML separation between feet during gait, the absence of enhancing this separation when fast approaching a crossroads (i.e. the turn-zone) may potentially increase the risk of tripping over one’s feet especially when executing a spin-turn. As previously noted, Taylor et al. (2005) found that relative to straight gait, the ML distance between feet was reduced when executing spin-turns while walking at preferred speed and advised this could increase the risk of tripping, especially when coordination is an issue. Moreover, this issue of potentially tripping over one's feet when turning has also been raised with regards to in-place (i.e. stationary) turning with regards to variability in the minimal separation between feet. Meinhart-Shibata, Kramer, Ashton-Miller & Persad (2005) visually cued young (n=10, mean 21.8 years & older (n = 10, mean 72.5 years) community dwelling female subjects to randomly turn 180^0 right or left from stationary standing to lift up a light weight bowl with both hands and place it on a posterior located table. Meinhart-Shibata et al. (2005) identified a preferred (as opposed to non-preferred) direction strategy as the direction in which the subjects chose to turn in a circle. Meinhart-Shibata et al. (2005) noted that relative to young females, older women were more variable in their minimum foot separation distance when turning to the none-preferred direction [variability of minimum foot separation distance 17.4(7.6) v. 10.9(4.4) mm]; and although no age-related difference was seen in the magnitude of the minimum foot separation distance, within the older group the feet were closer together when turning to the non-preferred as opposed to preferred direction [average minimum foot separation distance: elderly females: preferred direction 49.2(17.6) v. non-preferred direction 34.9(13.1) mm]. Meinhart-Shibata et al. (2005) suggested the narrower & more variable distance separating the feet during the stationary non-preferred direction 180^0 turn may make the risk for tripping from foot-foot interference greater during the non-preferred direction turn. Thus, as for the present study showing a trend for only young adults increasing right heel-to-heel base of support walking fast (relative to at preferred speed) in approach of the turn-zone irrespective of direction, given the greater need to modulate ML GRFs at higher speeds (Xu et al., 2004; Orenduf et al., 2006; Fino et al., 2015), a transient “prophylactic” increase in ML separation between limbs when walking fast (as compared to preferred speed) in approach of a crossroad, may be a beneficial strategy to compensate/make-allowance for any possible variability in minimal foot separation & potentially lessen the tripping risk. It is interesting to note that although no significant age*speed interaction (nor trend) was found for left heel-to-heel base of support (p = 0.523), the mean normalized left BOS in young adults was “numerically” (not statistically) larger at fast speed (as opposed to preferred speed) whereas the mean in the elderly was numerically the same across speeds [normalized left H-H BOS mean (standard error): young adults preferred speed 0.110 (.008) v. fast speed 0.114 (.010) leg-length; elderly adults preferred speed 0.092 (.008) v. fast speed 0.092 (.010) leg-length]. (Appendix AB).

Preserving a “prophylactic” safety space or cushion between feet upon approach may possibly also be of benefit to step-turns as the turn-execution swing foot does not immediately “step-out” upon toe-off but travels forward a short distance. Hollands et al. (2001) found that when young adults were late-cued for 60^0 step-turns, the onset of medial-lateral foot displacement into the turn direction was delayed 170 msec. after the initiation of toe-off. While not discussed by Hollands et al. (2001), should the use of an anticipatory foot strategy narrow step-width of the penultimate footfall (Patla et al. 1999; Paquette et al., 2008; Hollands et al., 2010), this delay in the ML trajectory of the turn execution swing limb following toe-off may conceivably pose a risk for tripping over one's own feet (i.e. left swing-foot tripping over the right planted ultimate-pivot foot). Moreover, this risk for tripping from foot-to-foot contact upon approach of turns may be especially heightened when attentional resources are taxed from visual processing required to control the avoidance maneuver (Brown et al., 2005) and an increase in swing-limb stiffness has been triggered (Weerdesteyn et al., 2003). It is also interesting to note that Berg et al. (1997) reported tripping-over-ones-own-feet/for-no-apparent-reason was the sixth most frequent reason surrounding a fall at 10%.

When considering the combined effect of the trend for the elderly having less of an increase in stride-length & no increase in right heel-to-heel base-of-support when walking fast, and the coordination required to regulate step changes across two orthogonal planes, research during straight gait appears to suggest AP and ML step-variability act independent of each other. Morris, Bilney, Matyas, & Dalon (2007) found no association between step-length and H-H BOS across an interval of five-successive-steps. Moreover, given the negative autocorrelation for H-H BOS across two successive strides, Morris et al (2007) suggested the regulation of H-H BOS is likely sensory feedback based, whereas step-length may be under greater cortical influence. Moe-Nilssen, Aaslund, Hodt-Billington, & Helbostad (2010) noted that AP interstep trunk acceleration variability and step-length variability were both associated and collectively pointed to a common construct. (Likewise vertical interstep trunk acceleration variability and step-time variability were also both associated and pointed to a second construct). However, low test-retest reliability (ICC) was noted for step-width variability across two trials; and neither ML step autocorrelation nor ML interstep trunk acceleration variability was associated with any gait measures. Hence, Moe-Nilssen et al., (2010) suggested ML interstep trunk acceleration variability may identify a third separate construct. In further support for independent regulation of gait in the sagittal as opposed to frontal plane, Collins & Kuo (2013) reported that in young adults speed showed a strong significant positive relationship with step-length, accounting for 59% of the variance in step-length; however, speed did not significantly correlate with step-width ($R^2 = 0.063$), and only accounted for 3.4% of the variance in step-width. Collins & Kuo (2013) suggested that step variability may involve two independent components which are distinguished both spatially & temporally: one in the anterior-posterior direction which experiences a more gradual change related to long-term random fluctuations in speed over several steps; and a second component in the ML direction which is more sudden and fluctuates step-to-step to regulate balance. Thus, given it has been suggested that gait variables related to propulsion i.e. step-length, may be regulated by a different neuro-circuitry than variables related to stability i.e. BOS (Socie & Sosnoff, 2013), and as both step-length (stride-length) and step-width (BOS) are adapted when approaching turns (Shkuratova et al., 2005; Strike and Taylor, 2009; Huxham et al., 2008; Paquette et al., 2008; Paquette and Vallis, 2010), further research appears warranted into the combined regulation of these two variables when turning and any implications it may have on the risk for tripping.

To this last point of the need for additional research into the combined effect of simultaneous changes in step-length & step-width (or minimum foot separation) when approaching turns and the risk for tripping, there is a hint in the literature of an increase in step-width just prior to circumventing being of benefit to safety. Paquette and Vallis (2010) found that when late cued at preferred speed to circumvent a cylindrical obstacle, relative to young adults the elderly had a greater reduction in step length (21% v. 16%), but a smaller increase in step-width ending in the ultimate pivot footfall for both the step-out (.38 v .50 m) and cross-over (.21 v .31m) circumvent maneuvers. Paquette and Vallis (2010) suggested a larger step width during these late cued complex direction changes may potentially be a safer strategy; and although this suggestion of Paquette & Vallis was made solely within the context of regulating ML COM displacement, it is not a far stretch to see how it may be applicable to the risk of tripping as well. Nonetheless, with all this said, given the age-related trend in the present study showing young adults (but not the elderly) increase right BOS when walking fast (as opposed to at preferred speed) was not direction-based but applied to both straight & right-turn trials, however entertaining, any suggestion here of this being a prophylactic strategy on the part of young adults to lessen the risk of foot-to-foot contact when approaching turns is dubious at best.

Discussion continued on the Age*Speed trend for the elderly showing less increase in stride-length walking fast

This finding of a trend in the elderly having less increase in stride-length when walking fast as opposed to preferred speed may also represent a weaker elderly push-off (shorter stride) strategy to decrease posterior-anterior perturbations. Winter, Patla & Frank (1990) reported that the slower straight gait walking speed seen in the elderly was not due to a decline in cadence, but rather the result of a shorter stride and longer period of DLS % GC. Moreover, Winter et al. (1990) found push-off power generation was sharply reduced in the elderly (0.191 v. 0.296 j/kg), and suggested both the decrease in stride-length and increase in DLS% GC were the consequence of this smaller push-off. Winter et al. (1990) proposed that given the forward & upward thrust generated by push-off, weaker elderly push-off may be an adaptive strategy to minimize perturbation.

Although no statistically significant age-related difference was seen with regards to the increase in speed when walking fast, the present finding and interpretation with regards to stride-length is otherwise in agreement with the literature comparing both young and elderly community dwellers walking straight across different speeds. Shkuratova, Morris & Huxham (2004) reported that relative to young adults (mean 25.3 years), the elderly (mean 71.5 years) had less of an increase in both stride-length [preferred: young 1.38(.12), elderly 1.35(.17) m v. fast: young 1.63(.14), elderly 1.50(.19) m)] and speed [(preferred: young 1.23(.21), elderly 1.25(.21) m/s v. fast: young 1.83(.29), elderly 1.67(.27) m/s)]. Shkuratova et al. (2004) viewed the less increase in both stride-length & speed in elderly fast straight-gait as an age-related adaptation to lessen perturbations when accelerating and thereby aid stability. It is worth noting the non-normalized stride-length & speed values reported by Shkuratova et al. (2004) appear slightly lower than the non-normalized values recorded in the present study for both stride-length [preferred: young 1.52(.07), elderly 1.44(.15) m v. fast: young 1.84(.14), elderly 1.65(.20) m)] and speed [preferred: young 1.45(.12), elderly 1.39(.14) m/s v. fast: young 2.14(.24), elderly 1.92(.23) m/s].

As was previously discussed, in interpreting the smaller elderly increase in stride-length when walking fast (relative to preferred speed), the present study cannot determine whether or not elderly (or young for that matter) stride-length declined off a higher earlier peak value across the final two strides. Nonetheless, the smaller elderly increase in stride-length when fast approaching the turn zone irrespective of direction does have some semblance to the more proactive reduction in elderly step length previously reported to allow more time when approaching curbs (Lythgo et al., 2007); and afford greater caution when early-cued in approach of turns (Paquette et al., 2008), & late-cued in approach of a circumvent task (Paquette et al., 2010).

Discussion continued on the Age*Speed trend for only young adults showing an increase in right H-H base-of-support walking fast but not the elderly

As previously noted, the present study cannot make any claims as to the status of the right H-H BOS value other than as it applies to one of the final two strides recorded prior to stepping off the Gaitrite. Moreover, it is unlikely young adults persisted in the use of a wider BOS across all right strides of the fast walk trial given the negative autocorrelation reported for BOS across two strides is believed to help maintain a straight gait (Morris et al., 2007) (and all BOS measures in the present study were recorded across the linear approach phase prior to turning) and at least when needing to turn most BOS change happens across the final two approach strides (Paquette et al., 2008). Yet this finding of a trend in young adults, but not the elderly, showing an increase in right heel-to-heel base of support when walking fast as opposed to at preferred speed, while unlikely a strategy employed when approaching turns given the trend was also seen for straight walking trials & across cue conditions, continues to be a challenge to interpret.

Moreover, with regards to straight gait, there are conflicting accounts as to whether or not step width changes across speeds. Thus, in young adults, there are reports in the literature of speed having no correlation with step-width (Collins & Kuo, 2013), and speed having no effect on step-width across a range from slowest to preferred to fastest speed (Sekiya, Nagasaki, Ito, & Furuna,1997). Still further, Orendurff, Segal, Klute, Berge, Rohr, & Kadl (2004) found that step-width increased in young adults (21-45 years of age) as speed decreased below 1.6 m/s, which approximated the preferred walking speed value in that group [step-width: at 1.6 m/s, 17.1(5.3) cm; at 1.2 m/s, 18.7(3.7) cm; and at 1.0 m/s, 21.3(4.7)]. Not surprisingly, Orendurff et al., (2004) also reported an increase in the ML COM displacement at slower speeds [ML COM displacement: at 1.6 m/s; 3.85(1.41) cm; at 1.2 m/s, 4.41(1.23) cm; and at 1.0 m/s, 5.96 (1.68)]. Orendurff et al. (2004) suggested that due to the greater ML COM displacement, walking at slower speeds may present a greater challenge to stability for those with gait deficits. However, it must be noted that Orendurff et al. (2004) did not assess walking at speeds greater than preferred or above 1.6 m/s.

A similar finding of an increase in step-with when walking slower than preferred was seen in another study limiting the top speed to 1.6 m/s, yet its dual-task paradigm was found to result in a wider step-width relative to the single-task. Klein, Poggensee, & Ferris (2014) had young adults walk on a treadmill across a range of speeds (0.4, 0.8, 1.2 & 1.6 m/s) while performing a secondary spatial working memory task (remembering the spatial location of nine numbers in a 3x3 grid shown over a 32 s time period). In agreement with Orenduff et al., (2004), Klein et al. (2014) also noted that in young participants step-width decreased as speed increased to approach more preferred levels (i.e. step-width was narrower at 1.2 m/s as opposed to 0.4 m/s) . Moreover, Klein et al. (2014) found that at each individual speed, when compared to the single-task of treadmill walking, step-width was wider when performing the spatial-working-memory dual-task. Klein et al. (2014) suggested the wider steps afforded greater stability when performing the cognitive task. In light of the visual-motor processing needed when approaching the hazard cones bordering the turn-zone (Brown et al., 2005; Patla & Vickers, 2003), some considering may possibly need to be given to whether the faster young adult speed, while not significantly different to that of the elderly, may have increased the visual processing cost and contributed to only the young showing an increase in right H-H BOS when walking fast in approach of the turn-zone.

The literature with regards to the association of speed and step width in the elderly likewise lacks clarity. Brach, Berthold, Craik, VanSwearingen, & Newman (2001) reported elderly participants showed a step-width decrease at faster speeds during straight gait (r= -0.24, p=.02) (Brach et al., 2001). Yet) found a quadratic, parabolic, “U-shaped” relationship between step-width and speed during straight gait in the elderly, as step-width was smallest at the middle speed levels (preferred & some-what fast) and greatest at the extreme speed levels (slow & fastest-possible). Moreover, whereas Klein et al., (2015) found that a spatial-memory task widened step-width to aid stability in the young, Nordina, Moe-Nilssen, Ramnemark, & Lundi-Olsson (2010) in the elderly reported that when performing a serial 3s subtraction task either a step-width increase or decrease of 20% from the median value was associated with greater fall risk odds ratio of 2.5; yet when performing a motor task of carrying a cup with a saucer (which required steadying of the upper extremity & trunk) either a step-width increase or decrease of 14% from the median value was associated with a lower fall risk odds ratio of approximately 0.2. Nordina et al. (2010) proposed that although there is an association between a change in step-width with fall risk as a consequence of performing a dual-task, whether the absolute change in step-width increases or decreases the risk for falling is dependent upon the classification or type of dual-task. Thus, although the attention allocation needed for either anticipatory-feedforward or online-feedback visual-motor-control (Brown et al., 2005) may appear “attractive” as an explanation for the increase in right BOS seen in young adults at fast speed, interpreting BOS changes from the perspective of cognitive-motor interference is not straightforward; moreover, such an explanation is doubtful given Al-Yahya et al. (2011) reported that although task & gait-variable specific, the effect of cognitive-motor interference in general appears greater in the elderly.

Despite the lack of straight gait literature providing a viable explanation for the increase in right BOS seen in young adults (but not the elderly) at fast speed in the present study irrespective of direction & cue condition, there is an interesting suggestion from a fast walking turn-related study comparing just two possible directions (straight v. left step-turns) that when late-cued, errant anticipation of direction (i.e. mistakenly anticipating a turn-left signal when instead late-cued to continue straight) may cause performance (with regards to hip abductor moment & angle) to mimic if not over-mimic that seen when early-cued for the opposite direction (i.e. performance when late-cued to continue straight, resembles that when early-cued to turn-left; or on the flip-side when late-cued to turn-left, resemble that when early-cued to stay straight).

In greater detail, Houck et al., (2006) early v. late-cued young adults walking at a fast but comfortable speed of 2.0 m/s. for straight v. left 45^0 step-turns (side-step-cuts). Houck et al (2006) reported a task x planning (i.e. direction x cue) interaction across the loading phase of gait (10-30% of stance). Namely, when late-cued to continue walking straight, during loading the pivot limb internal hip abductor moment increased (i.e. became more negative, given negative = abduction) relative to when early-cued to walk straight, to the point of being similar in amplitude to the early-cued left-turn (thus suggesting anticipation & possibly learning of the hip moment requirement needed when early-cue to turn left but not continue straight). However, when late-cued to turn-left, during loading the pivot limb internal hip abductor moment decreased (i.e. became less negative although did not switch to positive = adductor) relative to when early-cued to turn-left, to the point of being similar in amplitude to early-cued straight walking (thus suggesting anticipation & possibly learning of the hip moment requirement needed when early-cued to walk straight, but not turn-left) [right pivot hip internal moment across 10-30% of stance (in Nm/kg) with negative = abduction: step-turn early-cue -1.62(.31), straight late-cue -1.59(.33), step-turn late-cue -1.39(.30), straight early-cue -1.34(.49)]. (Note, given the Bonferroni correction for the 8 multiple comparisons equaled $p<0.006$, this direction x cue interaction for internal hip moments suggesting subject anticipation when late-cued was considered only a trend as $p=0.014$). Moreover, assessment of the pivot hip abduction angle during stance suggested the “wrong” direction late-cue anticipation of the internal hip abductor moment may have even been too extreme. As such, Houck et al. (2006) found that across the first 30% of right ultimate pivot limb stance, the pivot limb hip abduction angle was significantly wider (i.e. larger) when late-cued to continue straight (straight*late) as compared to all other three direction*cue conditions, including left*early; and in contrast the pivot limb hip abduction angle was significantly narrower (i.e. smaller) when late-cued to turn (i.e. left*late) as compared to all other three direction*cue conditions, including straight*early [right hip angle (negative = abduction in degrees): straight*late-cue -14.2^0 (3.6), straight*early-cue -11.8^0 (2.7), step-turn*early-cue -10.6^0 (4.6), step-turn*late-cue -6.6^0(4.7)]. As the late-cue to turn not only resulted in a lower hip abductor moment & abduction angle (relative to the pelvis), but was also accompanied by no change in lateral foot placement (relative to the COM) yet a greater degree of trunk roll away from the turn (relative to the room), Houck et al., (2006) suggested the anticipation of the internal hip abductor moment when late-cued to either continue straight or turn-left, though errant, nonetheless still demonstrated the importance of hip neuromuscular control in preserving ML trunk alignment & balance during single-limb stance. Thus, when late-cued, mistaken anticipation may make performance mimic if not over-mimic that seen when early-cued for the opposite direction. However, although this finding of Houck et al. (2006) may be worth considering when only two direction options exists (straight, left), given the present study randomly cued for three direction options (straight, right, left), errant anticipation as an explanation for the increase in right H-H BOS seen in young adults when walking fast and collapsing for direction & cue-constraint is highly improbable.

Despite the absence of a readily apparent explanation for the increase in right BOS seen in young adults walking fast relative to preferred speed (irrespective of direction & cue), an attempt nonetheless will at least be made to offer potential explanations as to why no similar increase in right BOS at fast speed was seen in the elderly in the present study. However, it should be mentioned at the outset, that all these explanations do not seem justified given the increase in BOS was not specific to right-turns only. To begin with, based upon the previous finding of young adults showing a greater increase in step width at the pivot footfall for both strategies (step-out & cross-over) yet the absence of trunk roll when late-cued to circumvent, Paquette & Vallis (2010) suggested use of a foot strategy may suffice to ML displace the COM in young adults, whereas use of a foot strategy alone may be insufficient in the elderly as they appear to require the addition of a trunk strategy as well. Interestingly, although Paquette et al., (2008) reported that both age-groups showed similar step-width changes across the final three approach steps when early-cued for 40^0 turns (similar increase approaching spin-turns & similar decrease approaching step-turns), the elderly again seemed more dependent upon both strategies in initiating trunk roll into the turn direction prior to ML COM displacement, whereas in young adults ML COM displacement preceded trunk roll. Thus, while it is not unreasonable to speculate the elderly may be less capable of robust lateral foot displacement to ML regulate the COM when approaching turns, particularly if constrained by a fast walking speed or limited response time, as mentioned above the non-specificity of direction with regards to the young adult increase in right BOS at fast speed makes this unlikely.

Another possible explanation for the absence of an increase in right H-H BOS in the elderly walking fast is the wider step-out may generate an an over-burdensome increase in ML COM acceleration and ML perturbation. In particular, Winter (1995) reported that ML acceleration of the COM was proportional to the distance (cm) separating the center of pressure and the vertical projection of the COM onto the ground, and volitional rapid lower-limb movements have been shown to be destabilizing to upright trunk alignment and necessitate automatic postural adjustments to control COM displacement (Hughey & Fung, 2005). Moreover, Moraes, Lewis & Patla (2004) early-cued young adults walking at a preferred speed for alternate foot placement and reported a 66.1% preference for medial displacement of the final 4th footfall when avoiding an obstacle. Moraes et al. (2004) suggested early awareness of obstacle position for alternate foot placement may have permitted anticipatory containment of the COM despite limb-crossing shrinking the BOS, and cautioned that the greater frontal plane acceleration generated by step-out BOS widening also has potential to destabilize. Given the elderly have been shown to have greater difficulty preserving ML balance, a wide step-out could potentially be more destabilizing in older adults. Kavanaugh, Barrett & Morrison (2005) reported a decrease in acceleration smoothness of the trunk in the ML direction in the elderly along with greater head-trunk acceleration coupling in the ML plane. Kavanaugh et al. (2005) suggested that lateral stability is intrinsically problematic in the elderly during gait, and the greater ML direction coupling may be a compensation for less ML stability. Hence, the absence of a increase in elderly right H-H BOS when walking fast in approach of the turn zone may be an adaptive strategy used by the elderly to minimize ML perturbations to the trunk, but again this seems unlikely given the finding in young adults at fast speed was not specific for turns.

The greater metabolic cost incurred from use of a wider step width may be another reason why no increase in right H-H BOS was noted in the elderly when walking fast. Donelan et al. (2001) reported that for step-widths wider than the preferred width of 0.13(.03) leg length, the increase in both metabolic & mechanical costs was not linear, but a function of the square of step-width. As previously mentioned, Donelan et al. (2001) reported the preferred step-width did not significantly differ from that corresponding to the lowest metabolic cost at 0.12(.05) LL, nor the average foot width of 0.11 (.01) LL = 10(1) cm. Interestingly, the metabolic cost for straight walking represents a higher percentage of the VO2 max in the elderly as compared to that seen in young adults. Waters & Mulroy (1999) computed that when walking at preferred speed, the rate of oxygen consumption, expressed as a percentage of VO2 max, was 32% VO_2 max in young adults (20-30 years old), and 48%

VO_2 max in the elderly 75 years of age. Moreover, Peterson & Martin (2010) reported a systematically greater net metabolic cost of walking in the elderly [mean 71 (4) years] as opposed to young adults [mean 25(3) years] as speed increased from 0.89-1.57 m/s, with the average difference being 23% higher across the range in older adults. Additionally, as the total EMG muscle coactivation index (comprised from the sum of four flexor/extensor antagonist muscle pair indices: two from the thigh & two from the shank) had a positive association with the metabolic cost of walking, and the thigh coactivation in itself greater in the elderly, Peterson & Martin (2010) suggested the greater metabolic cost for walking across speeds seen in the elderly can in part be attributed to greater lower-limb muscle cocontraction. Accordingly, in the present study, when using a step-out foot strategy accelerate the COM in approach of turns (Paquette et al., 2008), the likely greater metabolic cost at fast walking may have made the elderly more inclined to not stray from the preferred-speed step-width pattern for the sake of either comfort or efficiency. Applying this issue of speed and metabolism to a sample of young adults, Lenoir et al. (2006) found a greater left turn direction bias when running as compared to walking, and suggested the greater metabolic demand required of running, likely necessitated a more efficient and comfortable preferred direction turning strategy. It is interesting to note the leg-length (LL) normalized preferred step-width of 0.13(.03) LL as measured by Donelan et al.,(2001), and the leg-length normalized right H-H BOS values obtained in the present study for the early-cued straight walking trials were roughly in the same ball-park [early-cue straight trials at preferred-speed: young 0.11(.04), elderly 0.10(.02) LL; early-cue straight trials at fast-speed: young 0.13(.03) , elderly 0.10(.03) LL]. It is worth recalling that for linear straight gait (i.e. the linear steps in approach of the turn in the present study), step-width and H-H BOS (the equivalent of stride-width) are one and the same (Huxham, Gong, Baker, Morris, & Iasek, 2006). However, again this explanation is also unlikely given the increase seen in right BOS at fast speed in young adults was not limited to right-turns.

Another potential explanation for the absence of a wider right BOS at fast speed in the elderly is the slower sensori-motor processing reported in older adults (Woollacott & Shumway-Cook, 2002). To that point, Tirosh & Sparrow (2004) early (10 msec. after left swing limb heel strike) & late-cued (450 msec. prior to left swing limb toe-off) young (mean age= 25 years) and healthy elderly (mean age = 69) to rapidly terminate gait. Tirosh & Sparrow (2004) noted that relative to straight walking, when stopping the left trail limb propulsive forces were reduced only in the young subjects as the elderly did not modulate left push off. Although both age-groups increased peak horizontal braking and reduced peak horizontal propulsive GRF in the right lead foot relative to unconstrained walking, lead foot braking forces were smaller and propulsive forces greater in the elderly. Tirosh & Sparrow (2004) proposed an age related decline in neuromuscular stance limb performance may be the reason for the less proficient modulation of propulsive forces and restraint of horizontal COM velocity. This finding of Tirosh & Sparrow (2004) of a decline in elderly neuromuscular proficiency is in agreement with Cao et al. (1998) who attributed a prolonged elderly deceleration time to a lower reduction in the duration of stance-limb push-off once late-cued to turn. Thus, it is not unreasonable to speculate that when needing to step-out using a foot strategy to modulate ML GRFs when approaching turns (Paquette et al., 2008) the ability to widen the BOS/step width may decline in the elderly when approaching a direction change (Paquette & Vickers, 2010) particularly when walking at a fast speed (Xu et al., 2004; Orenduff et al. 2006; Fino et al. 2015) in light of the decline in older-adult sensori-motor processing & neuromuscular performance. But yet again, as the increase in young adult right BOS at fast speed was not limited to right turns, this scenario is unlikely.

Another possible explanation the principal investigator of the present study would like to suggest for the absence of an elderly increase in right BOS at fast speed is the wider ML safety margin reported in older adults may suppress a BOS increase from use of a step-out foot strategy when in fast approach of the spatially constrained turn zone. Hackney & Cinelli (2013) reported a consistent ML safety margin distance between the obstacle and shoulder at the crossing when circumventing in both age-groups, however this distance in the ML plane was wider in the elderly [(68.59(4.8) v. 31.38(2.9)cm]. Moreover, as ML COM variability upon approach had a positive association with the ML clearance distance at the instant of crossing in both groups, Hackney & Cinelli (2013) suggested the larger ML trunk excursions may enlarge the perception of body width (i.e. body width + ML COM variability) such that the altered perception drives the action of a larger ML safety margin. Hackney & Cinelli (2013) proposed the findings demonstrate how the visual system regulates the amplitude of an avoidance response. It is also worth noting that Gerin-Lajoie, Richards, & McFadyen (2008) computed protective (personal) space during an obstacle circumvention task (with an ample 2 m of clearance on either side) as young adult participants approached at three different speeds (preferred, 25% slower, and 25% faster) . Surprisingly, Gerin-Lajoie et al. (2008) reported young adults showed no change in both the shape and transverse cross-section area of personal space across preferred 1.44(0.17) m/s, slow 1.10(12) m/s and fast 1.79(17) m/s walking speeds which suggested systematic preservation of the safety margin. Although this would appear to indicate personal space is not dependent upon gait speed when circumventing around obstacles, Gerin-Lajoie et al. (2008) nonetheless cautioned of the possibility that in a different environmental context, personal space may become larger should a faster speed cause concern about gait-adaptation response-time to a potential threat to stability. Thus, regardless of whether or not speed affected the personal space safety envelope, given use of a step-out foot strategy upon turn approach would entail widening of step-width/BOS

(Paquette et al., 2008), the greater ML safety margin reported in the elderly may in part explain the lack of a right BOS increase when in fast approach of the entrance to the width-constrained turn zone. However, as noted in the other possible explanations, this is also unlikely as the right BOS increase at fast speed seen in young adults was not exclusive to right-turns only but seen during straight trials as well. This finding warrants further study.

Discussion of increase in right H-H BOS turning right only when cued early; and a decrease in left H-H BOS turning right when cued-early at fast-speed yet when cued-late at preferred-speed

In interpreting the present findings with regards to right and left H-H BOS changes, it is important to consider the significant difference resides in comparing the right turning trials v. the straight walk trials, not in comparing right v. left limb BOS relative to each other. Moreover, although one right & one left H-H BOS measure was recorded per trial, the BOS changes seen in the present study do not necessarily represent successive right BOS widening followed by left BOS narrowing in the same trial (or vice versa) as the right/left stride sequence was not controlled.

Nonetheless, in an effort to find meaning in the results of the present study showing left H-H BOS narrowing and right H-H BOS widening, it is very helpful to consider Paquette et al (2008) reported that regardless of right v. left direction, when both age-groups were early-cued for 40^0 turns, step-width narrowed across the final three approach steps during step-turns, but widened across the final three approach steps during spins-turns. These three final recorded approach steps in Paquette et al., (2008) equate with the two final approach strides ending in ultimate pivot footfall placement. Although only two strides of data were also recorded per trial in the present study, it is helpful to recall that the final recorded footfall on the Gaitrite primarily corresponded with the penultimate footfall (76%), and to a lesser extent the antepenultimate footfall (24%). Thus, when interpreting the data of the present study based upon the early-cue findings of Paquette et al (2008), the final approach step-width data of Paquette et al (2008) corresponding to the ultimate pivot footfall should be omitted from the discussion. Accordingly, when comparing the change in step-width relative to straight gait for either the ante-penultimate or penultimate footfall as reported by Paquette et al (2008) for each turn-strategy, the footfall in closer proximity to the turn showed the greater change in the step-width amplitude. Namely, a greater extent of step-width narrowing relative to straight gait was seen across the step corresponding with penultimate footfall placement as opposed to the antepenultimate footfall during step-turns, and a greater extent of step-width widening was seen across the step corresponding with penultimate footfall placement as opposed to the antepenultimate footfall during spin-turns [step width comparison across turn-strategies: young step-turns: straight 0.08, ante-penultimate 0.09, penultimate 0.06 m; and young spin-turns: straight 0.08, ante-penultimate 0.07, penultimate 0.10 m; and for elderly step-turns: straight 0.10, ante-penultimate 0.10, penultimate 0.08 m; and elderly spin-turns: straight 0.10, ante-penultimate 0.09, penultimate 0.11 m]. Hence in summary of extracting meaning in the H-H BOS results of the present study, when juxtaposed against the previous early-cue findings of Paquette et al (2008) that approach step-width narrowing characterized step-turns, whereas approach step-width widening characterized spin-turns, and given that in the present study only right turns were included in the analysis and the data was primarily anticipatory (i.e. feed forward) in nature given the low percentage of post-late-cue footfalls (right-turns 11%, straight walks 22%), it seems reasonable to assume that the data showing a left H-H BOS decrease (i.e. narrowing) primarily reflects that of right step-turns *(Figure* 28.), whereas data showing a right H-H BOS increase (i.e. widening) primarily reflects that of right spin-turns *(Figure* 29.).

03, 03

Walk 7/6/2014 11:00:30 AM

Gender: M
Age: 29
Left - Leg - Right: 93 94

Long Gap 2 (Toe In/Out)

Bilateral Parameters	Left	Right
Step Time (sec)	.40	.42/2.6
Cycle Time (sec)	.83	.81
Step Length (cm)	96.14	95.02/1.3
Stride Length (cm)	192.03	190.64
H-H Base Support (cm)	8.97	13.80
Single Support (%GC)	42.0	42.8
Double Support (%GC)	16.0	14.4
Swing (%GC)	41.9	42.9
Stance (%GC)	58.1	57.1
Step/Extremity Ratio	1.02	1.02
Toe In / Out (deg)	3	2

Parameters	
Distance (cm)	286.2
Ambulation Time (sec)	1.25
Velocity (cm/sec)	228.9
Mean Normalized Velocity	2.45
Number of Steps	3
Cadence (Steps/Min)	144.0
Step Time Differential (sec)	.03
Step Length Differential (cm)	1.13
Cycle Time Differential (sec)	.02

L Length	R Length	L Width	R Width
29.60	31.20	8.00	8.30

Primary Dr.

Sample Normal Values

1 early turn right fast

Figure 28. Decrease in left H-H BOS observed on the Gaitrite display when approaching a right step-turn in a young adult male after being cued-early at fast-speed. The gait progression is from left-to-right with the penultimate footfall being the final recorded footfall. The narrowing in left BOS likely contributes to regulation of ML COM acceleration, and the left-ward diagonal body displacement prior to turning right-ward may aid to systematically preserve a ML safety envelope between the turn-execution swing footfall and the right corner hazard cone at the entrance to the turn-zone. The left BOS narrowing may initiate disequilibrium into the right-turn direction, and potentially pose a risk for tripping over one's own feet prior to turning.

03, 03

Walk 7/6/2014 11:02:54 AM

Gender	Age	Left - Leg - Right	
M	29	93	94

Long Gap 2 (Toe In/Out)

Bilateral Parameters	Left	Right
Step Time (sec)	.40/.3	.40
Cycle Time (sec)	.80	.80
Step Length (cm)	89.87/.3	95.77
Stride Length (cm)	185.91	185.53
H-H Base Support (cm)	10.09	15.63
Single Support (%GC)	39.6	41.7
Double Support (%GC)	18.8	18.8
Swing (%GC)	41.6	39.6
Stance (%GC)	58.4	60.4
Step/Extremity Ratio	.96	1.03
Toe In / Out (deg)	7	3

Parameters	
Distance (cm)	275.5
Ambulation Time (sec)	1.20
Velocity (cm/sec)	229.6
Mean Normalized Velocity	2.46
Number of Steps	3
Cadence (Steps/Min)	150.0
Step Time Differential (sec)	.00
Step Length Differential (cm)	5.90
Cycle Time Differential (sec)	.00

L Length		R		L Width		R	
30.00	☐	31.10	☐	6.90	☐	8.20	☐

Primary Dr.

Sample Normal Values

2 early turn right fast

Figure 29. Increase in right H-H BOS observed on the Gaitrite display when approaching a right spin-turn in the same young adult male after again being cued-early at fast-speed for a 2nd trial. The participant initiated this trial with his opposite foot which explains why trial 1 was a step-turn, whereas trial 2 a spin-turn. The gait progression is again from left-to-right with the penultimate footfall being the final recorded footfall. The widening in right BOS likely contributes to regulation of ML COM acceleration, and the left-ward diagonal body displacement prior to turning right-ward again may aid to systematically preserve a ML safety envelope between the turn-execution swing footfall and the right corner hazard cone at the entrance to the turn-zone.

Overall, the findings of early spatial temporal gait changes when approaching turns on one level may represent a distributed systematic pre-planning of foot placement prior to entrance of the turn zone. Moraes, Lewis & Patla (2004) early-cued young adults walking at a preferred speed for alternate foot placement to avoid a planar obstacle located over the normal landing area of the 4th of 5 total footfall taken on the Gaitrite (i.e. the 4th footfall essentially represented the penultimate footfall prior to stepping off the Gaitrite's edge). Moraes et al. (2004) observed the 2nd & 4th footfalls both contributed to the ML x-coordinate component of the final avoidance 4th footfall vector (with both the 2nd & 4th footfalls having the same sign of direction), and the contribution to the AP y-coordinate component of the final avoidance 4th footfall vector showed a progressive increase across all four successive footfalls. As the angle of the adaptation vectors across the 2nd & 3rd footfalls positively & increasingly correlated with the angle of the final adaptation vector at the 4th footfall, Moraes et al. (2004) suggested participants systematically pre-planned the vector displacements of their approach footfalls to align with the ultimate intended direction goal.

Applying this point of a distributed systematic pre-planning of BOS changes across approach footfalls, when early-cued regardless of speed, the left H-H BOS narrowing (*Figure 28*.) and right H-H BOS widening (*Figure 29*.) may represent an anticipatory feedforward strategy to systematically preserve a ML safety envelope between the turn-execution swing footfall and the right corner hazard cone at the entrance to the turn-zone. As previously noted, research has suggested the approach phase when circumventing is systematically regulated to preserve a consistent safety distance. Hackney & Cinelli (2013) had young and elderly adults choose their own direction when avoiding two (2.45 x 0.17 m) vertical obstacles whose separation distance varied between 0.6-1.8 m. Hackney & Cinelli (2013) reported that both groups preserved a consistent ML safety margin distance between the edge of the obstacle and the participant’s shoulder at the instant of crossing [although this ML safety distance was greater in the elderly (68.6 v. 31.4 cm)]. Additionally, both age-groups preserved a consistent AP distance before changing direction, and despite the elderly approaching significantly closer in the AP plane (elderly 2.41 v. young 3.86 m), when normalizing for approach velocity no age-group difference was seen in the AP time-to-contact (2.4 s) at which circumvention was initiated. Hackney & Cinelli (2013) suggested this as support for systematic maintenance of a personal space envelop. In another study illustrating how the ML clearance when circumventing is systematically preserved regardless of strategy, Vallis & McFadyen (2003) had young adults circumvent 5 trials to the right & left around a 2m high x 0.23 diameter obstacle placed 3m directly in front. As previously mentioned, Vallis & McFadyen (2003) observed two circumvent strategies across participants, namely, a lead-out strategy (i.e. execution limb away from obstacle, similar to a step-turn) used 48.3% of the time, and a lead-in strategy (execution limb close to obstacle similar to a spin-turn) used 51.7%. Despite the obstacle having a diameter of only 23 cm, the average total ML COM displacement from the start of the walk to the crossing was 50.70(5.91) cm, yet for unobstructed straight gait the average total ML COM displacement was just 7.11 (2.47) cm. Moreover, although the configuration of step-width change across footfalls upon approach to circumvent the obstacle differed between the lead-in v. lead-out maneuver, Vallis & McFadyen (2003) found the ML clearance of the COM from the obstacle at crossing was nonetheless similar [lead-in 47.26(7.64 cm) v. lead-out 48.32(5.69) cm].

In a related circumvention study showing a systematic change in BOS to maintain ML personal space, Gerin-Lajoie, Richards, & McFadyen (2005) had young subjects walk straight toward a table at the end of an 8 m path, and at the half-way point circumvent left of a mannequin that was either stationary directly ahead or in-motion crossing right-to-left at a 45^0 angle with the final location or stopping point of the mannequin (i.e. obstacle), whether stationary or in-motion, known in only half the trials. Gerin-Lajoie et al. (2005) found the obstacle clearance safety margin, measured as the minimum transverse distance spanning the left arm of both the participant & mannequin to be consistent at one-third step-length across all obstacle and certainty conditions. Moreover, Gerin-Lajoie et al. (2005) noted that regardless of the mannequin being stationary or in motion, when the final location or stopping point of the object was known in advance, participants ML deviated off the control no-obstacle straight path sooner (i.e. anticipatory initial path deviation starting about 4.5 m or 5-6 steps prior to crossing the obstacle), and relative to average step-width of no-obstacle control straight-gait, a trend was seen for earlier step-width widening resulting in less step-width change across the final approach stride where the greatest percentage of change was found.

The pattern of early step-width change when there was certainty about final location, was most notable for the stationary obstacle condition, where statistical widening was seen from the start (6 steps prior to crossing), causing the change in final approach (ultimate) step-width to be less for the known as opposed to unknown condition. Gerin-Lajoie et al. (2005) suggested priority of late planning cues for in-motion object regulatory conditions as a potential explanation as to why step-width modulation was sooner when the mannequin was stationary as opposed to in-motion, yet also entertained the possibility of earlier visual interference of not being able to see the table target when the mannequin was stationary as another potential explanation. It is worth noting Gerin-Lajoie, Richards, Fung & McFadyen (2008) reported young adults showed no change in both the shape and transverse cross-section area of personal space across preferred 1.44 m/s, slow 1.10 m/s & fast 1.79 m/s walking speeds which also suggested systematic preservation for a safety margin.

From a turn-related study involving continuous-repeated direction changes at one end of a room to the opposite end, there is indication some participants may use a strategy of systematically veering from one corner to another even in the absence of an obstacle. Taylor & Strike (2016) had young adults continuously walk back-and-forth 10 x across a 12m distance and perform a180^0 turns at each end-zone (which had a depth of 1.5 m and unconstrained width). As noted previously, qualitative video analysis revealed that one of the three approach strategies involved use of an elongated “figure-of-eight” pattern whereby the young adults approached the end-zone when turning rightward by subtly diagonally veering to the opposite left-corner; yet when turning leftward, subtly diagonally veering to the opposite right-corner of the end-zone. Although Taylor & Strike (2016) only discussed this subtle diagonal displacement upon approach within the context of the figure-of-eight pattern bringing about a reversal in the turn direction bias at each end-zone, such contra-lateral movement of the body upon approach (i.e. displacement towards the left corner when approaching to turn right) would undoubtedly help avoid swing-foot contact should a right-corner floor object be present when either stepping-out or crossing-over. Interestingly, although this “figure-of-eight” strategy was used less often than the other two strategies (pivot 44%, arc or lap 41%, elongated figure-of-eight 15%) it is worth noting the end-zones did not contain pylons or corner obstacles (i.e. red hazard cones). Nonetheless, it should be apparent that either lateral placement of a left penultimate footfall in anticipation of a right spin-turn (i.e. an increase or widening in the right H-H BOS) (*Figure 29*.) or medial placement of a right penultimate footfall in anticipation of a right step-turn (i.e. a decrease or narrowing in the left H-H BOS) (*Figure 28*.) would contribute to a systematic diagonal veering away from the right cone obstacle at the entrance to the turn zone (*Figure* 7.). While the amount of ML safety clearance at the shoulder level has been studied during circumvention (Hackney & Cinelli, 2013; Vallis

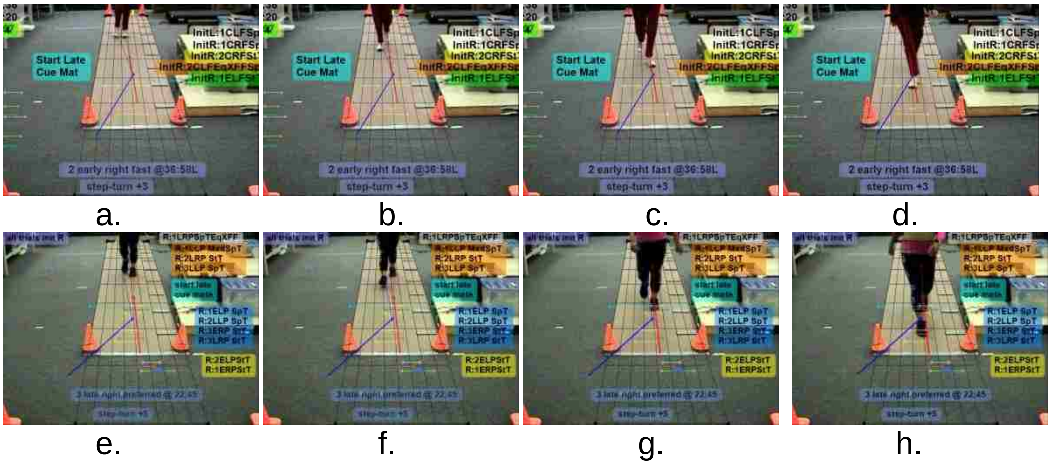
& McFadyen, 2003; Gerin-Lajoie et al., 2005; Gerin-Lajoie et al., 2008), and both the amount of lead limb horizontal placement relative to the front edge of an obstacle & vertical toe clearance have been studied for a step-over task (McFadyen & Price, 2002), the principal investigator of the present study is unaware of literature reporting on the ML safety margin for the turn-execution foot relative to a corner obstacle when turning. But perhaps just as pertinent, any systematic anticipatory displacement away from obstacles prior to circumventing (Hackney & Cinelli, 2013; Vallis & McFadyen, 2003; Gerin-Lajoie et al., 2005; Gerin-Lajoie et al., 2008) or diagonal veering away to the opposite corner when approaching a turn i.e. veering left when approaching a right-turn (Taylor & Strike, 2016), may in both cases suggest a benefit of including a forward progression of zigzag walking in gait training programs for turns. The inclusion of agility training in exercise-based fall prevention programs with the use of activities such as zigzag walking has been advocated by Donath, van Dieen, & Faude (2015).

Another plausible explanation within the assumption of the right H-H BOS widening being an anticipatory strategy in approach of spin-turns, and the left H-H BOS narrowing being anticipatory strategy in approach of step-turns is both represent use of a penultimate foot strategy to regulate COM acceleration. As previously described, according to Winter (1995), the ML acceleration of the COM is proportional to the difference in the ML point of location of the vertical projection of the COM onto the ground and the point location of the vertical ground reaction force vector known as the center of pressure (COP_{NET}). With regards to regulating COM acceleration through the COP located beneath the foot during gait, MacKinnon & Winter (1993), Winter (1995), and Pandy et al., (2009) have all suggested that swing-limb ML foot displacement at initiation of single-limb-support is a critical factor in controlling frontal plane total-body balance. Similar to the situation in relaxed stance with feet side-by-side pelvic width apart, Winter (1995) believed that for ML balance during straight gait, the invertors/evertors once again played a small role (in my view the ML equivalent of an “in-place” ankle strategy in the frontal plane), whereas the hip abductors / adductors were of primary importance from the standpoint of adjusting ML foot placement of the swing-limb (i.e. in my view the ML equivalent of a step strategy) to regulate COM acceleration through both the location of the COP and the subtalar joint frontal-plane gravitational moment-arm.

With this background information of the ML COM acceleration being proportional to the difference in the ML point of location of the vertical projection of the COM onto the ground and the point location of the vertical ground reaction force vector (COP_{NET}), several researchers have previously explained similar changes in ML placement of the penultimate footfall prior to turning from a biomechanical perspective (i.e. use of a foot strategy). With regards to lateral placement of the penultimate footfall, as already mentioned Paquette et al. (2008) reported an increase in step-width of the penultimate footfall relative to the preceding antepenultimate footfall in both young adults and seniors during early-cued 40^0 spin-turns (but not step-turns). Paquette et al., (2008) suggested use of an anticipatory foot strategy in the form of lateral placement of the penultimate footfall with its COP in approach of spin-turns facilitated COM acceleration into the new path direction to better preserve medial-lateral stability of the COM within the narrow BOS following limb cross-over. As for medial placement, Patla et al., (1999) noted step-width narrowing at the penultimate footfall in young adults during early-cued 60^0 step-turns (but obviously this was not available when late-cued upon penultimate foot contact), and suggested this anticipatory foot strategy may help minimize any COM acceleration opposite the desired direction change. Similarly, Paquette et al. (2008) reported a decrease in step-width from medial placement of the penultimate footfall relative to the preceding antepenultimate footfall in both young adults and seniors during early-cued 40^0 step-turns as opposed to spin-turns. Paquette et al. (2008) suggested that since BOS increases upon stepping-out with the turn-execution footfall, large changes in step width in order to better steer the COM trajectory when approaching step-turns are not necessary. Moreover, in agreement with the finding in the present study of a decrease in left H-H BOS when cued-late at preferred speed in both age-groups, Hollands et al. (2010) likewise noted step-width narrowing from medial placement of the penultimate footfall in the healthy middle-aged-to-elderly controls (mean 60.4 years, range 40-83) of a stroke-related study during “quasi” late-cued (upon ante-penultimate footfall contact) right & left 45^0 step-turns in which the limb initiating gait was controlled. Hollands et al. (2010) were in agreement with both Patla et al. (1999) and Paquette et al. (2008) in that a narrowing of step-width at the penultimate step minimizes COM acceleration contra-lateral to the turn direction. It should be noted that as Hollands et al. (2010) late-cued upon ante-penultimate contact, the late-cue in the present study was also delivered upon ante-penultimate foot contact but in only about 46% of the late right-turn trials, as the late-cued was otherwise delivered upon penultimate foot contact in the other 54% of the late-cue right-turn trials, with neither age-group nor speed changing these percentages much (see Appendix C). Hence, given the low percentage (i.e. only 46%) of late-cue trials were triggered by contact of the ante-penultimate FF with the late-cue-mat in the present study, it is surprising a left BOS narrowing strategy when cued-late at preferred-speed was even detected in the present study, especially given that only approximately 11% of late cue right-turn trials contained a “reactive” post-late-cue footfall (15% preferred, 7% fast with these percentages similar for both age-groups). Nonetheless, despite only 46% of late-cued right-turn trials were cued upon antepenultimate foot contact (40% young adults, 50% elderly), and the final recorded footfall corresponded to the penultimate footfall in 76% of trials (Appendix B), a reactive response was still found in the present study as early as the penultimate footfall.

This finding in both age-groups of the left H-H BOS being narrower when turning right as opposed to straight when cued early walking at fast speed, yet cued-late at preferred speed (*Figure* 25.) is the only significant three-way interaction and in my view is the single most intriguing finding of the present study. The Speed*Cue*Direction interaction likely reflects both a greater ML GRF (Orenduff et al., 2006) & centripetal force (Fino et al., 2015) requirement at fast speed, yet a reduced capacity to meet the GRF requirement when late-cued as opposed to early (a priori) i.e. smaller ML GRF peak amplitude & longer time to peak amplitude (Kim et al., 2014) and a likely shorter pivot limb stance phase (Rand & Ohtuski, 2000). However, regardless of speed or cue condition, this interaction found in the present study likely represents displacement of the penultimate footfall opposite or away from the intended turn direction, thus reducing the H-H BOS measure corresponding to the ante-penultimate footfall. Previous research has already identified displacement of the ultimate pivot footfall/COP away from the turn direction regardless of strategy when either cued-early walking fast (Fino et al., 2015; Houck et al., 2006) or cued-late at preferred speed (Hollands et al., 2001; Mak et al., 2008; Hase & Stein, 1999); and displacement of the penultimate footfall away from the turn direction (i.e. medial) during step-turns at preferred speed has already been reported when both early-cued (Patla et al.,1999; Paquette et al., 2008) and late-cued upon ante-penultimate foot contact (Hollands et al., 2010). However, regardless of age-group, the principal investigator of the present study is unaware of prior research within one study reporting the finding of medial placement of the penultimate footfall (i.e. BOS narrowing) in approach of a turn when cued-early walking fast but not when cued-early at preferred speed.

Continuing with the assumption for the present study that in both age-groups [as described above based upon the findings of Paquette et al., (2008)], right H-H BOS widening represents an anticipatory feedforward strategy when approaching spin-turns, while left H-H BOS narrowing represents an anticipatory feedforward strategy in approach of step-turns, and presuming such narrowing is the result of medial penultimate foot placement, could indicate the potential for frontal plane instability even prior to turning. Xu et al. (2004) has already reported early-cue anticipatory lateral body leaning into the direction change, most notably at a fast walking speed causing the COM trajectory to actually displace lateral to the COP trajectory of the right penultimate footfall when approaching right step-turns & lateral to the right ultimate footfall when approaching right spin-turns (in both cases aiding acceleration into the turn). As Xu et al. (2004) attributed the change in the COM to COP trajectory primarily to body leaning, yet did not report on the use of a ML foot strategy, the finding in the present study of narrowing in the left H-H BOS (*Figure* 30.) may possibly suggest the simultaneous use of a medial penultimate foot placement strategy may heighten the anticipatory frontal plane disequilibrium triggered upon approach of step-turns, which may be necessary when the task is constrained by a fast speed (Orenduff et al., 2006; Fino et al., 2015) or late-cue(Houck et al., 2006; Kim et al., 2014). [Note, anticipatory from a late-cue perspective given 46% of late-cues were delivered at the ante-penultimate footfall]. Given in the present study no age-related difference was seen with regards to the left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed, this may possibly suggest that the healthy elderly group -in whom no significant age-related decline in gait speed was apparent- were equally as tolerant as the young adults to the ML disequilibrium required to initiate turns. Moreover, this finding of no-age related difference in left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed might parallel the mixed-turn sub-group finding which though not considered significant, showed that when in a hurry with future direction unknown, healthy elderly at low-fall risk did 9 “extra-step” mixed-turns possibly hinting an issue with AP stability (Cao et al., 1997, 1998; Tirosh & Sparrow, 2005; Crenna et al., 2001), yet just 3 of the “small-amplitude” variety of mixed-turns again possibly hinting at tolerance to ML disequilibrium (Conradsson et al., 2017; Mak et al., 2008).



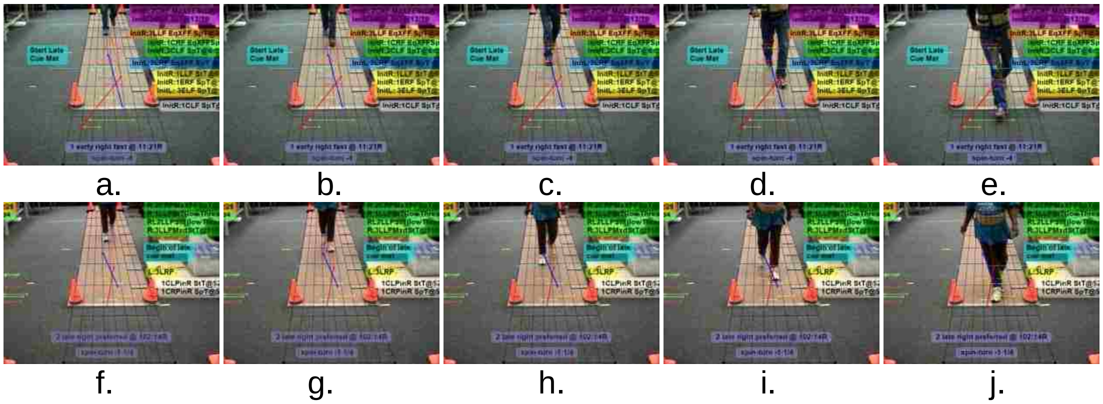
a. b. c. d.

e. f. g. h.

Figure 30. Photo image sequence showing the Direction*Speed*Cue interaction for left H-H BOS narrowing during right step-turns when both early-cued walking fast (a-d) and late-cued walking at preferred speed (e-h). Contribution to left H-H BOS narrowing from the use of a medial penultimate foot placement strategy can be appreciated in photo d. when early-cued at fast speed, and in photo h. when late-cued at preferred speed.

Somewhat related to the finding of the COM falling lateral to the COP of the ultimate pivot footfall during spin-turns (Taylor et al, 2005; Fino et al., 2015), especially at fast-speeds (Xu et al., 2004; Fino et al., 2015), Hase & Stein (1999) using video, electro-goniometer & EMG analyses, found that when late-cued and performing a 180^0 spin-turn (i.e. cued at the left penultimate heel-strike followed by a right ultimate foot pivot), young-to-middle-aged-adults activated the right biceps femoris to extend, externally rotate & medially displace the right swing-limb (i.e. eventual ultimate pivot foot) towards the midline. Hase & Stein (1999) were in agreement with Patla et al. (1999) in suggesting this late-cue medial pivot foot strategy reduced frontal plane COM displacement/acceleration opposite the right spin-turn direction, and if cued early enough, medial placement of the right penultimate footfall (i.e. left H-H BOS narrowing as reported in the present study) could facilitate regulation of COM acceleration in a like-manner during right step-turns. Although the present study was unable to record Gaitrite data for the ultimate pivot foot, video analysis in the present study was able to capture ultimate pivot foot placement, and appeared to support the observation of Hase & Stein (1999) for the use of a medial pivot foot placement strategy when late-cued in approach of spin-turns. Moreover, given Hase & Stein (1999) only tested participants walking at a preferred speed, video observation from the present study would appear to add the likelihood for use of a medial pivot foot strategy even when early-cued for spin-turns but constrained with a fast-hurried walking speed (*Figure* 31.). Additionally, the use of a medial ultimate pivot foot strategy appeared on video to be most robust when the spin-turn was constrained by the combination of a fast walking speed & late-cue (*Figure* 32.)

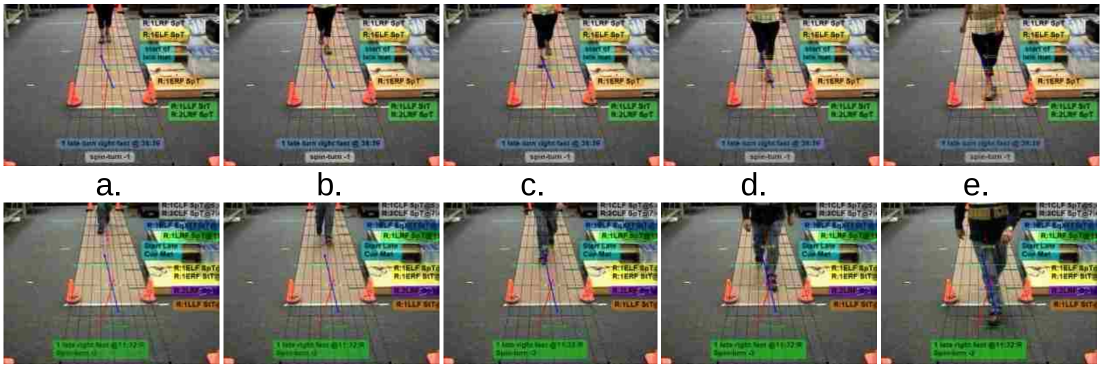
It is worth noting the methodology of the present study did not include the use of force plates, and the same can be said of Hase & Stein (1999). To this point, some studies have indicated the possibility of force plate targeting altering the vertical & AP GRFs during the initial loading phase of gait (Sanderson, Franks, & Elliott; 1993) or even alter the second peak of the hip joint contact force as measured with an instrumented prosthesis (Bergmann, Graichen, & Rohlmann,1993). Accordingly, the principal investigator of the present study would suggest that in previous studies which assessed changes in ML foot placement (or step-width, stride-width), use of a medial pivot foot strategy during spin-turns may have gone undetected either as a consequence of early-cuing at a preferred speed i.e. low-level of task difficulty (Xu et al., 2006; Taylor et al., 2005; Paquette et al., 2008) or force plate targeting in studies constrained with a fast-speed or/and late-cue (Xu et al., 2004; Mari et al., 2012; Kim et al., 2014).



a. b. c. d. e.

f. g. h. i. j.

Figure 31. Photo image sequence showing H-H BOS narrowing caused by medial ultimate pivot foot placement during approach of right spin-turns when both early-cued walking fast (a-e) and late-cued walking at preferred speed (f-j). Contribution to left H-H BOS narrowing from the use of a medial ultimate foot placement strategy can be appreciated in photo e. when early-cued walking fast, and photo j. when late-cued walking at preferred speed. Although the present study was unable to record Gaitrite data for the ultimate pivot foot and hence unable to measure BOS changes corresponding to the penultimate footfall, the narrowing is apparent on video.



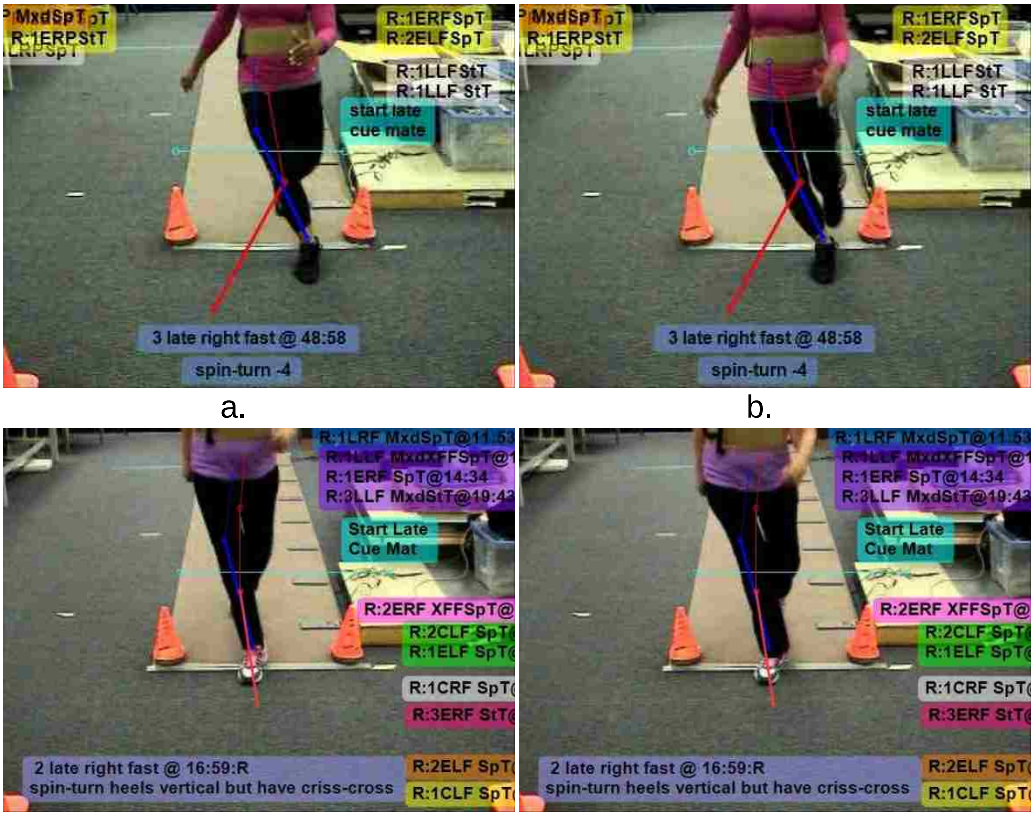
a. b. c. d. e.

f. g. h. i. j.

Figure 32. Photo image sequence showing H-H BOS narrowing caused by medial ultimate pivot foot placement in the present study appeared most robust during right spin-turns from the combination of a late-cued while walking fast here shown in an elderly female (a-e) and elderly male (f-j). Contribution to left H-H BOS narrowing from the use of a medial ultimate foot placement strategy can be appreciated in photo e. when early-cued walking fast, and photo j. when late-cued walking at preferred speed. Although the present study was unable to record Gaitrite data for the ultimate pivot foot and hence unable to measure BOS changes corresponding to the penultimate footfall, the narrowing is apparent on video.

Regardless of whether left H-H BOS narrowing is the consequence of a medial ultimate pivot foot strategy during right spin-turns as reported by Hase & Stein (1999) and captured on video in the present study, or the result of a medial penultimate pivot foot strategy when approaching right step-turns as reported by Patla et al., (1999), Paquette et al., (2008), & Hollands et al., (2010), and recorded by the Gaitrite in the present study, in both instances the left BOS narrowing has potential to increase the risk for instability & slips. Based upon the observation (when early-cued for 90^0 turns at a fast walking speed) of lateral body leaning into the turn during mid-stance causing the COM to track outside the COP of the right penultimate footfall when approaching right step-turns & outside the right ultimate footfall when approaching right spin-turns, Xu et al. (2004) suggested such lateral placement of the COM could commence ML disequilibrium as early as the penultimate footfall and pose a fall risk should other needed anticipatory postural adjustments be deficient (i.e. backward leaning to facilitate deceleration & control) yet Xu et al. did not report on the use of an anticipatory foot strategy. Moreover, Fino & Lockhart (2014) noted that during late-stance push-off when early-cued for 90^0 turns at fast speeds, the peak RCOF exceeded the minimum static COF recommendation set by OSHA. Given it had been previously shown that the COM displaced lateral to the BOS for a longer percentage of pivot limb stance (Taylor & Strike, 2005), Fino & Lockhart (2014) suggested a slip during push-off may present more of a fall-risk for spin-turns. Furthermore, similar to Xu et al.,(2004), Fino et al. (2015) likewise noted that the faster the speed the greater the body lean into the early-cued 90^0 turn; however, unlike Xu et al (2004) who only assessed mid-stance and reported the COM to be displaced beyond the COP at a fast speed, Fino et al (2015) found the COM tracked beyond the BOS (into the turn) regardless of speed or turn-strategy across the entire first-half of pivot stance although its trajectory was most lateral at the fast speed. Additionally, as the RCOF at loading for both turn-strategies surpassed the value needed for straight gait, Fino et al. (2015) suggested that given the COM fell outside the BOS irrespective of speed, a slip during loading while turning regardless of strategy, may have a greater chance of precipitating a fall than a slip during loading of straight gait.

In addition to late-cue or fast-speed left H-H BOS narrowing (whether from a medial penultimate foot strategy during step-turns or medial pivot foot strategy during spin-turns), when combined with trunk lean possibly contributing to the risk for slip-falls, such BOS narrowing may also increase the risk for tripping over one’s own feet. Cumming & Klineberg (1994) noted that 36% of elderly falls resulting in hip fractures and 46% of non- hip fracture falls were judged to be caused by tripping. Furthermore, Berg et al. (1997) reported that among elderly community-dwellers who had experienced a fall within the past year were asked to choose as many relevant causes for their fall (from a list of 16 potential reasons), while tripping over something (i.e. cord, curb) was tied for third/fourth place at 19%, the sixth most frequent reason cited was tripping-over-ones-own-feet / for-no-apparent-reason at 10%. The ML limb displacement inherent when turning would appear to only enhance any risk for tripping over one’s own feet. Indeed, as observed on video particularly when walking fast & cued-late for spin-turns, medial placement of the pivot foot at initial contact/loading at times went to such an extent as involving the ultimate pivot limb cross in front of the penultimate limb (*Figur*e 33.). As can be seen in both photo examples of fast*late-cue spin-turns shown in Figure 31, trunk roll does not appear aligned into the turn but instead in the opposite direction, possibly indicating pivot hip neuromuscular control was caught off guard (Houck et al., 2006). In such cases, the principal investigator of the present study suggests the intent of the medial ultimate pivot limb crossing may have had less to do with being anticipatory & proactive in accelerating the COM into the turn, but more to do with being reactive & defensive to first secure frontal plane balance (i.e. momentarily contain the COM and prevent it from displacing beyond the medial border of the right pivot foot). However, irrespective of the intent of the pivot limb-crossing, concern with regards to ML foot separation/clearance and the risk for tripping has already been described above during early-cued preferred-speed spin-turns (Taylor et al., 2005), and late-cued non-preferred direction (cross-over) stationary turns (Meinhart-Shibata et al, 2005). Moreover, Hollands et al. (2001) noted that when late-cued for 60^0 step-turns, the onset of medial-lateral displacement of the turn-execution limb into the direction-change was delayed 170 msec. after the initiation of toe-off indication the swing foot advanced forwards a distance before stepping-out. Obviously, use of a medial foot strategy either as a consequence of a fast speed or late-cue constraint during gait would only add to the concern for the risk of tripping over one’s own feet when turning. Additionally, should a medial foot strategy narrow the BOS when hurrying to approach a turn, and attention is being allocated to a secondary task (i.e. visual processing of an unpredictable open-movement task), the risk for tripping over one’s feet may be further compounded as foot clearance during an obstacle step-over task has been shown to be compromised when needing to process a late visual cue (Lo et al., 2015), and to a greater extent in the elderly (Chen et al., 1996).



a. b.

c. d.

*Figur*e 33. Photo sequence showing how in both young adults (a.-b.) and the elderly (c.-d.) when late-cued and performing a fast-speed right spin-turn, medial placement of the right ultimate pivot limb at initial contact/loading on occasion crossed in front of the left penultimate limb. The challenge this poses for ML foot separation/clearance as the left swing-limb needs to advance forward to execute the right spin-turn is apparent.

While the discussion thus far on left BOS narrowing from medial placement of the penultimate footfall has mainly focused on minimizing COM acceleration contra-lateral to the step-turn direction, it is worth speculating whether such a foot strategy which changes limb orientation may serve another function as well, such as enhancing efficiency by altering the contribution of various muscles within the penultimate limb to the total ML COM acceleration. Ventura, Klute, & Nepturn (2015) had middle aged adults perform preferred speed steady-state turning around a 1m radius circular path, and using musculoskeletal models and forward dynamic simulation, computed the contributions of various inner & outer lower-limb muscles to ML COM acceleration impulses. Ventura et al. (2015) noted that relative to straight gait, when comparing muscle contributions to the net ML COM acceleration impulse during circular path walking, although significant changes were seen in both the inner & outer limbs, during single limb-support the inner-limb experienced greater change in muscle contributions than the outer-limb. When reviewing the particular muscle contribution changes in each limb, Ventura et al. (2015) reported that for outer limb, relative to straight walking, reduced lateral impulse contributions opposite the turn direction were seen in stance for both the soleus and med/lat gastroc; whereas for the inner-limb, reduced medial impulse contributions opposite the turn direction were seen in stance for the gluteus medius and swing for the hip adductors, yet increased lateral impulse contribution into the turn direction was seen in stance for the med/lat gastroc. Pandy, Lin & Kim (2010) had previously reported that for straight gait, muscles known for AP progression & vertical support also make significant contributions to ML COM acceleration. In particular, Pandy et al., (2010) found the stance-limb vastus medialis, soleus, medial gastroc, plantarflexor-evertors, & iliopsoas assisted the hip adductors to accelerate the COM away from midline (laterally), whereas the stance-limb plantarflexor-invertors assisted the gluteus medius to accelerate the COM into the midline (medially). In agreement with Pandy et al. (2010), Ventura, Klute, & Nepturn (2015) found the stance gluteus medius to be the main contributor to the medial COM acceleration impulse, with a smaller contribution coming from the swing hip adductors; whereas the stance iliopsoas, gastroc, soleus and hip adductors all made some contribution to the lateral COM acceleration impulse. Interestingly, Ventura et al. (2015) found that in some instances the muscle contributions to the ML COM acceleration impulse during circular path turning were augmented (relative to straight gait) by adopting a different limb orientation rather than a change in force production. Ventura et al. (2015) suggested that shifting the impulse generation burden to the most appropriate muscles may bring about efficient COM displacement, and that the inner-limb may play a more important role during circular-path walking.

The efficiency benefit of reducing muscle contributions which accelerate the COM opposite the turn direction has also been demonstrated during early-cued spin-turns in children, and may be the primary strategy employed at the penultimate footfall. Dixon, Jansen, Jonkers, Stebbins, Theologis & Zavatsky (2015) performed simulation using muscle actuated dynamic models to compute changes in the contribution of muscles to the ML COM acceleration in typically developing children across both the ultimate (inner) &

penultimate (outer) limbs of early-cued (preplanned) 90^0 spin-turns. In agreement with both Pandy et al. (2010) & Ventura et al. (2015), Dixon et al. (2015) also noted opposing medial v. lateral COM acceleration contributions of the hip abductors v. ankle plantarflexors, respectively. Accordingly, Dixon et al. (2015) found that relative to straight gait, for ultimate-pivot-(inner) limb stance the contribution of the med gastroc & soleus to lateral acceleration into the spin-turn was greater, while the contribution of the gluteus medius/minimus to medial acceleration away from the spin-turn was smaller; whereas for penultimate (outer)-limb stance, the contribution of the med gastroc & soleus to lateral acceleration opposite the spin-turn was smaller, but no difference was seen in the contribution of the gluteus medius/minimus to medial acceleration into the spin-turn. Dixon et al. (2015) suggested that for the sake of efficiency, initiation of ML COM acceleration into the turn direction upon approach of the penultimate limb may involve a decrease in muscle contribution accelerating away from the turn, rather than an increase in muscle contribution accelerating into the turn.

Finally, similar to the reason cited for the small number of age-related differences, equipment/instrumentation limitations may have contributed to the relative shortage of late-cue H-H BOS changes given the last 55 cm of the Gaitrite carpet lacked sensors. In particular, although the final recorded footfall corresponded to the penultimate foot in 76% of trials (24% corresponded to the ante-penultimate foot) (Appendix B), the late-cue was delivered upon ante-penultimate foot contact in only 46% of the late-cue right-turn trials (54% of late right-turn trials delivered upon penultimate foot contact) (Appendix C). Hence, from this combination, very few post-late cue footfalls were recorded on the Gaitrite, especially for right-turns and at fast-speed [1 post-late cue FF: right-turns 11% (15% preferred, 7% fast) & straight walks 22% (preferred 32%, fast 12%). Accordingly, in the majority of the 240 late-cue trials (84% when collapsing for speed & direction), all 4 recorded footfalls were taken when direction was still unknown, and post-late-cue "reactive" feed-back gait changes & strategies were for the most part not recorded. On the other-hand, when cued-early, all 4 recorded footfalls were pre-planned and placed with direction already known, and as such anticipatory "proactive" feed-forward H-H BOS changes & strategies were more easily captured.

Discussion of slowed to a greater extent when cued late walking fast; stride-length shorter when cued-late

These findings in the present study of both a greater reduction in speed when cued-late walking fast and a shorter-stride when cued-late likely represent the effects of either dual-task cost related to visual processing of the late-cue signal, or a biomechanical strategy to "buy" more time to respond to the late-cue.

With regards to dual-task cost, the gait parameters of both speed and stride-length (step-length) may be most vulnerable to competition for attentional resources. Simoni et al. (2013) noted that during dual-task (skipping over letters of the alphabet) walking on the GaitRite, significant decreases were seen bilaterally in both speed [1.3(.03) v 1.0(.05) m/s] & stride-length [137L3.1) v. 128(3.1)] (as well as a decrease in cadence and increase in DLST). Hollands et al. (2014) reported that relative to the single-task turning condition, during a dual-90^0 turning-task involving serial 3's subtracting, the turn execution stride time took longer (2.2 v. 1.92 s). In a systematic review and meta-analysis of preferred speed ground walking studies involving a secondary cognitive (rather than secondary motor task), Al-Yahya et al. (2011) reported that dual-tasking has been shown to result in decreases in speed, stride length, & cadence, and an increase in stride-time. Al-Yahya et al. (2011) noted that when considering the various classifications of cognitive/executive-function dual-tasks [i.e. reaction-time tasks (stimulus-behavior); discrimination-tasks (decision-making); verbal-fluency-tasks (spontaneous word production as-per criteria); working-memory-tasks (holding information); &mental-tracking-tasks (holding information with processing/manipulation)], a reduction in speed appears to be robust for most types of dual-tasks. Although comparisons were not available for all cognitive-task match-ups and evidence is still incomplete, Al-Yahya et al. (2011) suggested that at this point, gait performance appears to be affected to a greater extent from tasks utilizing internal interference (mental tracking, verbal fluency) as such tasks may partake of the same complex neural circuitry; as opposed to tasks incorporating external interference (i.e. reaction-time tasks) in which there may be rationing of more lower-order “stimulus-driven” circuitry. Moreover, Al-Yahya et al. (2011) reported that research (especially as it related to a mental-tracking task) suggests greater differences for both speed & stride length (most notably for speed) as opposed to cadence when comparing controls v. neurological patient-groups. Al-Yahya et al. (2011) added that based upon this observation, it is believed speed & stride-length are likely controlled by higher centers (pre-frontal cortex & basal ganglia), whereas cadence may be regulated more at the brainstem & spinal level. With regards to age-related differences in healthy adults, Al-Yahya et al. (2011) reported that although cognitive-motor interference overall appears to affect gait in the elderly more so than young adults, actual support for an age-related difference (as well as association with the MMSE cognitive function score) is most robust for the dependent variable gait speed when the dual-task requires mental-tracking (holding with processing information), yet meta-regression shows no relationship between attention-related gait changes and tasks requiring verbal fluency. Finally, although the principal investigator acknowledges the present study did not incorporate in its methodology a traditional dual-task paradigm to evaluate attentional costs as it relates to gait performance, it is worth noting Al-Yahya et al. (2011) has advised that the dual-tasks often used are not practical and have limited application to everyday life-situations (i.e. lack external validity).

As already discussed in reference to the reduced preference for step-turns & spin-turns relative to mixed-turns when late-cued as opposed to early, the negative cost on limb clearance during obstacle-crossing from a late secondary visual-spatial attention task has been reported; and while acknowledging a "traditional" dual-task-paradigm was not employed in the methodology of the present study, it would not be unreasonable to speculate that visual attention directed to the late-cue signal light may have contributed to a reduction in speed & stride-length. Chen et al., (1996) noted that when crossing a virtual obstacle displayed one-step prior and synchronized simultaneously with the late appearance of a secondary attention-dividing visual-verbal reaction task [requiring subjects say "ah" immediately upon seeing the red lights lit in an LED display mounted on a 12 cm circular panel centrally placed 0.5 m beyond the end of the walking path], obstacle avoidance success rates significantly decreased in both age-groups although the decrease was more in the elderly [reduction in dual-task obstacle avoidance success rate relative to single-task performance: young 14.7% v. elderly 32.0%]. Additionally, Lo et al., (2015) found that when young adults were asked to verbally identify the direction of opening in the letter "C" shown 2-3 steps-ahead, when projected on the floor one-step before the obstacle, the amount of trail-limb toe-obstacle clearance decreased, and when projected one-step after the obstacle only a trend was seen for a reduction in toe-clearance for both limbs. Lo et al., (2015) suggested the decrease trial-limb toe-clearance when engaging in the secondary visual-task prior to obstacle crossing suggests visual-spatial-attentional resources were likely being expended in planning the primary step-over task; yet the finding of only a trend for a decrease in clearance in either limb when the image was placed after the crossing may suggest the required visual information had already been gathered by the young subjects.

Supporting the finding of Lo et al. (2015) that a decrease in toe-obstacle clearance was evident only when the secondary visual task was shown prior to but not after crossing, gait adaptations afforded by feedforward visual-motor control have been shown to be pre-planned at least 2 steps in advance. Patla & Vickers (2003) reported that when negotiating across a 10m environment containing 17 footprint targets posing no threats to stability or tripping, young adults required a minimum time of 2 steps in order to extract information regarding target location in relation to current body & limb position, and then calculate needed adjustments in step-length & width so as to engage in anticipatory-feedforward visual-motor control of accurate foot placement. Interestingly, Patla & Vickers (2003) also found the number of steps-ahead that participants gazed upon did not differ based upon the trial number, possibly suggesting both the absence of a learning-effect or mental mapping, as visual information acquired in one trial did not carry-over to guide gait changes in subsequent trials. Moreover, there is also suggestion that when a cue to verbally respond is delivered two-steps (one-stride) prior to crossing (in present study the late-cue was delivered 2 footfalls prior 56% of trials, and three-steps prior 46% of trials), the need for both online visual motor-control & attentional resources may increase at the crossing even in young adults. Brown et al. (2005) had young & elderly participants step-over a 60 cm wide x 22.5 cm high x 15 cm deep foam block while walking at preferred speed, and engage in a secondary dual-task requiring a verbal response to the sound of a buzzer delivered either during crossing or the stride before (pre-crossing) by saying the word “top” as rapidly as possible. Brown et al., (2005) noted that relative to unobstructed gait, whereas young adults had longer reaction time scores for the verbal response task only when cued at pre-crossing, reaction times in the elderly were longer during when cued both at pre-crossing & crossing. Brown et al., (2005) proposed that whereas young adults primarily relied upon pre-planned gait adaptations in using anticipatory feed-forward visual-motor-control at the crossing, the elderly being more conservative about obstacle contact may have in addition employed online visual-motor control. Additionally, with awareness of the two-step minimum time requirement proposed by Patla & Vickers (2003) for feedforward visual-motor control, Brown et al., (2005) suggested advanced awareness of an obstacle’s location permits pre-planning during approach for gait adaptations subsequently used at crossing; however, an unexpected step-over task (i.e. a late-cue) would likely impose greater dual-task cost during the crossing phase. Thus, based upon the collective findings of Chen et al. (1996), Lo et al. (2015), Patla & Vickers (2003) and Brown et al., (2005), the principal investigator of the present study would suggest that from the perspective of attention allocation needed for visual processing of an open-motor-task (i.e. an unpredictable or unexpected late-cue direction change), although not the classic dual-task paradigm, may nonetheless have more practical application when considering the costs to gait performance.

Interestingly, although Lo et al. (2015) reported a decrease in toe-obstacle clearance when the secondary visuo-spatial attention task was shown one-stride prior to crossing, unlike the present study, Lo et al. (2015) reported no decrease in gait speed when approaching the crossing irrespective of whether the image was projected on the floor before or after the obstacle [mean gait velocities when approaching: single-task obstacle-only 1.28(.07), dual-task image before obstacle 1.32 (.14), dual-task image after obstacle 1.29 (.07)]. However, the finding of Lo et al. (2015) of no dual-task cost on gait-speed may be methodological in nature, as relative to the present study, the secondary visual task of Lo et al., (2015) was in closer proximity (i.e. adjacent) to the center of visual fixation needed to safely execute the primary motor task of linear obstacle-crossing. Accordingly, the secondary visual task used by Lo et al., (2015) may have served as a visual target and heightened attention to relevant task features in the vicinity of the crossing environment (Peper, Oorthuizen & Roerdink, 2012). In contrast to Lo et al. (2015) projecting the visual image on the ground either one step before or after the obstacle for a linear step-over task, the present study not only placed the direction signal board eye-level at the far end of the straight path some 305 cm beyond the Gaitrite's edge (i.e. start of the turn-zone), but the right/left turn paths were both 90^0 eccentric to the heading direction at the instant of the late-cue. The more eccentric location of the direction board with its signal lights in the AP plan (and possibly even more so in ML plane as will be shortly discussed) is not a trivial matter. Patla et al. (1999) reported an early-cue axial orientation sequence which was initiated with head yaw; however, when cued-late, trunk roll preceded head yaw which differed with Hollands, Sorensen & Patla (2001). Hollands et al., (2001) attributed the discrepancy in late-cue head yaw onset to experimental protocol as the visual direction-cue lights used by Patla et al. (1999) to signal right-turn magnitude were placed eye level at the end of the straight walking path, whereas Hollands et al., (2001) positioned the path cue lights on the floor at the end of each designated travel direction. Accordingly, when cued-late, the participants in the study by Patla et al. (1999) likely had to visually attend and prolong gaze on a forward travel path in order to ascertain the direction of their destination; and accordingly may have had little time to process the indirect information of the cue to re-orient both vision (gaze) & head yaw. Hence, differences in placement of the late-cue visual information, relative to the location of where the motor task actually needs to take place, may explain why the present study found late-cue slowing upon approach whereas Lo et al. (2015) did not.

Lending support for the potential of greater attention allocation when needing to process eccentric visual information, it is worth considering the multiple-resource model to predict DTC. In particular, with regards to competition for dichotomous visual resources, the fourth dimension of the multiple resource model as proposed by Wickens (2002, 2008) allows for time-sharing between a focal-foveal-vision task (i.e. object/text/symbol recognition conveyed via the ventral visual pathways) and an ambient-peripheral-vision task (i.e. perceiving orientation & displacement when targeting a direction during gait as conveyed via the dorsal visual pathways); however, time-sharing is not possible for two focal vision tasks (Wickens, 2002). Hence, as will be discussed in further detail but was just briefly introduced with regards to the eccentric placement of the direction board signal lights relative to turn path of the present study, the capacity to time-share foveal & peripheral vision presents a greater challenge as the two visual information sources needed to perform both tasks become more spatially separated.

Based upon a reach/grasp task to forward adjacent targets within an arm's length distance, Goodale, Westwood & Milner (2004) likewise have advanced a distinction between two visual processing mechanisms, namely, vision for perception & vision for action. Goodale et al. (2004) proposed vision for perception allowed for object identification; was mediated by the ventral stream comprised of projections originating in the primary visual cortex which then spread to regions of the inferior temporal cortex; utilized an allocentric scene-based frame of reference for relative computation of target metrics and was thus subject to size contrast illusions; automatically generated a perceptual representation of the target once seen, even though a response may not be cued, which is then stored in memory with minor decay (lasting minutes or possibly much longer) although information from the retina is not computed into motor coordinates at this early time; and is responsible for visual memory of target characteristics to allow later cognitive operations & encoding to support feed forward off-line control of delayed movements should the same target no longer be visible when the response is finally cued (yet how & where the memory representation is encoded to affect the motor plan is unknown). In contrast, Goodale et al. (2004) proposed vision for action governed programming & control for visually guided motor tasks; was mediated by the dorsal stream comprised of projections originating in the primary visual cortex which then spread to regions of the posterior parietal cortex; utilized an egocentric frame of reference for absolute computation of target metrics and thus immune to size contrast illusions (for reaching the egocentric reference was considered to be the effector or hand); computed movement control parameters at the cue to respond immediately before initiation of movement (on-line) without memory storage, and as such egocentric referenced target coordinates decay rapidly (last under 2 s) once the target is no longer visible (understandably so given static egocentric-referenced target coordinates are an oddity and instead are often unpredictable); engaged in programming for visual-motor control only during real-time but not before, and only if the target is visible at the instant the movement is to be made. [It is worth noting here that in contrasting the terms planning and programming, Goodale et al. (2004) suggested action planning is mainly a perceptual ventral stream mechanism initiated once an object goal is perceived, whereas action programming is a visuo-motor dorsal stream mechanism occurring just prior to movement onset and requiring immediate on-line transformation of direct retinal target information into a metrically precise motor program. Despite the distinction between visual planning v. programming, Goodale et al., (2004 considered both to be feed forward modes of visual-motor control. Interestingly, with regards to the influence of one pathway on the other, in studying a linear forward arm-reach grasping task, Goodale et al. (2004) noted that it remains unclear whether the off-line & on-line visual mechanisms compete for any similar dorsal pathways when it comes to how the off-line perceptual-based memory representation ultimately impacts the motor plan].

In applying the concept of vision for perception v. vision for action mechanisms (Goodale et al., 2008) to the present study, against the backdrop of dichotomous time-sharing of attentional resources for focal & ambient vision (Wickens 2003, 2008), given the use of ventral pathway vision appears likely needed for recognition of the late-direction signal, whereas dorsal pathway vision would appear capable of providing adequate on-line peripheral visual-motor control to turn at the cue, the likelihood for dual-task cost in the present study appears low on the surface. However, when contrasting the methodology/task enviroment of the present study with that of Goodale et al., (2008) in which there was minimal spatial separation between the information coming from both the hand-effector and the forward adjacent target arrays, when late-cued in the present study the two visual information sources (cue light v. potential new travel paths) were spatially-separated i.e. the direction-cue information was presented eye-level on the signal board at the end of the straight path 425 cm beyond the start of the late-cue mat, 114 cm above the base of the red hazard floor cones marking the turn zone entrance, and perpendicular to the right/left 90^0 travel paths when needing to change direction (*Figure* 8.). Hence, there is reason to speculate the greater visual-spatial eccentricity of the present study (relative to the forward reaching task of Goodale et al., 2008) may have been more inclined to reduce time-sharing of attentional resources between concurrent ambient & focal vision tasks, and possibly increase the need for eye scanning, particularly when faced with the uncertainty of a late-cue and the prospect of needing to turn 90^0.

To this point, the capacity to time-share focal and ambient vision during dual-tasking has been shown to diminish as the vertical and horizontal distance between the two visual sources of information increases. Horrey &

Wickens (2004) used a driver-simulator to compare performance of participants engaged in a primary task of vehicle-control requiring ambient-vision (lane & speed maintenance) while simultaneously performing one of two conditions of a secondary in-vehicle-technology task (IVT) of voice-dialing requiring focal vision to read-off digits from either an adjacent head-up display condition (7^0 below the horizon above the hood but directly in front of driver) v. a wide-separation head-down display condition (38^0 below the horizon and 34 cm to the right of the driver). Horrey & Wickens (2004) found that with regards to vehicle control, relative to the single-task of no IVT, dual-task cost were noted for lane position (absolute lane deviation) & speed maintenance for both display conditions when performing the secondary IVT; however, while no obvious difference in vehicle control performance was seen between the two display conditions, greater variability in lane keeping was nonetheless observed in the eccentric head-down display (relative to the adjacent head-up display). Horrey & Wickens (2004) suggested that while drivers were able to use ambient vision for vehicle control while concurrently performing the focal vision IVT regardless of display condition, the greater variability for the eccentric head-down display (as opposed to adjacent head-up display) indicated the capacity to use ambient vision became less as a consequence of the wider spatial-separation. Horrey & Wickens (2004) suggested that besides using peripheral vision for lane-keeping, drivers likely engaged in visual scanning (i.e. saccadic eye movements) for the eccentric condition in switching attention between the road and display as a consequence of the wider separation. Furthermore, in addition to measuring vehicle control while performing the secondary IVT task, Horrey & Wickens (2004) also assessed response time to random critical-hazards requiring focal-vision (i.e. response time when maneuvering to avoid obstacles randomly appearing 0.75 s following onset of the IVT task). Thus, relative to the control single-task of responding without concurrent performance of the secondary IVT task, while no statistical difference in response time was seen for the adjacent head-up condition, dual-task slowing of response-time was observed for the eccentric head-down display condition (response time: control single-task without IVT 1.42, adjacent head-up display condition 1.50, eccentric head-down display condition 1.68 s; note, the hazard to avoid did not appear until 0.75 s after onset of the IVT digit string display). Hence, unlike vehicle control which used concurrent ambient vision and resulted in similar DTC for both the adjacent & eccentric IVT displays (i.e. similar vehicle control performance declines for absolute lane-deviations & speed) yet greater lane-position variability for the eccentric IVT display, given the random hazard detection primary-task competed for the same focal vision channel resources as the secondary IVT task, Horrey & Wickens (2004) now found degradation in performance of the eccentric spatially-wider condition was much more obvious, as compensation with ambient vision was of no avail. [Interestingly, from the standpoint of the secondary task, Horrey & Wickens (2004) also reported a spatially precipitated degradation in performance of IVT voice-dialing (necessitating focal/foveal vision in order to read-off digits from the display). As such, although the onset time latency of the secondary IVT verbal response task (relative to the showing of the digit string on the display) was prolonged during simulated driving regardless of display condition, the onset latency was again longer for the eccentric head-down as opposed to adjacent head-up display (onset latency of IVT voice dialing: control no driving task 0.8, driving with adjacent head-up display 1.1, driving with eccentric head-down display 1.2 s)]. Thus, while the findings of Horrey & Wickens (2004) indicates the effect of spatial eccentricity on DTC is obviously more apparent when there is time-sharing between two focal vision tasks (i.e. random hazard detection & IVT), spatial eccentricity nonetheless appears capable of even impacting performance when one of the tasks permits the use of ambient vision (i.e. greater lane-position variability for the head-down eccentric IVT display relative to the adjacent head-up display).

In applying the concept of spatial separation/eccentricity potentially disrupting time-sharing of attentional resources for focal & ambient vision (Horrey & Wickens, 2004) to a turning task, while there is some indirect indication that the greater the spatial-separation (i.e. the larger the turn angle) the longer the onset latency for re-directing vision to the new travel path, the necessity to visually gaze upon locations eccentric to the current heading has been called into question regardless of cue-time constraint. Hollands, Patla &

Vickers (2002) used an eye-tracker-helmet & video camera to assess both the location of visual gaze fixations & head orientation (sampling at 30 Hz) in young adults who received early v. late cuing (1 step prior upon penultimate foot contact) to randomly perform straight v. right/left 30^0 & 60^0 step-turns at preferred speed. In this particular study, a separate visual cue-light, used for both early & late cuing, was positioned on the floor at the end of each destination path/lane. Hollands et al. (2002) found that when late-cued, while no statistical difference was seen in onset latency (relative to penultimate foot contact which triggered the late-cue) between initiation of saccadic eye movement v. initiation of head movement towards the path cue-light (onset latency relative to late-cue: eye saccadic 326 v. head-orientation 349 ms), the onset-latencies increased with turn angle (collapsing for body part: 263 ms @ 30^0 v. 407 ms @ 60^0). Although not discussed by Hollands et al. (2002), the prolonged onset latency at the wider turn angle may suggest a delayed response as a consequence of greater spatial separation between information sources (i.e. separation between the straight current heading and new direction path). A delay in onset of saccadic eye movement to a target as a consequence of greater spatial separation between travel paths may be particularly relevant for the elderly. Chapman & Hollands (2006) have previously shown that during straight gait, older adults scan to an upcoming foot target sooner than young adults (duration between saccadic eye movement to an upcoming step target prior to preceding toe-off: elderly 1.33 s

v. young 450 ms) suggesting both feedforward visual-motor control based upon target location, and greater time needed by the elderly to both sample & transform target information into a motor response. Not surprisingly, when early-cued, Hollands et al. (2002) found that the onset of both saccadic eye & head movement towards the path cue-light preceded penultimate foot contact by approximated -50 ms (onset latency relative to penultimate foot contact at start of the turn-execution stride: eye saccadic -40 v. head-orientation -50 ms); and although the onset-latency increased with turn angle (collapsing for body part: -145 ms @ 30^0 v. 55 ms @ 60^0), the increase was significant only for the saccadic eye-movement (i.e. when early-cued the greater spatial separation only affected response time for visual scanning not head reorientation). Interestingly, Hollands et al. (2002) reported that, regardless of early v. late cuing, these young participants spent a longer percentage of the total duration of gaze fixated on environmental features falling within the current heading i.e. plane of progression (as opposed to fixated on environmental features residing eccentric to the current heading) both before & after the cue (or start of the turn-execution stride in the case of the early-cue condition) [before the cue: early-cue 67% current-heading v. 33% eccentric to current-heading, late-cue 78.8% current-heading v. 21.2% eccentric to current-heading]; after the cue: early 91.9% current-heading v. 8.1% eccentric to current-heading, late 89.5% current-heading v. 10.5% eccentric to current-heading]. Given that when direction was known in advance, participants fixated on the new upcoming path for less than 1/3 of the total time prior to the turn-execution stride, Hollands et al. (2002) suggested visual information required for a direction change was most relevant immediately prior to the movement i.e. penultimate foot contact. However, when interpreting & critiquing this finding of Hollands et al. (2002) suggesting that when approaching turns the percentage of the total gaze duration directed at locations eccentric to the current heading when late & early-cued is relatively small at 21 & 33%, respectively, the environment in which the participants were required to turn must be considered. In particular, Hollands et al (2002) required participants turn at a maximum angle of just 60^0 in a non-cluttered environment with all travel paths defined by tape markings placed on the floor yet free of physical objects. Patla & Vickers (2003) have suggested that during locomotion gaze fixation is more likely to be actively directed to target locations in the terrain which threaten stability. In contrast to the object-free turn environment used by Hollands et al. (2002), in the present study, four red hazard floor cones physically & spatially defined the 90^0 turn-zone (*Figure* 8.) located immediately beyond the Gaitrite's edge (i.e. a rear & front row of cones spaced a depth of 95 cm apart, with the two cones in the rear-row spaced a width of 155 cm apart, and the two cones in the front-row spaced a width of 75 cm apart). The floor cones of the present study may have aroused concern for tripping and been looked-upon as clutter and threats to stability (not to mention the final Gaitrite sensor pad which further constrained the turn-zone entrance). Thus, given focal-vision is non-shareable (Wickens, 2002), and in light of the presence of physical objects (i.e. the red hazard floor cones) strewn around the periphery of the 90^0 cross-road in the present study, in contrast to Hollands et al. (2002), at the instant of the late-cue or possibly even sooner & intermittently during the approach phase, participants in the present study may have had a greater need to actively direct the location of focal vision & attentional resources from the current heading (i.e. direction signal board) to potentially threatening eccentric features of the terrain (i.e. red hazard floor cones bordering the turn-zone) possibly needing avoidance if suddenly late-cued for a 90^0 direction change (or intermittently actively switching focal vision to and fro potentially threatening eccentric features of the terrain v. the current heading if scanning upon turn approach). It is for this reason of the potential tripping threat posed by the red hazard floor cones bordering the turn-zone that the principal investigator of the present study believes it is worth speculating on the potential for spatial eccentricity (between the late-cue and travel path environments) to hamper time-sharing of attentional resources between focal & ambient vision and possibly contribute to DTC on gait (i.e. greater slowing & stride shortening when cued-late).

Another obvious and essential point to consider besides the location of gaze fixation when interpreting any potential for spatial eccentricity of visual information sources on the DTC of gait is the frequency at which saccadic eye movements occur when approaching turns. To the point it is worth noting that Hollands et al. (2002) sampled gaze at a relative low frequency of just 30 Hz. Acknowledging the challenge of determining when a gaze fixation is initiated and terminated, Stuart et al. (2017) have recommended a sampling frequency of > 200 Hz. The sampling of gaze at just 30 Hz could in-part explain why Hollands et al. (2002) did not report on the frequency of saccadic eye movements across early v. late cues to turn. Nonetheless, as will be discussed shortly, there is suggestion in the literature that relative to straight gait, when direction is known in advance (i.e. early-cued), the frequency of visual sampling (i.e. saccadic eye movements) increases upon approach of turns (Patla et al., 1996; Galna et al., 2012; Stuart et al., 2017), and this greater sampling may incur greater visual-data processing costs to slow gait (Gerin et al, 2005; 2006).

Although the principal investigator of the present study is unaware of studies assessing the frequency of visual sampling when late-cued to turn, literature with regards to unanticipated obstacle crossing appears to suggest the use of ambient vision suffices and no increase in sampling is needed, yet the linear nature of such a forward step-over task may not resemble the sampling behavior when late-cued to turn. Marigold, Weedesteyn, Patla, & Duysens (2007) used a video based eye tracker (vertically sampling at 120 Hz) and unexpectedly released an obstacle (40 x 30 x 1.5 cm) in front of either the left v. right lower extremity of young adult females across available response times of one step or less (219-462 ms) while walking on a treadmill and either gazing centrally to the location where the obstacles were held by an electromagnetic bridge prior to release (i.e. foveal/central vision), or gazing in front of the treadmill at a floor target two steps ahead of the location of object release (i.e. ambient/peripheral vision). Marigold et al (2007) reported similar success rates regardless of whether participants used central v. peripheral vision (failure rate: peripheral 2.9 v. central 2.1%). Moreover, for the peripheral vision condition, saccades were seen in only about 18% of the trials (left release only 16.2%; left or right relase19.8%), and when present the fixation point was the future landing spot of the foot beyond the obstacle. [Additionally, the angle of downward eye rotation averaged 20.5^0, its onset latency following obstacle release averaged 500 ms, and 83% of saccadic movements were accompanied by almost simultaneous downward head pitch of about 5.1^0. Interestingly, the onset of the ipsilateral biceps femoris preceded that of saccadic eye movement by about 350 ms]. Marigold et al. (2007) proposed that, given the low percentage of trials using saccades for the unexpected step-over task, a shift in central vision was not consistently needed as foot trajectory during crossing was safely controlled using peripheral vision. Marigold et al. (2007) advanced that rather than overtly moving the eyes to redirect attention, participants may have covertly directed attention towards the obstacle in the peripheral field. As the failure rate increased during the peripheral vision trials when the lower visual field was covered, and participants instead had to rely upon the sound of the obstacle’s landing (failure rate 26.8%), Marigold et al. (2007) suggested the lower visual field played a key role in hazard detection. Although it was concluded saccades did not increase for an unexpected (linear) step-over task, Marigold et al. (2007) nonetheless cautioned that environments or foot placement areas that are more complex or challenging may precipitate a greater frequency of visual scanning. Since turning involves lateral COM displacement, this finding of Marigold et al. (2007) of no increase is visual scanning when unexpectedly crossing an obstacle may not apply to non-linear movements.

While it may be unknown at this time whether or not a late-cue to turn incurs greater visual sampling of the environment and mental processing costs, the literature does appear to suggest that sampling transition regions (i.e. a turn zone) is helpful to integrating a larger global-spatial map should a rapid path change be necessary within the same trial. Marigold & Patla (2007) had young adults walk along an 8.1 m long x 1.5 m wide path (hidden before the start of each trial) in which the middle 2.5 m length was comprised of a 5 x 3 grid of 15 different terrains (solid, compliant, rocky, slippery, inclined) with each terrain having an area of 0.5 x 0.5 m. Despite sampling at just 30 Hz, Marigold & Patla (2007) reported a higher number of visual fixations across the entire path when comparing trials in which participants negotiated across the 2.5 m span of multi-surfaces when compared to control (uniform solid surface) walks (18.8 v. 11.5), with a greater percentage of fixations directed to the multi-surface span as compared to the equivalent 2.5 m span of the control walk (91.1 v. 55.8%). In contrast to Patla & Vickers (2003) who reported the predominance of travel gaze fixation when negotiating a non-hazardous-flat terrain whether with or without footprints (approximately 60% of the total travel time), Marigold & Patla (2007) noted that when approaching (and to an even greater extent once making contact)with) the multi-surface terrain, forward looking gaze carried along by the body was less helpful, being employed less than 1% of the time, and suggested a greater need for active visual scanning to important features as terrains become more challenging. Marigold & Patla (2007) found that during the approach phase of the multi-terrain mid section of the path, 63% of fixations were aimed at the initial two (of five) rows (verse 22% of gaze aimed at the final two of five rows); and once making foot contact with the multi-surface terrain, 95% of fixations were aimed at the last two (of five) rows. Additionally, as 56% of fixations took place about 2 steps ahead [i.e. 1.2 (.11) s time span between gazing and stepping upon the surface)], Marigold & Patla (2007) suggested the possibility that the complex spatial arrangement may be stored for a couple of steps with further online fixations or ambient vision providing ongoing updates. Through the process of trans-saccadic integration, a spatial-temporal internal model of the environment could be formulated upon approach, allowing for an effective response to an unanticipated travel path occurrence within the same trial.

Moreover, Marigold & Patla (2007) reported that when free to step on the surfaces of their choice, although the majority of gaze fixations were directed to areas eventually stepped-on, 12.3% of fixations were to transition regions where 3-4 different surfaces met (and a similar percentage to transition areas where 2 different surfaces met), yet just 17% of steps landed on such transition regions. Marigold & Patla (2007) suggested that fixating on ground transition regions allows acquisition of information about length & width needed to guide foot placement when the surface poses a threat. Marigold & Patla (2007) further advanced that fixating on ground transition regions upon approach may allow the brain to covertly attend (possibly through the use of parafoveal ambient vision) to more than one surface, and facilitate integration of a larger amount of visual information simulating a global spatial map, should a targeted surface prove too difficult and a sudden path change is needed in that same trial. Thus, in applying the findings of Marigold & Patla (2007) (derived from a task in which participants approached & negotiated a multiple-surface terrain hidden prior to the start of each trial) to the present study where participants were early v. late-cued for turn direction, although gaze was not assessed in the present study, it is not unreasonable to speculate that when late-cued, in light of the uncertainty of future path direction and potential tripping-threat posed by objects placed in the terrain, upon approach participants may have increased the frequency of visual sampling of transition regions (i.e. the four red hazard floor cones bordering the turn-zone and thus defining the end of the Gaitrite/entrance to the turn-zone, straight v. right path, & straight v. left path), so as to develop a more comprehensive global-spatial map of the turn zone environment to effectively respond to a sudden change in path.

While additional research appears warranted to determine what if any effect the uncertainty of direction has on the frequency of saccadic eye movements when late-cued to turn, there is suggestion from an open-motor skill involving circumvention, that the visual-processing mental costs on gait upon approach may be greater when the regulatory condition of the final location/stopping point of the obstacle is either unpredictable or the obstacle is in-motion. Gerin-Lajoie, Richards, & McFadyen (2005) used motion analysis to assess speed & step-length changes in young subjects who walked straight along an 8 m walkway, before circumventing left of a mannequin (obstacle) randomly located either stationary directly ahead at the mid-point, or in-motion crossing right-to-left at a 45^0 angle to its final destination at the mid-point. As catch trials were also included (although not analyzed) in which there was a change in the final location or stopping point of either the stationary or in-motion mannequin, respectively, in only half the trials did participants know in advance and were certain (predictable i.e. early-cue) as to the final location or stopping point of the mannequin, whereas in the other half of trials participants were uncertain (unpredictable i.e. late-cue). Among the gait parameters assessed were average speed excluding the first-two steps taken, and step-length adaptation across the six-steps preceding crossing with adaptations expressed relative to average step-length during control no obstacle gait. With regards to gait speed, while Gerin-Lajoie et al. (2005) noted a slowing trend upon approach when the mannequin was stationary (relative to no-obstacle control gait), the slowing reached significance (relative to both control gait & the stationary mannequin) when the mannequin was in motion; yet somewhat surprisingly certainty (i.e. certain v. uncertain) of the final location/stopping point of the mannequin had no significant effect on gait speed (i.e. just a trend for a slower speed when the final location/stopping point was uncertain as opposed to certain). With regards to step-length, relative to no obstacle control gait, when the final location/stopping point was certain, Gerin-Lajoie et al. (2005) found that all six approach steps were shorter when the obstacle was in-motion obstacle, whereas no step-length difference upon approach was seen when the mannequin was stationary. However, when the final location/stopping point was uncertain, Gerin-Lajoie et al. (2005) reported a similar “configuration” (pattern) of step-length reduction for both the stationary & in-motion mannequin conditions, as relative to no obstacle control gait, step-length was shorter for the final 3 or 4 approach steps prior to crossing for the stationary obstacle & in-motion obstacle, respectively, with the greatest shortening across the final 2 steps (i.e. steps ending in penultimate & ultimate foot placement). Additionally, when comparing the stationary v. in-motion conditions to each other, the extent of the step-length shortening when the final location/stopping point was uncertain was greater when the mannequin was in-motion, with this difference being significant for the penultimate and trending at the ultimate step (% step-length shortening relative to average for no-obstacle gait when the final location/stopping point was uncertain i.e. late-cue: obstacle in-motion: ante-penultimate step -7.5%, penultimate step -16%, ultimate step -15%; obstacle stationary: ante-penultimate step -7%, penultimate step -10.5%, ultimate step -10%). Although neither the frequency of saccadic eye movements nor the location of gaze fixation were assessed, Gerin-Lajoie et al. (2005) nonetheless suggested a need for greater visual sampling when the regulatory condition of the mannequin's final location/stopping point was uncertain (relative to when it was certain) to allow integrated monitoring of current v. targeted COM trajectory, with this greater amount of data incurring higher information processing costs. In contrast, Gerin-Lajoie et al. (2005) reasoned a relatively lower visual sampling frequency and data processing cost when the obstacle's final location/stopping point was certain, as information gaps could be filled in from predictions grounded in stored movement configurations of similar past experiences. Gerin-Lajoie et al. (2005) further reasoned that the somewhat surprising absence of a significant decline in gait speed when the final location/stopping point was uncertain, as compared to certain, likely indicated the mannequin avoidance task may have been too familiar. Thus, participants likely had less need for online visual processing when avoiding the mannequin, and instead depended upon intrinsic models of environmental coordinates derived from prior experiences. Yet, given the non-significant trend towards slowing when the final location/stopping point was uncertain, Gerin-Lajoie et al. (2005) believed additional slowing would be expected as obstacle path becomes even less predictable and the task more challenging. Similarly, Gerin-Lajoie et al. (2005) also suggested greater mental information processing costs as the likely explanation for both the greater speed reduction and step-length shortening when the regulatory condition of the mannequin was in motion as opposed to stationary. Applying the suggestions of Gerin-Lajoie et al. (2005) to the results of the present study in which stride-shortening & greater slowing was seen when a late-cue brought an element of unpredictability as to future direction yet objects in the environment were stationary (i.e. red hazard floor cones), may indicate greater visual sampling & data processing costs as a possible explanation when there was uncertainty about the imminent travel path direction. To this point, it is worth adding that irrespective of whether any potential increase in the frequency of visual sampling be a strategy to allow more integrated monitoring of one’s trajectory within the environment when there is uncertainty about an obstacle’s future location/path (Gerin-Lajoie et al., 2005), or the consequence of spatial separation/eccentricity between two visual sources of information not allowing for concurrent use of focal & ambient vision (Horray & Wickens,

2008) (i.e. current mannequin location/path v. potential future avoidance locations/paths), it is worth recalling that Wickens (2002) has suggested scanning may present a challenge to the 4th dimension of his multiple-resource-model for sharing of visual attentional resources. Accordingly, Wickens (2002) advised that when estimating visual interference, weighing by a constant may be necessary across different tiers of information acquisition measured in terms of visual angle separation between two focal channels (i.e. foveal vision < 4^0; eye-field vision necessitating saccades 4^0-30^0; and head-field vision requiring changes in head-orientation > 30^0).

In regards to the finding of a greater reduction in speed when cued-late walking fast as opposed to at preferred speed, although the principal investigator of the present study is unaware of dual-task costs as it relates to gait changes increasing with speed (interaction of task condition x gait speed), there is suggestion at least in the elderly, that performance of the secondary cognitive task may decline during fast non-preferred treadmill walking. Tomporowski & Audiffren (2013) compared young & elderly performance of a secondary auditory switch-test task [alternately switching from a series of discriminating between consonants v. vowel letter pairs, to a series of discriminating between odd v. even number pairs] while walking on a treadmill at preferred & fast speeds (50% faster). Tomporowski & Audiffren (2013) reported that whereas cognitive flexibility in terms of performance when switching from number to vowel discrimination (or vice versa) was unaffected by walking speed in young adults, the elderly showed an increase in error rate for switches (trials switching from vowel to number discrimination or vice-versa) at fast speed. In a related-study involving only young adults, Klein, Poggensee, & Ferris (2014) had participants walk on a treadmill across a range of speeds (0.4, 0.8, 1.2 & 1.6 m/s) while performing a secondary spatial working memory task (remembering the location of nine numbers in a 3x3 grid). Klein et al. (2014) likewise reported that walking speed had no affect on error rate in young adults when performing the spatial working memory task, nor was there any affect of speed on either reaction time or electro-cortical activity. Nonetheless, given a spatial-memory-task was employed, and referencing Al-Yahya et al. (2011), whose systematic review and meta-analysis revealed gait changes were most robust when the secondary task employed mental-tracking (holding with processing), Klein et al. (2014) cautioned that dual-task costs as it relates to the interaction with speed may be task-specific and vary with task difficulty. Thus, while little research appears to exists with regards to the effect of walking speed on the DTC of gait (whether on a treadmill or let-alone on level-ground), if an assumption is allowed that uncertainty of a future path may precipitate greater visual sampling & incur higher information processing costs (Gerin-Lajoie et al., 2005) i.e. uncertain stemming from a late-cue, the potential for a faster gait to even further complicate the processing of the greater amount of visual late-cue data (relative to early-cue visual data) cannot be ruled-out.

Another much more readily obvious explanation for the greater reduction in speed when cued-late walking fast, and shorter-stride when cued-late is biomechanical. Winter, Patla, Frank & Walt (1990) suggested that a decrease in stride-length (and double-limb support time) is one of the consequences of a smaller push-off. The gait changes brought-about by such a reduction in push-off may afford additional planning time when there is uncertainty regarding a change in upcoming direction. Paquette & Vallis (2010) reported that for the final approach step ending in ultimate pivot foot contact, relative to straight unobstructed walking, when late-cued right v. left for a circumvention task, both age-age-groups showed a reduction in both step length (21 v. 16%) and step velocity (step length/step time) (24 v. 16%) although the decrease was greater in the elderly. Paquette & Vallis (2010) suggested the slower step velocity and shorter step-length when cued-late (relative to unobstructed straight walking) may allow more time between steps to plan and execute a direction change, which may be especially beneficial for the elderly.

As already noted, the ability to rapidly modulate both propulsion & braking forces in order to abruptly decelerate has been linked with turn success when late-cued. Cao, Ashton-Miller, Schultz, & Alexander (1997) visually late-cued young & elderly adults walking at preferred speed for 90^0 turns using available response times ranging between 375-750 ms and reported that 99% of turn failures were attributed to an inability to arrest the forward momentum of the COM within the available response time. In a follow-up study, Cao, Schultz, Ashton-Miller, & Alexander (1998) further suggested the time to peak velocity was the greatest contributor to an age related increase in the required response time. Cao et al (1998) advanced that a delay in reaching peak velocity allowed a further build-up of forward momentum which would ultimately need to be arrested (“braked”) when turning. Although neither GRFs or EMG were assessed, among the potential reasons suggested by Cao et al. (1998) for the longer time to peak velocity in the immediate post late-cue period were prolonged calf muscle contraction in the cue limb or reduced plantarflexor “braking” energy absorption.

In light of the need to rapidly decelerate forward momentum when making an abrupt change in direction, it is not surprising that use of a similar distal-to-proximal extensor “braking” muscle synergy has been observed & proposed when unexpectedly late-cued to turn and unexpectedly late-cued to terminate straight gait. Hase & Stein (1999) used a non-noxious electrical stimulus over the right ankle to unexpectedly and randomly cue middle-aged adults (26-57 years) walking at a preferred speed to perform a rapid 180^0 direction change. Based upon electromyography (EMG) analysis of the right lower extremity limited to right-turns (although participants were free to turn in either direction), Hase & Stein (1999) found that when abruptly cued, a distal to proximal (extensor synergy) muscle activation sequence preceded the turn, similar to that used to decelerate forward gait during an abrupt stopping task (Hase & Stein, 1998). Thus, when late-cued in proximity of right heel strike which tended to trigger a right step-turn (given 7 of the 10 participants turned within 2 footfalls following cuing), the muscle activation sequence pattern to decelerate the right penultimate (cue) limb was soleus/biceps femoris & erector spinae (followed by the right gluteus medius then tibialis anterior immediately afterwards). Additionally, when late-cued in proximity of left heel strike for a right spin-turn, EMG analysis of the right swing (future ultimate pivot) limb revealed a mechanism which also reduced forward momentum as the right biceps femoris was activated to extend the hip, as were both the vastus lateralis & soleus immediately prior to heel contact contributing to knee & ankle stiffness. Hase & Stein (1999) suggested deceleration when approaching turns may afford time to use either the foot or hip strategy as proposed by Patla et al. (1991). This similarity in the distal to proximal muscle activation pattern between rapid stopping and the initial part of turning prompted Hase & Stein (1999) to suggest the neural mechanisms for the two tasks may be similar.

While studies comparing early v. late cued braking & propulsion GRFs when turning may be hard to come-by (let alone speed or stride-length changes), research involving rapid gait termination has verified that a late-cue to stop constrains the ability to reduce propulsion forces; yet the small separation between cue conditions characteristic of the methodology often used in gait termination research, may be inadequate to identify many early v. late cue gait adaptations on a spatial-temporal level. Tirosh & Sparrow (2004) used motion and force plate analysis to compare abrupt gait termination in young and elderly participants who were visually cued during left stance both early (10 ms post left-limb heel-strike) & late (450 ms prior to left-limb toe-off). [Out of concern faster preferred walking speeds would abbreviate the available response time to adapt stance GRFs if a stop-cue were otherwise delivered at a constant percentage of the gait cycle, Tirosh & Sparrow (2004) instead chose to keep the total response time constant at 450 ms prior to left-limb (swing-limb) toe-off for the late-cue condition]. With regards to GRFs, when comparing early-cue stops v. late-cue stops v. unconstrained “no-stop” control trials (and collapsing for age-group), Tirosh & Sparow (2004) noted left “trail” (cue)-limb stance peak propulsion forces were smallest when early-cued yet largest for control walks for both the horizontal posterior-anterior GRF (early 0.052, late 0.105, control 0.195 N/body-weight), and vertical GRF (early 0. 794, late 0.957, control 1.096 N/body-weight) [yet when not collapsing for group, an age-related interaction revealed the elderly did not reduce propulsive forces in the left trial limb when stopping relative to control trials]. However, for the right “lead” (forward)-limb, stance peak braking forces were larger for both cue-conditions relative to control walks [although an age-related interaction showed the elderly had less of an increase in braking in the right forward limb]. With regards to spatial-temporal data, Tirosh & Sparrow (2004) reported that relative to the early-cue condition (10 ms post left heel-strike), when late-cued (450 ms prior to left-limb toe-off) the stopping distance was longer (0.45 v. 0.34 of stature). [Yet no age-related difference was seen in stopping distance, as although the elderly had a longer mean stopping time as a consequence of a higher % of two as opposed to one-step stops, the second step was often of small length not advancing beyond but instead short of the right step (59.2% of two-step responses were of short step-length)] . Moreover, when collapsing for early v. late condition, as each participant performed 50 trials across two-probability conditions for a stop cue, when comparing the low-10%-probability-to-stop condition (5 stop trials randomly interspersed with 45 no-stop “catch” trials) v. the high-80%-probability-to-stop condition (40 stop trials randomly interspersed with 10 no-stop “catch” trials), the stopping distance was greater for the low-10%-probability-to-stop condition (0.40 v. 0.38 of stature). However, as the difference in stopping distance between probability conditions though significant was nonetheless relatively minor (suggesting that regardless of probability condition a stop was still anticipated), and no decrease in speed was seen upon approach relative to control walking (as would otherwise be expected when anticipating an upcoming adaptive response such as rapid stopping), Tirosh & Sparrow (2004) suggested preplanning for the abrupt stopping task (regardless of early v. late cuing) took the form of preference for a two-step strategy (particularly in the elderly) rather than a slower gait. This last point is worth contrasting with the present study, as although Trish & Sparrow (2004) found no anticipatory decrease in speed when approaching a randomly cued stopping task & suggested a small effect for stimulus probability (i.e. with regards to the stopping distance when comparing a high v. low probability of being cued to stop irrespective of early v. late cuing), both the early & late cue to stop were given across the same spatial footfall (i.e. the early-cue was delivered 10 ms post left-limb heel-strike v. the late-cue 450 ms prior to left-limb toe-off) . On the other hand, in the present study where greater slowing & stride-length shortening was seen when late-cued, the spatial separation between early v. late cues was much more pronounced (distance of leading edge of cue mat to start of turn-zone: early-cue mat 445 cm, late-cue mat 120 cm). Additionally, as each time-constraint (early v. late cue) had a 50% probability in the present study, and as the early-cue mat was placed just 15 cm from the starting location of where gait was initiated, when the early-cue was not triggered upon initially stepping on the Gaitrite, participants in the present study easily learned to anticipate the late-cue by default (although were still unsure of direction) which may have precipitated the reduction in both speed & stride-length.

In addressing why speed may have slowed to a greater extent when cued late walking fast as opposed to preferred speed, it is likely that a fast walking speed further limits the available response time, making the need to decelerate and “buy time” even more urgent. Xu, Carlton, & Rosengren (2004) early-cued young adults to continue walking straight or perform 45^0 & 90^0 right step-turns & spin- turns at preferred & fast walking speeds. Xu et al.

(2004) noted that for the striking phase of the step prior (i.e. the penultimate footfall, as the ultimate pivot footfall GRF was not assessed), both the medial-lateral & anterior-posterior (braking) impulses increased with speed; and for the propulsive phase of the penultimate footfall, both the ML & AP (propulsion) impulses decreased with speed. Yet despite this finding across speeds, it is important to underline that Xu et al. (2004) did not have a late-cue condition.

Although the principal investigator is unaware of prior turn-related studies assessing any potential interaction between walking-speed & direction-cue-time-constraint on gait, a look at the literature as it relates to gait termination again may be helpful. [As already mentioned above, it was out of concern the available response time to adapt GRFs would be compromised to a greater extent in those walking at faster speeds when late-cued to stop, that Tirosh & Sparrow (2004) decided to keep the late-cue total response time constant (at 450 ms prior to left-limb toe-off) when comparing young v. older adults, rather than cue both groups at the same percentage of the gait cycle]. Hence, support for the need for greater deceleration upon approach when late-cued walking fast and a motor response is thought imminent, may possibly be found from a gait termination finding suggesting velocity-dependent modulation of the braking synergy, which due to the shorter available response times of faster speeds, appears to suppress the soleus braking GRF in the penultimate-cue-limb, which if not would otherwise be counter-productive to deceleration once the COM is beyond its COP during latter stance. Crenna, Cuong, & Breniere (2001) assessed EMG activity in young adults (mean age 32 years) who were randomly visually late-cued to rapidly terminate gait (50% probability) upon right penultimate heel strike with a force place across slow, preferred & fast walking speeds. As preliminary testing showed participants more frequently required a second short right step in order to stop (i.e. one stride cycle as opposed to just one left-step) when walking fast as opposed to at preferred speed (frequency of needing a second short right step to stop: fast-speed 98% v. preferred-speed 30%), a stride-protocol to stop was chosen but the length of the additional step was kept constant by having participants place the foot of the 2nd right foot alongside the left ("ultimate") lead-limb. [Preliminary testing also revealed that regardless of whether or not participants needed the 2nd additional right short step to stop, qualitatively the EMG activity in both the penultimate (cue) trail limb and ultimate (lead) limb were unaffected]. Thus, Crenna et al. (2001) reported the right penultimate trail (cue) stance limb showed a distal-to-proximal posterior braking synergy (initiated about 150 ms post cue) mainly comprised of the soleus (onset time 13% of control stride) & hamstring (onset time 18% of control stride), and to a lesser extent the gluteus medius (onset time 35% of control stride). Interestingly, Crenna et al (2001) noted that for the penultimate trial (cue) limb when late-cued, as speed increased (slow-preferred-fast) the braking response was progressively enhanced proximally at the hamstrings (i.e. decreased onset latency, increased duration & amplitude), but progressively dampened distally at the soleus (i.e. increased onset latency, decreased duration & amplitude). This decrease in soleus activity at faster walking speeds was positively associated with a reduction in the area of the braking GRF wave of the penultimate trail-limb during single-limb stance (relative to that of control gait at a comparable speed). Furthermore, the left swing ultimate (lead) limb exhibited a proximal-distal braking synergy mainly comprised of the quadriceps (onset time 31% of control stride, which unlike control gait preceded heel-strike leading to co-contraction with the hamstrings and increased knee stiffness) & soleus (onset time 38% of control stride). Interestingly, for the lead limb when late-cued, as speed increased (slow-preferred-fast) the braking response was progressively enhanced both proximally at the quadriceps & distally at the soleus. The increased muscle activity in the quadriceps & soleus in the left swing ultimate limb at faster walking speeds was positively associated with an increase in the area of the braking GRF wave of this lead-limb during single-limb stance (relative to that of control gait at a comparable speed). Crenna et al. (2001) concluded the stance (trail) penultimate cue-limb and swing (lead) ultimate limb adapt differently to increases in walking velocity, with the swing ultimate (lead)-limb showing positive parallel quadriceps & soleus scaling, but the stance penultimate (trail)-limb showing positive scaling for the proximal hamstrings but negative scaling for the distal soleus. Crenna et al. (2001)

proposed that given the available response time widow to apply a deceleration force becomes narrower at faster speeds, making soleus onset relatively latter, once the COM has advanced beyond the COP of the penultimate cue foot towards the 2nd half of stance, action from the soleus at that point would actually be counter-productive to braking.

This finding of Crenna et al. (2001) that when walking at a fast-speed and late-cued to terminate gait the soleus GRF braking is suppressed in the penultimate-(cue)-trail-limb yet boosted in the ultimate-lead-limb (i.e. velocity-dependent modulation of the distal braking synergy differing across limbs) may have even greater importance for a turning task. To this point, Glaister, Orenduff, Schoen, Bernatz & Klute (2008) have reported that when young adults walked at a preferred speed (no testing done at fast speed) with a priori awareness of direction for 90^0 step-turns, the penultimate limb was the biggest contributor to deceleration, whereas the ultimate pivot limb was the largest contributor to ML displacement of the COM & propulsion into the new travel path. Thus, given the suggestion of Crenna et al. (2001) for the likelihood of greater difficulty decelerating upon penultimate foot contact when late-cued walking fast (as opposed to late-cued at preferred speed), it is reasonable to speculate that when not receiving an early-cue in the present study, by default participants may have decelerated in anticipation of the late-cue, so there would be enough available response time when walking fast (as opposed to preferred speed) to activate the soleus of the penultimate cue-limb, before the COM had advanced beyond its COP during the latter-half of stance. By so doing, any remaining forward momentum could then be halted in the subsequent ultimate (pivot) lead limb, rather than requiring an extra step before ML accelerating the COM into the turn direction. The suggestion of a similar distal-to-proximal extensor "braking" muscle synergy at the penultimate cue or trial-limb when both abruptly making an unexpected turn as well as abruptly terminating straight gait (Hase & Stein, 1998,1999);the prominent deceleratory function played by the penultimate limb when approaching early-cued turns (Glaister et al., 2008); and the potential for suppression of soleus GRF in the penultimate-(cue)-trail-limb when late-cued to terminate gait at a fast-speed (Crenna et al., 2001), taken-together further highlight the need to include deceleration/gait termination in fall prevention turn-related training programs.

An interesting observation coming out of gait termination studies comparing GRFs across the combined effects of speeds & time constraints is the similarity for some kinetic measures (i.e. rate of deceleration force generation) in the ultimate-lead-limb when both late-cued at a preferred cadence/speed & early-cued at a fast cadence/speed. Bishop, Brunt, Pathare & Patel (2004) used force plates & EMG to compare early-cued (prior to the walk) & late-cued (across a range of 0-450 ms prior to ultimate-lead-limb contact) stopping in young adults walking across three different speeds based upon the percentage of preferred cadence (i.e.100%, 125%, 150% preferred cadence while maintaining preferred step-length). In addition to analyses across cadences, comparisons were made for interactions between cue*limb-conditions (i.e. early-cued v. late-cued * ultimate-lead-limb v. penultimate-trial-cue-limb, yet excluding the late-cued*penultimate-trail-cue limb given the late-cue was delivered across a range of 0-450 ms prior to ultimate-lead-limb contact), combined with comparisons between trials in which an extra-step-was-needed to stop v. those in which an extra-step-was-not-needed to stop. Bishop et al. (2004) noted that the peak breaking GRF increased with cadence, and was greatest for the interactive combined condition of late-cued*ultimate-lead-limb-not-needing-an-extra-step [i.e. greater peak than seen for control-walks, late-cued*ultimate-lead-limb-but-needing-an-extra-step, and early-cued*penultimate-trail-limb], although no difference was seen in the peak braking GRF between the late-cued*ultimate-lead-limb-not-needing-an-extra-step v. the early-cued*ultimate-lead-limb regardless of cadence. Moreover, Bishop et al. (2004) reported that the rate of deceleration force generation also increased with cadence (although similar for 125 v. 150% cadence), and the rate was highest for the interactive combined condition of late-cued*ultimate-lead-limb-not-needing-an-extra-step; however, most important, no difference was seen when comparing the rate of deceleration force generation for the late-cued*ultimate-lead-limb-not-needing-an-extra-step at 100% cadence v. the early-cued*ultimate-lead-limb at 150% cadence. Bishop et al., (2004) also found that when at 100%

cadence and not-needing-an-extra-step-to-stop, the rate of deceleration force generation in the late-cued*ultimate-lead-limb was 2-3x greater than that seen when early-cued for either-limb; and when early-cued to stop, the participation of the penultimate- trail-limb to the rate of deceleration force generation declined with an increase in cadence [which would appear to have some parallelism with the finding of Crenna et al., (2001) for a decrease in the penultimate limb soleus braking GRF when cued-late at a fast-speed] . Additionally, with regards to EMG, similar to Hase & Stein (1999) [who reported the onset for hamstring & soleus braking preceded heel strike of the ultimate pivot (swing)-limb when late-cued one step-prior for a turning task], Bishop et al. (2004) also noted hamstring & soleus activation prior to heel-strike of the early-cued-lead-limb for gait termination at the preferred 100% cadence (note: for control-walks at 100% cadence, soleus onset in the was post heel-strike). Not surprisingly, for the late-cued-lead-limb at preferred cadence, Bishop et al. (2004) observed soleus activation to be concurrent with heel-strike. However, as cadence increased, soleus onset in the early-cued-lead-limb occurred later in swing closer to heel strike. In light of the similarly in the kinetic measure of rate of deceleration force development, Bishop et al. (2004) suggested commonality between late-cued*preferred-cadence stopping & early-cued*fast-cadence stopping.

A similar finding of resemblance between both late-cued*preferred-speed and early-cued*fast-speed gait termination has likewise been reported on a kinematic-level with a suggestion that fast-speed (early-cue) stopping may be clinically useful as a means to envisage (preferred-speed) late-cue stopping. Ridge, Henley, Manal, Miller, & Richards (2016) used motion & force plate analysis on typically developing 11-17 year old youths (mean age 14.4 years) who were randomly cued for a gait termination task either early (planned - a priori) v. late (unplanned- visual stop sign one-step prior upon penultimate foot contact) across preferred (100%) and fast (150% preferred) speed blocks. During both the preferred & fast walking trials, participants were asked to self-monitor their current walking velocity in an attempt to preserve the target speed until terminating gait. While participants tried to maintain the target speed, Ridge et al. (2016) recorded average walking step-length v. stopping step-length, assessed approach velocity by sampling across the last 0.5 seconds prior to penultimate foot contact of the stopping task, and recorded peak joint extensor moments along with peak hip & knee flexion angles at terminal stance for the ultimate-lead-limb. Ridge et al. (2016) reported that for trials in which gait was terminated within one-step (if late-cued), as expected peak hip & knee flexion angles and peak knee extensor moments in the ultimate-lead-limb were greater when walking fast as opposed to preferred speed (which was suggested to aid absorbing GRF), and hip & knee flexion angles were smaller across the entire trial when cued-early (as opposed to late). Not surprisingly, in contrast to the findings in the present turn study in which there was no self-monitoring for target speed, and a reduction in stride & speed (especially fast-speed) was seen when late-cued, Ridge et al. (2002) - who did have participants self-monitor for target speed- found no statistical difference between early v. late-cue approach walking speed at either the preferred 100% (early-cue 1.23 v. late-cue 1.19 m/s) or fast 150% (early-cue 1.87 v. late-cue 1.80 m/s) speed blocks; and although the terminal stopping step was shorter than the average step-length as recorded upon approach for both preferred-speed conditions and the fast*early-cue condition, the average & terminal steps were of equal length for the fast*late condition (approach walking step-length v. stopping step-length: preferred*early 84.4 v. 73.2; preferred*late 83.7 v. 70.8; fast*early 103.4 v. 90.6; fast*late 100.8 v. 99.6 normalized by leg-length). Furthermore, of greater importance, given no significant difference was seen in ultimate-lead-limb peak hip & knee angles during terminal stance when comparing the a priori early-cue*fast-speed stops v. the penultimate late-cue*preferred-speed stops [peak hip flexion angle: late*preferred 30.4(7.0)^0 v. early*fast 30.5(8.0)^0; peak knee hip flexion angle: late*preferred 34.5(10.0)^0 v. early*fast 38.5(9.9)^0], Ridge et al. (2016) suggested fast speed (early-cue) gait termination may be clinically useful as a way to project performance of late-cue (preferred-speed) gait termination. In applying this finding of Ridge et al (2016) obtained on youths (mean age 14.4 years) to adults, although gait in children is believed to be fairly stable by age 7, there is indication maturity may not be at the level seen in young adults even as late as12-13 years

(Lythgo, Wilson, & Galea, 2009). Nonetheless, given the deceleration phase when approaching both rapid turns & stops has been likened to each other (Hase & Stein, 1999), and in view of the finding of Bishop et al. (2004) of a similar rate of deceleration force generation between early-cue*fast-speed v. late-cue*preferred-speed gait termination in young adults, it appears reasonable to speculate that a training program of early-cued turning (a closed-motor skill) at a fast speed regulatory condition, may generalize and transfer benefits to late-cued turning (an open-motor skill) at a preferred speed regulatory condition.

Discussion of slowed when cued-early to turn right as compared to straight; stride-length shorter when cued-early to turn right as compared to straight

The finding of slowing and stride shortening when cued-early to turn right as compared to continue straight may be the result of greater visual-spatial information processing needed for preplanning & feedforward motor control when changing direction relative to continuing with linear gait. Warren (2007) has suggested that the visual system can extract information derived from the optic flow field of expansion and process the information to regulate obstacle negotiation at the step level. Warren (2007) states that the visual system converts this perceptual information into units of eye height based on the rate of change of target or object image/visual angle expansion upon the retina; and then uses this rate of change to compute a target/obstacle’s dimensions, location, distance & tau-time-to contact. Warren (2007) states the visual-system can further calibrate the distance/time to contact to the target/obstacle by body-scaling or action-scaling this information into units proportional to leg-length, shoulder-width or current stride-length, stride-time, respectively, thus allowing for feedforward control for target/obstacle negotiation.

The capacity to use vision in this manner for feedforward guidance of foot placement to a target has been shown to require information be extracted at least 2 steps prior, however as path complexity increases, greater use of online vision may be necessary. Patla & Vickers (2003) used a mobile eye tracker and video to assess two types of gaze behaviors in young adults negotiating footprint cluttered environments: travel gaze fixation & footprint “landing target” gaze fixation. Travel gaze fixation was characterized by the eyes being held stationary at a constant angle and focused ahead (interrupted only by oculo-motor reflexes compensating for acceleratory motion of the head) while carried along with the rest of the body. During travel gaze fixation, gaze was mostly fixated on space between targets ahead (although this distance was not assessed) and occasionally at the end of the walkway. Patla & Vickers (2003) suggested travel gaze fixation allowed for the extraction of information related to self-motion and environmental features through optic flow, with this information used to direct the lower extremity to the designated footprint target. In contrast, footprint gaze fixation involved gaze being actively shifted to areas of interest (i.e. future footprint targets). Patla & Vickers (2003) reported the young adults allocated a greater percentage of the total travel time to travel gaze fixation (used 61%) as opposed to footprint gaze fixation (used 15%). In particular, the total duration (% of the total travel time) in which participants engaged in travel gaze fixation when negotiating the non-hazardous-flat terrain was unaffected by whether or not footprints were present (no footprints 58.8% v. evenly spaced footprints 62.2% v. unevenly spaced 61.6%), with the duration of travel gaze fixation averaging ≤ 600 ms for 70% of the total occurrences and ≤ 300 ms for 41% of the total occurrence. Most important, Patla & Vickers (2003) noted that when engaging in footprint gaze fixation, on average the young participants looked two steps ahead in order to extract information for feedforward control, and interestingly the two step average held regardless of footprint spacing [i.e. early (steps 3-5) or late phase (steps 13-15) of the trial], or even trial repetition number. The total duration (% of the total travel time) in which participants engaged in footprint gaze fixation was low and likewise unaffected by whether or not the spacing between footprints was even or uneven (evenly spaced footprints 16.3% v. unevenly spaced 13.8%), with the duration of footprint gaze fixation averaging ≤ 600 ms 96% of the total occurrences and ≤ 300 ms 64% of the total occurrences. Patla & Vickers (2003) concluded that when negotiating footprints posing no threats to stability or tripping, young adults primarily use feed-forward visual-motor preplanning regardless of whether targets are regularly or irregularly spaced; and a minimum distance/time of 2 steps is needed in order to extract information regarding target location in relation to current body & limb position, and then calculate needed adjustments in step-length & width for accurate foot placement. Patla & Vickers (2003) reasoned that the use of travel gaze fixation to negotiate the path was possibly not only because the terrain was sterile (i.e. free of tripping hazards) but also since footprint targets naturally landed in the fovea as the body advanced forward. Hence, either travel gaze fixation or footprint gaze fixation (if ≥ 2 steps ahead) could similarly be used to extract target location information in order to calculate spatial-temporal step adjustments permitting feedforward control. Nonetheless, Patla & Vickers (2003) did suggest that the more hazardous or challenging-to-balance the terrain, the greater the need for online guidance of foot placement (i.e. footprint gaze fixation < 2 steps ahead). [As the two step average held regardless of trial repetition number, Patla & Vickers (2003) suggested each walking trial started anew as responses were not planned from a mental map, but rather for each trial visual information was again extracted, processed and translated into a motor act, supporting the contention of Goodale et al (2004) for the rapid decay of referenced target coordinates used for vision for action. [Note, this last suggestion of Patla & Vickers (2003) does not in anyway undermine the suggestion of Marigold & Patla (2007) that scanning transition regions of challenging terrains upon approach may possibly permit the brain to use ambient vision to covertly attend to greater than one surface, and thus integrate a larger global spatial map, to support a sudden path change within the same trial]. It is also worth noting that Patla & Vickers (2003) reported that, relative to the no-footprint path, travel time was significantly longer when negotiating the footprint paths regardless of even or uneven spacing (no footprint 7.1 v. evenly spaced footprints 8.26 v. unevenly spaced 8.52 s).

Feedforward visual motor control during locomotion has been shown to be accompanied by intermittent visual sampling when a change in swing-limb trajectory is required, and when early-cued the frequency of sampling prior to the turn execution stride has been shown to increase with turn angle. Patla, Adkin, Martin, Holden, & Prentice (1996) had young adults wear liquid crystal opaque glasses and activate a hand-held switch whenever the need arose to make the lens transparent in order to view the environment while walking along a 9 m path under various conditions of footprints, environmental threats (obstacle, hole, barrier) & paths. Patla et al. (1996) noted that relative to the no footprint path, the evenly-spaced footprint path had a higher number of visual samples/walk (5.0 v. 1.67) & total sampling duration/walk (2.7 v. 0.7 s) but lower inter-sample interval (0.27 v. 0.36 s). Across conditions, the time needed to complete the walk was slightly increased when intermittently sampling the terrain (travel time: control gait 9 s v. 9.4 s), although this slowing was not considered particularly meaningful. Additionally, Patla et al. (1996) reported that across conditions, the mean sampling frequency was 0.5-1 Hz, duration 500 ms; however, when a threat such as a hole in the walk path was encountered, a large increase in sampling rate was evident in the vicinity. Accordingly, Patla et al. (1996) suggested that for static environments (i.e. a stationary regulatory condition) visual sampling is not time-constrained (as when an object is in-motion) but rather spatially- constrained at key locations such as those which pose a threat; and hence visual sampling of the terrain is not continuous but intermittent thus permitting the sharing of visual system resources with other tasks. Moreover, when asking the young adults to perform early-cued straight v. right 45^0 & 90^0 turns at the midpoint of the 9 m path, and partitioning the walking trial into three-phases: a feedforward control phase (time from start of walk up to penultimate footfall contact), an online control phase (time covering the turn-execution stride), and a final control phase (time after the turn-execution stride up to end of walk), Patla et al. (1996) reported a significant increase in sampling of the terrain as turn-angle increased, with the demand increasing almost 4-fold at 90^0. Interestingly, and most pertinent to the discussion at-hand, for this turn-task in which direction was known in advance (a priori), no change was seen in sampling across the online control phase, but instead the increase in visual scanning was confined to the turn-approach feedforward control phase i.e. start to penultimate foot contact (total number of samples across feedforward control phase: control straight gait 0.5 v. 45^0 1.1 v. 90^0 1.2; total sampling duration across feedforward approach phase: control straight gait 0.1 v. 45^0 0.35 v. 90^0 0.43 s. Note: the longer total sampling duration was the consequence of an increase in sample number i.e. frequency, not an increase in the duration per sample). Patla et al. (1996) suggested the visual information extracted & processed during the approach feedforward phase was then used to control both the stance pivot-limb and the ballistic swing-phase of the turn step. Patla et al. (1996) did propose that if the environment were not static, information gathered during approach would no longer be reliable, and online control would be needed to regulate swing trajectory.

As a greater demand for visual sampling of the terrain is known to take place in the vicinity of path hazards and during the feedforward approach phase for early-cued direction changes, there is additional suggestion the greater visuo-spatial data processing costs incurred from increased sampling may reduce gait speed (even though the environment may be static & predictable). As previously mentioned, Gerin-Lajoie, Richards, & McFadyen (2005) had young adults walk along an 8 m path and at the midpoint circumvent left of a mannequin directly ahead randomly either stationary or in-motion crossing right-to-left at a 45^0 angle to its final destination, with catch trials making the final location or stopping point of either the stationary or in-motion mannequin known for certain (i.e. early-cue) in only half of the trials yet uncertain (i.e. late-cue) in the other half. With regards to gait speed, Gerin-Lajoie et al. (2005) noted that relative to both the control-no-obstacle condition and stationary obstacle condition, gait speed was slower when the obstacle was in-motion. Yet even when the obstacle was stationary, a slowing trend was apparent relative to the no obstacle condition. In a later follow-up study using the same protocol as Gerin-Lajoie et al. (2005), Gerin-Lajoie, Richards, & McFadyen (2006) compared gait speed changes and protective (personal) space in healthy-active elderly and young adults as they walked at preferred speed along a 10 m path, and again at the midpoint circumvented left of a random stationary directly-ahead or in-motion mannequin with the final location or stopping point known in advance in only half the trials. Relative to no obstacle control gait, the data of Gerin-Lajoie et al. (2006) suggested that not only did both age groups decrease approach gait speed when the mannequin was in-motion, but both groups also showed significant slowing when the obstacle was stationary as well. Moreover, when comparing gait speed with the obstacle stationary v. in-motion, no statistical difference was seen. In agreement with Gerin-Lajoie et al. (2005), greater slowing was also seen by Gerin-Lajoie et al. (2006) when the final location or stopping point of the mannequin was uncertain (i.e. late-cued) as opposed to certain (i.e. early-cued). Thus collectively, although the findings of both Gerin-Lajoie et al. (2005) & Gerin-Lajoie et al. (2006) clearly suggests that when circumventing, speed related gait changes stemming from visual information processing costs required for preserving the personal-space safety-margin are greater when the regulatory condition has the obstacle in-motion & or its final location unpredictable, the data nonetheless indicates such costs may still reach significance (relative to control no obstacle gait) even when an obstacle is stationary & its final location certain. Hence, in light of the physical presence of the cones constraining the width of the entrance to the turn zone to approximately 73 cm in the present study (a potential safety concern for tripping particularly when a ML COM displacement is needed to turn), the possibility for greater visual scanning & processing costs (needed to maintain a personal-space safety-margin) contributing to greater slowing when early-cued to right turn (as opposed to continue straight) must be considered even though the environment in the present study was static & predictable.

In further support that when early-cued visual information processing costs during the feedforward approach phase may have contributed to the decrease in speed & stride-length, research suggest a link between the frequency of visual scanning prior to turning (saccadic eye movements), attentional resources and dual-task cost. Galna, Lord, Daud, Archibald, Burn & Rochester (2012) found that lateral saccadic eye movements were often not seen in healthy elderly controls (and even those with Parkinson) across single & dual-task (digit-recall) straight gait conditions, producing a frequency distribution for linear walking which was positively skewed. However, Galna et al. (2012) noted an increase in saccadic frequency upon approach of spatially-confined early-cued 40^0 turns (performed once beyond a 0.8 m wide spatially-confined doorway) relative to straight gait, as well as an increase when performing the dual-task although the healthy elderly controls increased saccadic eye movements to a greater extent than did those with Parkinson. Galna et al. (2012) suggested the concurrent secondary digit-recall task (rather than visual sampling of the environment) may have been of greater priority to the Parkinson group (than it was a priority to the healthy elderly controls). Interestingly, in somewhat agreement with the finding of Patla et al. (1996) of the increase in visual scanning being confined to the turn-approach feedforward control phase (i.e. time from the start of the walk up to penultimate footfall contact), Galna et al. (2012) also found that when healthy elderly controls walked the 2.5 m distance in approach of early-cued turns (for the single task condition), the frequency of saccadic eye movements across the last 30% of the approach was less than that seen across the first 70% of approach (saccadic frequency single-task: first 70% of approach 1.12 v. last 30% of approach 0.79 saccades/s); however, parity was apparent for saccadic movements across the two phases of approach during dual-task turning (saccadic frequency dual-task: first 70% of approach 1.19 v. last 30% of approach 1.16 saccades/s). Additionally, Galna et al. (2012) noted the duration of the approach phase was prolonged in the healthy elderly control group (and Parkinson group as well) when required to turn (relative to straight gait) & when concurrently engaged in the secondary digit-recall task (relative to single-task) [duration to walk the 2.5 m approach distance to the door entrance: straight gait trial (single 2.07 v. dual 2.42 s); 40^0 turn trials (single 2.22 v. dual 2.52 s)]. Interestingly, with regards to straight gait trials (not turn trials), Galna et al. (2012) found a negative relationship between standardized attentional measures & saccadic frequency during approach of single task straight walking but not during dual-task walking in the healthy elderly controls (i.e. lower attentional scores related to higher saccadic frequency during single-task straight gait) possibly suggesting a dual-task attention allocation policy favoring the concurrent secondary digit-recall (cognitive) task over saccades. Galna et al. (2012) suggested the possibility that individuals may have attempted to offset cognitive deficits by more frequently scanning the environment. Applying a similar sample, protocol & method as Galna et al. (2012), Stuart, Galna, Delicato, Lord & Rochester (2017) used electroculography & motion analysis in a second Parkinson-related study to compute the number of saccades > 5^0 amplitude/time to walk 2.5 m. Stuart et al. (2017) noted that the healthy elderly controls showed an increase in the frequency of saccadic eye movements (horizontal & vertical combined) while walking the 2.5 m distance in approach of early-cued 40^0 right/left turns relative to straight gait. Moreover, in contrast to the increase in saccadic frequency previously reported by Galna et al. (2012) in healthy elderly controls during a digit-recall dual-task, Stuart et al. (2017) found that relative to the single-task condition of either straight walking or turning beyond the door entrance, a decrease was seen in saccadic frequency when performing the secondary task of listening to a string of numbers and then verbally repeating digits at the end of the walk trial. Stuart et al. (2017) suggested the reduction in saccadic frequency in the healthy elderly control group (and Parkinson group as well) upon approach during the dual-task condition gave indication for the attention requirement of saccades when walking. Interestingly, Stuart et al. (2017) reported that regardless of single or dual-task turning, Pearson correlation showed that in the healthy elderly control group (but not the Parkinson group), a higher saccadic frequency upon approach was associated not only with a faster walking speed but a greater step-length as well. (However, Stuart et al. (2017) also noted that for the Parkinson group, regression analysis/structural equation modeling revealed attention deficits were associated with both a reduction in saccadic frequency & gait speed). Although no mention was made of the location gaze fixations, Stuart et al. (2017) suggested saccadic eye movements allow for sampling/exploration of the environment and acquisition of visual information needed for feed forward control of direction changes. Stuart et al. (2017) also proposed competition for attentional resources between gait, saccades and cognitive processes, which instead of saccadic initiation may result in priority being given to either gait or the secondary cognitive task. Based upon the findings of Stuart et al., (2017), Galna et al., (2012), Gerin et al., (2005, 2006), and Patla et al., (1996), it seems reasonable to suggest that when early-cued, greater visual information processing costs from an increase in visual-sampling of the terrain, may have in-part contributed to slowing & stride shortening upon approach of the turn-zone (which was spatially confined with stationary hazard cones).

Another potential explanation for the slowing and stride shortening when early-cued to turn right (as compared to continue straight) may be biomechanical so as to reduce forward progression and destabilizing forces in preparation for the lateral direction change, and possibility aid accuracy with turn-angle (foot-placement) in the turn-zone. Shkurtova et al (2004) noted that relative to straight walking, when negotiating a figure-of-eight path, both young and elderly adults showed a similar decrease in walking speed & stride-length. Shkurtova et al. (2004) suggested the decrease in speed & stride-length may have reduced forward momentum and instability when changing direction. Strike &Taylor (2009) had young adults perform early-cued preferred speed yet abrupt right & left 90^0 step-turns and measured spatial-temporal and GRF changes across the final approach stride ending in ultimate pivot foot placement. Relative to control straight gait, when approaching the right step-turns, Strike & Taylor (2009) observed a reduction in both stride-velocity [final approach stride velocity 1.38(.17) v. straight control gait 1.42(.23) m/s] and stride-length [final approach stride length 1.57(.23) v. straight control gait 1.78(.12) normalized to leg-length], yet an increase was seen in the ultimate footfall A-P braking impulse [final approach ultimate footfall 0.16(.06) v. straight control gait 0.11(.03) normalized to body weight x $(\text{leg-length/gravity})^{1/2}$]. Strike and Taylor (2009) suggested these anticipatory pre-planned adaptations in the final turn approach stride are likely important for successful turning. It is worth noting that Strike & Taylor (2009) also measured stride velocity when actually executing the 90^0 direction-change as well as the step-turn angle achieved. As turning left resulted in a slower turn-execution (not turn-approach) stride velocity [turn-execution stride-velocity: left step-turn 1.09(.13) v. right step-turn 1.13(.13)], yet a larger achieved turn-angle [step-turn angle: left step-turn 82.8(5.3) ^{0} v. right step-turn $80.2(5.5)^0$], Strike & Taylor (2009) suggested a possible link between greater slowing and turn angle accuracy, however, cautioned additional research was needed. In the present study, neither turn-angle nor its accuracy was assessed or even mentioned to participants. Nonetheless, out-of-concern about making contact with the red hazard floor cones and potentially tripping, accuracy of foot-placement within the vicinity of the turn-zone may have been given priority. Huxham, Baker, Morris, & Iansek (2008) early-cued healthy elderly controls in a Parkinson related study to perform both 60^0 & 120^0 right turns towards colored targets while walking at a preferred speed. Relative to straight gait, Huxham et al., (2008) noted a decrease in both step-speed and stride-length across the final turn approach stride ending in ultimate pivot foot placement at both turn angles. Huxham et al. (2008) believed a decrease in stride-length was fundamental to turning. Dixon, Stebbins, Theologis, & Zavatsky (2013) allowed children (ages 8-15) to choose both direction & strategy when making preferred speed 90^0 turns around a small object located in the middle of a walkway. Dixon et al., (2013) reported that for the turn-approach stride ending in ultimate pivot foot placement, relative to straight walking, a decrease was noted in both stride velocity and normalized stride length regardless of turn-strategy [approach stride velocity: straight 1.30, spin-turn 1.16, step-turn 1.16 m/s; and approach stride length: straight 1.56, spin-turn 1.40, step-turn 1.44 normalized to leg-length:]. Dixon et al. (2013) suggested the reduction in both stride-velocity & stride-length seen in children may have contributed to preserving a stable base of support. Paquette, Fuller, Adkin & Vallis (2008) early-cued young & elderly adults to perform right/left 40^0 step-turn/spin-turns and assessed gait changes across the final three steps ending in ultimate pivot FF contact. Paquette et al., (2008) reported that only the elderly showed a decrease in step-velocity & step-length upon approach, as regardless of turn-strategy, step-length was shorter for the step ending in the ultimate as compared to the ante-penultimate footfall, and step-velocity was slower for the step ending in the ultimate as compared to both the ante-penultimate & penultimate footfalls. Paquette et al., (2008) suggested the slower step velocity & shorter steps seen in the elderly when approaching turns may represent a cautious, conservative strategy to minimize sagittal plane perturbations. It bears mention that Paquette et al. (2008), who only tested at preferred speed, reported the elderly had slower step velocity & shorter steps even during straight gait. In contrast, in the present study, regardless of direction, no significant age-related difference was seen for gait speed; and although young adults took longer strides, an age*speed interaction suggested the longer strides were taken only at fast speed (present study approach stride-length collapsing for direction & cue: preferred-speed young 1.66 v. elderly 1.55; fast-speed young 2.00 v. elderly 1.78 normalized to leg-length). Hence, the elderly participants in the present study [mean age 69.7(3.13) years] may have had better functional balance during gait than those tested by Paquette et al. (2008) [mean age 83.5(5.18) years] which may explain the absence of an age-related difference in the present study for speed or step-length when approaching turns. Hence, collectively from a biomechanical perspective, the findings of Shkurtova et al., (2004), Huxham et al., (2008), Dixon et al., (2013), Paquette et al., (2008), and Strike & Taylor (2009) would appear to suggest that when approaching a turn with direction known in advance, reductions in both walking speed & stride-length likely participate in a strategy used to regulate the COM within the AP boundary of the BOS, and possibly facilitate ML steering control as well. The importance of both posterior-to-anterior deceleration (Hase & Stein, 1999) and containing the forward trajectory of the COM (Xu et al., 2004) prior to turning has already been established. As noted by Winter, Patla & Frank (1990), a slower walking speed and shorter stride are two of the consequences of a reduction in push-off, which may in fact be an adaptive strategy employed by the elderly to minimize both forward & upward perturbations during straight gait. Given the suggestion that excessive shortening of stride may increase the risk for tripping (McFadyen & Price, 2002; Allert et al., 2014; Chen et al.; 1994), the magnitude & rate of stride-length shortening across approach-steps may need further exploration, particularly in view of the BOS changes simultaneously taking place when cued for turn-direction both early (Patla et al. 1999; Paquette et al., 2008) & quasi-late (Hollands et al., 2010) and likewise found in the present study as well.

Finally, similar to the reason cited for the small number of age-related differences, and shortage of late-cue findings with regards to BOS changes, equipment / instrumentation limitations from the standpoint of the last 55 cm of the Gaitrite carpet lacking sensors, likely contributed to the absence of slowing and stride-shortening upon approach when late-cued to turns as compared to continue straight. As already stated, the final recorded footfall on the Gaitrite corresponded to the penultimate foot in 76% of trials (24% corresponded to the ante-penultimate foot) (Appendix B), yet in 54% of late right-turn trials the cue was delivered upon penultimate foot contact (46% of late right-turn trials delivered upon ante-penultimate foot contact) (Appendix C). Hence, from this combination of the penultimate foot often being both the final recorded footfall & cue foot, a low percentage of late-cue trials were able to record even as few as 1 post-late cue footfall, with the smallest percentage being for right-turns at a fast-speed [1 post-late cue FF: right-turns 11% (15% preferred, 7% fast) & straight walks 22% (preferred 32%, fast 12%).

Accordingly, in the majority of the 240 late-cue trials (84% when collapsing for speed & direction), all 4 recorded footfalls were placed on the Gaitrite when direction was still uncertain, and post-late-cue “reactive” feed-back gait changes & strategies for the most part were not captured, particularly when late-cued to turn-right. On the other-hand, when cued-early, all 4 recorded footfalls were pre-planned and taken with direction already certain, and as such, anticipatory “proactive” feed-forward gait changes & strategies were readily recorded when cued to turn.

Chapter V

SUMMARY & CONCLUSIONS

Summary Review of Problem

Elderly falls are often precipitated by excessive hurrying (Berg, Alessio, Mills, & Tong, 1997), and the odds of suffering a hip fracture from a fall turning are greater than a fall walking straight (Cumming & Klineberg, 1994). Most young adults can turn after one step of being cued for direction (Patla et al., 1991; Hase & Stein, 1999). The vast majority (99%) of turn failures in both older & young adults have been attributed to the inability to arrest forward momentum within the available response-time, although the elderly require a longer response time & distance (Cao et al., 1997). When approaching 40^0 turns at preferred speed with direction known beforehand, only the elderly show a cautious reduction in step-velocity & step-length, whereas both age-groups similarly modify step-width to regulate the COM (Paquette et al., 2008); and when late-cued for a circumvent temporal direction change, across the final approach step ending in ultimate pivot foot placement the elderly exhibit a greater decrease in step-velocity (24 v.16%) & step-length (21 v.16%) possibly affording extra planning/response time, whereas young adults show a wider increase in step-width which reduces their need to also use a trunk-roll strategy to ML displace the COM (Paquette & Vallis, 2010). In non-laboratory real-life “field” environments, architectural constraints have been shown to influence the frequency with which straight (linear) v. direction-altering (non-linear) steps are taken, as the percentage of non-liner steps is highest at 50% when space is confined or cluttered (Glaister et al., 2007). In more traditional laboratory non-cluttered environments, when late-cued for direction young adults prefer to unexpectedly turn 60^0 by stepping-out with a wide BOS using the limb ipsilateral to the new path (i.e. step-turn) as opposed to crossing-over with the contralateral limb using a narrow BOS & less minimal foot-to-foot separation i.e. a spin-turn (Patla et al., 1991; Hase & Stein, 1999; Taylor et al., 2005); when walking fast the elderly prefer to make large 90^0 turns by likewise stepping-out (Akram et al., 2010); and when performing the 180^0 anticipated direction change of the TUGS the use of small pivots & additional steps (i.e. mixed-turn) has been suggested as an early marker of a decline in elderly turn performance (Thigpen et al., 2000). Yet surprisingly there is a lack of turn-related research reporting on the interaction of both speed & cue-delivery time, and age-related differences in anticipatory approach phase gait changes & turn-strategy preferences when both groups are subject to the same response conditions for a permanent direction change constrained by a late direction cue and/or fast walking speed within the same study (Paquette, Fuller, Akins, & Vallis, 2008; Paquette & Vallis, 2010; Cao, Schultz, Ashton-Miller, & Alexander,1997, 1998).

Summary Review of Objectives

Hence, the objectives of the present study were to assess performance of a 90^0 permanent direction change task constrained across a combination of response conditions (preferred v. fast walking speeds & early v. late-cue delivery times) so as to determine: 1) whether any relationships exists between age-group & turn-strategy preference across response conditions; and 2) whether age-related differences exists in gait adaptations based upon the interaction between these same response conditions plus the independent variable of direction. It was hypothesized: 1) there would be a relationship between the factors of age-group (young v. elderly), walking-speed (preferred v. fast), direction-cue-time-constraint (early-cue v. late-cue) and turn strategy preference (step-turn v. spin-turn v. mixed-turn); and 2) spatial-temporal gait adaptations will be different in the elderly as compared to younger adults based upon the interaction between walking-speed, visual direction-cue-time-constraint and direction (straight-walks v. right-turns).

Summary Review of Methods

This study employed a quasi-experimental design as a convenience sample was used consisting of 10 young (21-40 years) and 10 elderly (65 to 75 years) healthy-adults with intact cognitive ability as measured with the MMSE and low-fall-risk functional-balance assessed with both the DGI & ABC scale. The methods, instrumentation & procedures called for participants to perform separate preferred v. fast-comfortable walking speed blocks of 18 trials along a 14’ (518 cm) Gaitrite[b] carpet, and once stepping-off either continue straight or change direction within a trapezium shaped turn-zone area bordered with four red- hazard-floor-cones (width: front 73 cm, rear 155 cm; depth: front-to-back 95 cm) (Figure 8), based upon a random early v. late visual cue for direction (from an eye-level signal light located beyond the straight-path) triggered at instant of foot contact with one of two programmable hidden switch-mats placed 4.45 m v. 1.2 m, respectively, before the start of the turn-zone.

Spatial-temporal gait adaptations when approaching the turn were recorded using the Gaitrite. However, as the last 55 cm of the Gaitrite carpet lacked pressure sensors, data for the ultimate foot used to pivot the turn was not available; and given more than half of late-trials were cued upon contact of the penultimate foot, little information was gathered on post-late-cue “reactive” gait changes (a limitation of instrumentation within the study). In order to simplify interpretation of findings, only straight & right-direction turns were assessed, although participants were nonetheless randomly cued for an equal number of left-turn trials.

Turn strategy performance was captured using one front-view video camera and measured using Kinovea[a] software. Operant definitions were formulated using: a) previous qualitative descriptions of wide BOS step-turns v. narrow BOS spin-turns (Patla et al., 1991; Hase & Stein, 1999; Taylor et.

al., 2005; Xu et al., 2006; Strike & Taylor, 2009), b) a crude estimate of whether or not the frontal plane widening or narrowing in step-width amplitude met a threshold proportion of change relative to the preferred-step-width characteristic of energy-efficient straight-gait (Donelan et al., 2001) with some indication "small-amplitude" mixed-turns may imply issues with ML stability/balance (Thigpen et al., 2000; Conradsson et al., 2017; Mak et al., 2008), and c) an estimate of the necessity for an extra-footfall before changing direction with some indication use of "extra-step" mixed-turn may imply issues with arresting forward momentum and AP stability (Thigpen et al., 2000; Cao et al., 1997, 1998; Tirosh & Sparow, 2004; Crenna et al., 2001). Based upon this method, intra-rater reliability of the principal investigator for scoring turn strategy preferences across two sessions was found to be excellent (intra-rater Kappa = 0.945).

Summary Review of Analysis

The spatial-temporal analysis was confined to the final-four recorded footfalls on the Gaitrite (i.e. final-two recorded strides) since when early-cued for direction most gait adaptations prior to turning take place across the final-three approach steps (Paquette et al., 2008). As the last 55 cm of the Gaitrite carpet lacked sensors, across trials the final step ended with placement of either the penultimate foot (76%) or ante-penultimate foot (24%), and only 1-post-late-cue-footfall was recordable in just 11% of right-turn trials & 22% of straight trials. The dependent variables of interest being average gait-speed, average stride-length (right & left combined), and separate measures for right H-H BOS & left H-H BOS. No attempt was made to control the foot initiating gait, stride-sequence, nor pivot-foot across all trials. For both age-groups, the finding for each dependent gait variable across response conditions primarily represented a comparison of right-turning v. straight-gait, not right-limb v. left limb. The Gaitrite data for step-turns, spin-turns & mixed-turns were all combined as no difference between step-length & step-velocity has been reported between step-turns v. spin-turns across the final three approach steps when early-cued for 40^0 turns at a preferred speed (Paquette et al., 2008). [A decision was made not to include cadence & double-limb-support-time (DLST) among the dependent of variables of interest as cadence was thought redundant since a similar decrease in speed, stride-length, & cadence has been reported when negotiating a figure-of-eight path (Shkurtova et al.,2004); DLST though a postural control parameter (Paterson et al., 2010) would be marginalized given the inability to record the ultimate pivot footfall which makes the greatest contribution to ML COM acceleration when turning (Glaister et. al., 2008); and as no change relative to straight gait has been reported in either cadence or DLST during continuous 220^0 right curved-path walking (Courtine & Schieppati, 2003)].

Statistical analyses of the data were performed using SPSS version 18 software. A four-way 2x2x2x3 loglinear analysis assessed the categorical data for right-turn-strategy preferences (step-turn, spin-turn, mixed-turn) across age-groups & the combination of response conditions, with any significant 2x3 lower-order interactions split into two 2 x 2 chi-square contingency tables in order to compute effect-size with mixed-turn as the reference (Fields, 2009). A four-way 2x2x2x2 Mixed-Design ANOVA assessed the interval/ratio spatial-temporal Gaitrite data for age-related differences across the same response conditions for the straight v. right-turn direction, with significant interactions interpreted by examining estimated marginal means & interaction plots i.e. slopes, differences between data points (Fields, 2009). In light of hypotheses being stated, no corrections were made for multiple comparisons (Perneger, 1998), and significance was set at $p < 0.05$.

Summary Review of Results

The results for turn strategy preferences revealed no 4-way age*speed*cue*turn-strategy interaction [loglinear K-way effects when k=4: Likelihood ratio $x^2(2) = 1.62$, $p = 0.44$]; however, out of all 24 cells comprising the 2x2x2x3 loglinear cross-tabulation table, the elderly*fast-speed*late-cue*mixed-turn cell was the one achieving a significant standardized residual at +2.4. There were no 3-way interactions for either age*speed*turn-strategy [loglinear partial chi-square association $x^2(2) = 0.41$, $p = 0.82$] or age*cue*turn-strategy [loglinear partial chi-square association $x^2(2) = 1.13$, $p = 0.57$]. There was no 2-way interaction found for age*turn-strategy [loglinear partial chi-square association $x^2(2) = 1.11$, $p = 0.57$] as both groups showed equal preference for spin-turns v. step-turns but performed a minority of mixed-turns (spin-turns 43.8%, step-turns 42.1%, mixed-turns14.2%). However, a speed*turn-strategy interaction [loglinear partial chi-square association $x^2(2)$ =8.41, *p*=0.15] and cue*turn-strategy interaction [loglinear partial chi-square association $x^2(2)$ =16.53, *p*=0.00], when broken-down using separate chi-square tests with Yates's continuity correction, revealed that relative to mixed-turns, preference for spin-turns decreased 3-fold walking fast as opposed to preferred-speed while that for step-turns was statistically unchanged [for spin-turns: chi-square using Yates's continuity correction $x^2(2)$ =6.8, *p*=.009, odds ratio 3.23x lower with 95% confidence interval (1.39, 7.46); for step-turns: chi-square using Yates's continuity correction $x^2(2)$ =3.4, *p*=.066)], yet preference for both step-turns & spin-turns decreased 5.5-fold & 4-fold, respectively, when cued-late for direction as opposed to early [for step-turns: chi-square using Yates's continuity correction $x^2(2)$ =13.8, *p*=.000, odds ratio 5.56x lower with 95% confidence interval (2.23,14.01); for spin-turns: chi-square using Yates's continuity correction $x^2(2)$ =8.2, *p*=.004, odds ratio 4.00x lower with 95% confidence interval (1.60,10.07)].

The spatial-temporal mixed ANOVA results for gait changes upon approach revealed no age-related interactions except for a age*speed trend for the dependent variable combined right/left stride-length suggesting the elderly had less of an increase in stride-length when walking fast as opposed to preferred speed [F(1,18) = 4.33, *p*=0.052 r=0.44, η^2 =.19, power =.50], and a difficult to interpret age*speed trend for the dependent variable right heel-to-heel BOS suggesting only young adults increased right BOS when walking fast as opposed to preferred speed [F(1,18) =4.31, p=0.053, r=0.44, η^2 =0.19, power =0.50]. Outside of these age-related trends, for the dependent variable speed, a main effect for cue showed both groups walked slower when cued late as opposed to early [F(1,18) = 33.10, p=0.00, r=0.80, η^2 =0.65, power =1.0], a speed*cue interaction revealed both groups slowed down more when cued-late while walking fast as compared to preferred speed, and a cue*direction interaction indicated that only when turning right as compared to continuing straight did both groups slow down when cued early F(1,18) = 10.46 p=0.01, r=0.61, η^2 =0.37, power =0.86]. Somewhat mirroring the above speed findings, for the dependent variable combined right/left stride-length, a main effect for cue showed both groups took shorter strides when cued late as opposed to early [F(1,18) = 43.41, p=0.00, r=0.84, η^2 =0.71, power =1.00], and a cue*direction interaction indicated that only when turning right as compared to continuing straight did both groups shorten stride when cued early [F(1,18) = 4.75, p=0.043, r=0.46, η^2 =0.21, power =0.54]. For the dependent variables right & left heel-to-heel BOS, a main effect for direction showed that when turning right as compared to continuing straight both age-groups widened right BOS [F(1,18) = 12.10 p=0.003, r=0.63, η^2 =0.40, power =0.91] yet narrowed left BOS [F(1,18) = 7.95 p=0.011, r=0.55, η^2 =0.31, power =0.76]; and while a cue*direction interaction indicated both groups widened right BOS only when cued-early to turn right as opposed to late [F(1,18) = 9.28 *p*=0.007, r=0.58, η^2 =0.34, power =0.82], a cue*direction*speed interaction (the only 3-way interaction found) revealed both groups narrowed left BOS when cued early to turn right walking fast but when cued late to turn right at preferred speed [F(1,18) = 5.80, *p*=0.027, r=0.49, η^2 =0.24, power =0.63].

Conclusions, Practical Considerations & Further Research Suggestions

In drawing conclusions from the findings, to the best knowledge of the principal investigator, the present study appears to be the first to report on the interaction of both speed (preferred v. fast) & cue-delivery time (early v. late), and compare age-related differences in approach phase spatial-temporal gait changes & turn-strategy preferences when both groups were subject to similar response conditions for a permanent direction change within the same study. However, while not considered during the initial planning or data-collection phases, it later became apparent the presence of above-ground physical objects bordering the turn-zone needed to be taken into consideration when interpreting the findings, particularly from the vantage point of safety-clearance-space, visual-information scanning & attention-resources needed to process complex landscapes. In considering the trapezium-shaped dimensions of the turn-zone area (Figure 8.), whereas the rear-two hazard floor cones were fairly widely spaced 155 cm apart, the front-two hazard floor cones constrained or “bottlenecked” entry into the turn-zone to a width of just 73 cm. This entry width was narrower than the minimum width requirement of both door entry into office-suites (81 cm) & hallways (91 cm) as stated in the American with Disabilities Act of 1990 (Office of Compliance, US Congress & Legislative Branch, 2008).

Surprisingly, despite the need to often function within cluttered environments, rather than using an above-ground physical object at each corner-bordering the turning area as in the present work and a couple of other turning studies (Cao et al., 1997; Conradsson et al., 2017), most prior turning-task research has instead defined the turn location either using an above-ground physical object at just one-corner (Huxham et al., 2006, 2008; Glaister et al., 2008; Fino et al, 2014, 2015) or with force-plates, floor-markings, or floor-mats [(Patla et al., 1991; Patla et al., 1999; Hase & Stein, 1999; Hollands et al., 2001;Thigpen et al., 2001; Taylor et al., 2005; Hollands et al., 2010; Hollands et al., 2014; Xu et al., 2004, 2006; Fuller et al., 2007; Paquette et al., 2008; Strike & Taylor, 2009; Akram et al., 2010; Mari et al., 2012; Mak et al., 2008; Lenoir et al., 200)]. Hence in interpreting the findings of the present study, although visual-gaze was not assessed (i.e. gaze fixation locations or visual-sampling/saccadic eye movements) nor a traditional dual-task paradigm (Al-Yahya et al., 2011) incorporated in the methodology, besides a biomechanical perspective, potential issues involving time-sharing between foveal & ambient visual resources (Wickens, 2002, 2008) and greater visual sampling to preserve a personal space safety envelope (Gérin-Lajoie et al., 2005) & associated data processing costs affecting gait (Gérin-Lajoie et al., 2006; Stuart et al., 2017) also needed consideration when attempting to draw meaningful conclusions.

With the foregoing in mind, the following practical considerations & further research suggestions are offered based upon the turn strategy & spatial-temporal results:

Inclusion of spin-turns in training for healthy elderly adults at low-fall-risk & no age-related decline in gait speed would appear to be appropriate as spin-turns may be ML space-efficient (although possibly less AP space efficient); further research is needed on the relationship between turns-strategy preferences & spatial constraints, and minimum ML foot-to-object safety margin

Inclusion of spin-turns in gait training programs for otherwise healthy elderly at low-fall-risk & no age-related decline in gait speed seems warranted, as despite the greater challenge to balance & risk for tripping, older adults continue to use this strategy possibly for its ML space efficiency, and perhaps even more so when direction cannot be anticipated and the environment is somewhat cluttered. Yet as spin-turns utilize a longer step-stride length, similar to the way they may be beneficial in areas spatially constrained in the ML, they may be less desirable when AP space is constrained. Additional research appears warranted to assess potential relationships between turn-strategy preferences, space-efficiency, & even AP v. ML margin of stability, and also determine the typical minimum ML foot-to-object safety margin distance of the turn-execution swing-limb & its variability across age-groups, task constraints (speeds, direction-cue response times, DTC) & environmental conditions (turn-angles, obstacle heights).

Previous research comparing both age-groups for a circumvention task in which there was ample side-clearance has shown that when free to choose direction, the elderly (as compared to young adults) show an even greater preference for a step-wide strategy (as opposed to a step-narrow) strategy when avoiding the obstacle i.e. step-wide strategy: elderly 81% v. young 63% (Hackney & Cinelli, 2013). Yet despite this overall preference & biomechanical advantage previously reported for wider BOS step-turns over narrower BOS spin-turns (Patla et al 1999; Hase & Stein, 1999; Taylor et. al. 2005, 2006; Xu et al., 2006), in the turn environment of the present study, which was spatially-constrained in the ML more so than AP plane by the presence of safety hazard cones bordering the trapezoid shaped turn-zone (figure 8) beginning at the edge of the GaitRite carpet (73 cm wide in the front, 155 cm wide in the back, and 95 cm deep), both healthy young & elderly adults showed overall equal preference for both step-turns v. spin-turns (collapsing for speed & cue), and a fairly similar preference pattern across response conditions . So the present study would be in somewhat agreement with other research suggesting that despite the greater biomechanical challenge, healthy elderly continue to use a sizable percentage of spin-turns (Akram et al., 2017; Conradsson et al., 2017).

Surprisingly, in a “field” (non-laboratory) study using video analysis, in which the frequency of straight v. non-linear steps taken by young adults across various real-life settings was quantified, although the percentage of non-linear/direction-change stepping was greatest in confined environments (i.e. a busy cafeteria v. exiting an office into a parking lot) only step-turns were observed on video, spin-turns were reportedly not seen regardless of the level of architectural constraint (Glaister et al., 2007). However this field study by Glaister et al., 2007) should be interpreted with caution as spin-turns were only very narrowly defined as “spinning” on the stance-foot, and participants were filmed using a posterior view which may have hindered observance of limb-crossing. Recently, when walking along a curved path having a width of 0.5 m marked with floor tape, which allowed for a “gentle” 90^0 direction change (radius of curvature = 2.75 m), after observing that young adults pivot the trunk & swing the outer-limb around the inner-limb in a manner resembling spin-turns, it was suggested that the frequent need to negotiate curved-paths (i.e. “gentle” turning) may somehow be an indicator as to why spin-turns are also used during more abrupt “online” turning off a straight path (Peyer, Brassey, Rose & Sellers; 2017). Thus, despite Glaister et al., (2007) reporting that young adults fail to use spin-turns even in architecturally spatially “tight” environments, the present study is nonetheless suggesting that the smaller minimum foot separation required of spin-turns (Taylor et al., 2005) may make this strategy more ML spatially efficient &

better suited for cluttered environments in which there is risk of tripping over above-ground floor objects. From this stand point, a ML spatially constrained entrance to a turning area may act as a “buffer” against age-group based turn strategy preferences, with preservation of a ML personal-space safety margin (Hackney & Cinelli, 2013) seemingly at odds with the ML biomechanical stability provided by step-turns (Patla et al., 1991; Taylor et al., 2005: Akram et al., 2010; Xu et al., 2004; Taylor et al., 2006).

Although previous research has shown young adults prefer step-turns over spin-turns when late-cued (Patla et al., 1991; Hase & Stein, 1999), in the present study which was somewhat spatially constrained with an above-ground object at each corner, relative to mixed-turns, when late-cued (as opposed to early) preference for step-turns decreased 5.5-fold while that for spin-turns 4-fold in both age-groups (Appendix O). Perhaps uncertainty of direction prohibited approach phase anticipatory COM displacement opposite the direction change needed to preserve ML personal-space (Hackney & Cinelli, 2013; Vallis & McFadyen, 2003; Gerin-Lajoie et al., 2005, 2008) & foot clearance between the sizeable “step-out” of step-turns (Huxham et al., 2006, 2008; Mari et al., 20120: Strike & Taylor, 2009) and an object present at the turn corner. Thus when an unanticipated turn is performed in a somewhat constrained environment bordered with physical objects, the space-efficiency of spin-turns may be more desirable. As such gait-training programs for healthy elderly at low-fall-risk would benefit from the inclusion of spin-turns.

Further research assessing potential relationships between turn-strategy preferences & varying levels of spatial clutter is needed.

Additionally, although for both age-groups a consistent ML shoulder-to-object safety margin distance has been identified when circumventing (Hackney & Cinelli, 2013) and a typical vertical toe-clearance distance has been reported during obstacle crossing (McFadyen & Price, 2002), research appears warranted to also determine the typical minimum ML foot-to-object safety margin distance of the turn-execution swing-limb during the step-out of step-turns & cross-over of spin-turns. A foot-to-obstacle safety margin distance or clearance space would likely be dependent upon a multitude of factors including trunk-sway i.e.ML COM variability (Hackney & Cinelli, 2013); whether the final location of the obstacle is uncertain as well as dual-tasking (Gerin-Lajoie et al., 2006); walking speed especially in threatening environments (Gerin-Lajoie et al, 2008); and obstacle dimensions (Fino et al., 2015). Accordingly, the minimum ML foot-to-object safety margin distance & possibly variability measures of the turn-execution swing-limb should also be examined across tasks & environmental constraints.

Furthermore, as spin-turns appear to utilize a longer step-length when compared to step-turns across both the ultimate pivot step & turn execution step (Mari et al., 2012; Paquette & Vallis et al., 2010), and as a longer step/stride-length has potential to increase the AP stability margin (Hof, 2008;

Hak et al., 2013; Suptitz et al., 2013; Chen et al., 1994), spin-turns may have potential to be of benefit to stability in the AP lane when attempting to arrest forward momentum which imposes a major challenge to turn performance when response time is constrained (Cao et al., 1997, 1998). However, similar to the manner in which a wider BOS benefits ML stability (Taylor et al., 2005; Patla et al., 1991) yet may be less efficient for ML space, while the longer step/stride-length of spin-turns may be of benefit to AP stability (Hof, 2008; Hak et al., 2013; Suptitz et al., 2013; Chen et al., 1994) when approaching turns, the longer step/stride-length may possibly be less AP space efficient. In the present study that did not appear to be so much an issue as the depth of the trapezium shaped turn zone was 95 cm (Figure 8.). Nonetheless, situations can arise where a turning area is spatially constrained in the AP dimension causing the longer step/stride-length requirement of spin-turns over step-turns to be undesirable, similar to the way the wider step-width/BOS requirement of step-turns would appear to be undesirable in an area spatial constrained in the ML dimension. Moreover, as A-P braking GRFs at the ultimate pivot foot have been reported to be less for spin-turns (Taylor et al., 2005) yet the challenge to modulating ML GRFs greater for spin-turns (Patla et al., 1991) especially at fast speed (Xu et al., 2004), the longer step/stride-length of spin-turns (Mari et al., 2012; Paquette & Vallis et al., 2010) likely is of little benefit to increasing preference for spin-turns over step-turns across response-time conditions. Further research into ML v. AP space-efficiency v.

stability margin for both strategies appears warranted as well as looking for any association between step/stride-length changes and turn strategy preferences.

Gradual progression of training which introduces clutter into the turning area; initial avoidance of faster-than-preferred speeds to facilitate use of spin-turn strategy

Gait training for walking turns would benefit from practice in which a graded progression of floor obstacles (i.e. clutter) is introduced into the turn environment. Manipulating environmental spatial constraints when training has already been suggested within the context of stationary 360^0 turning atop floor squares as, although turn strategy preferences were not examined, it was nonetheless observed that healthy elderly age-matched controls (and even more so those with Parkinson) require a greater number of combined forward/backward steps to turn in-place as the area of the floor squares decreased (Fietzek, Stuhlinger, Plate, Ceballos-Baumann, & Botzel, 2017).

However, to encourage use of more space-efficient spin-turns, it is also being suggested that faster-than-preferred “hurried” walking speeds should initially be avoided. In the present study, the greater biomechanical demand and lateral-body lean required when turning at fast speed (Orenduff et al, 2006; Xu et al., 2004; Fino & Lockhart, 2014; Fino et al, 2015) as expected likely reduced the preference for spin-turns (Akram et al., 2010) 3-fold relative to mixed-turns while preference for step-turns was statistically unchanged

(Appendix 0). Thus, attempts to encourage use of narrower BOS spin-turns over wider BOS step-turns in spatially confined environments may be thwarted by practice at fast as opposed to preferred walking speeds.

Use of “extra-step” mixed-turns rather than “small-amplitude” mixed-turns in healthy elderly at low-fall-risk & no-age related decline in gait speed may be an early indicator of decreased turn performance, increased risk of foot-object contact, & possible AP rather than ML stability issues; further research on mixed-turn sub-groups is needed not only within the context of visual-information processing but also since “extra-step” taking could be a strategy to also aid ML stability

When hurried with future direction uncertain, the taking of an extra footfall rather than the use of “small-amplitude” turning, may be an early indicator of turn performance decline in otherwise healthy elderly adults at low-fall risk (and possibly to a greater extent if taken in order to by-pass the expedient use of a spin-turn), potentially signify greater risk for object contact when turning in cluttered environments, and possibly hint at issues involving AP rather than ML stability. Further research is needed to study a larger sample to assess age-related*turn-strategy preferences for the various mixed-turn sub-types (i.e. “extra-step” v. “small-amplitude” sub-groups) not only across response conditions but also within the context of cognitive processing of visual information and the potential for extra-step taking being a strategy to aid an underlying issue with ML stability.

While no age-group* turn-strategy preference relationships were seen across all response conditions (i.e. preferred & fast walking speeds, and early & late cue constraints), BOS widening step-turns & BOS narrowing spin-turns were equally preferred by both groups over mixed-turns (spin-turns 43.8%, step-turns 42.1%, mixed-turns 14.2%)(Table 13). The operant definition for mixed-turn was largely based upon a previous suggestion that the use of partial pivots & extra steps when performing the 180^0 direction change of the TUGS may be an early-indicated of lower turn-proficiency in the elderly (Thigpen et al., 2000), and as such for the purposes of the present study mixed-turns included both small-amplitude change in BOS turning (i.e. sub-threshold widening for step-turns or narrowing for spin-turns relative to straight-gait) & the taking of additional steps to execute the turn (i.e. failing to turn at a similar AP location where the turn was previously initiated at the same speed). Interestingly, despite the absence of any age-group* turn-strategy preference across response conditions, the elderly-group*fast-speed*late-cue*mixed-turn cell was the only one out of all 24 cells within the loglinear 2x2x2x3 contingency table to have a significant standardized residual beyond +/-1.96 (Table 6, Figure 9); and of all four mixed-turn sub-groups represented in this one cell, the extra-footfall step-turn sub-group made the greatest contribution and was most biased towards the elderly (observed count: elderly 7 v. young 1) (Appendix AA). This is consistent with the findings of middle-aged/older adults taking an extra-step on a higher percentage of trials when late-cued in order to by-pass a large v. small angle spin-turn as opposed to step-turn (Mari et al., 2012); the elderly needing a longer response time (523 v. 408 ms) & response distance (68 v. 53 cm) to turn 90^0 within one step following a late-cue (Cao et al., 1997, 1998); the elderly more often taking an extra step for an unexpected rapid lane-shift than young adults, but especially in order to by-pass crossing-limbs as compared to side-stepping (Gilchrist, 1998); and a second short step more often required when unexpectedly terminating gait while walking fast as opposed to at preferred speed (Crenna et al., 2001); and the elderly more frequently needing two as opposed to one-step to unexpectedly terminate gait requiring a longer stopping time yet similar stopping distance given the second step is often short not advancing beyond the first (Tirosh & Sparrow, 2004). It is also worth noting that in the present study, when combining all turn-strategies, the percentage of trials in which the elderly (compared to young adults) required a response distance of 2-post-late-cue-footfalls as opposed to just 1 post-late-cue-footfall was approximately 10% greater at both speeds; however, the difference in percentages between the two age-groups were not found to be significant (Appendix C). It is for all these reasons that despite the loglinear analysis showing no 4-way age-group*speed*cue*turn-strategy preference relationship (Table 7-10), it is nonetheless being suggested that the taking of an extra footfall when hurried with future direction unknown, may be a strategy used by healthy older adults & an early-marker for reduced turn-performance, and possibly even more so if taken in order to by-pass an unexpected spin-turn (in favor of a step-turn) (Gilchrist, 1998; Mari et al., 2012). The other clinical implication is the need for an extra step may increase the risk for contact with nearby objects (Gilchrist, 1998) and possibly be the cause of some elderly falls (Tirosh & Sparrow, 2004).

Additionally, attentional resources needed to visually process a late-visual cue and sample the immediate environment may be especially taxing on the elderly. Namely, a secondary visual-spatial attention task one step prior to obstacle crossing has been shown to negatively affect limb clearance (Lo et al,.2015) & avoidance success especially in the elderly (Chen et al.,1996). Following a late-direction cue to circumvent, older adults have been found to be more proactive in visually scanning the ground beyond the obstacle & gathering more feedback information to ensure safe passage (Paquette & Vallis, 2010). An increased need for visual sampling when circumventing, particularly when an obstacle's final location or path is uncertain, has been suggested to incur greater mental processing costs on gait both without a dual-task paradigm (Gerin-Lajoie et al, 2005), and with a dual-task paradigm (Gerin-Lajoie et al, 2006). The need for online visual-motor control when negotiating a terrain is believed to increase as threats to stability within the environment increase (Patla & Vickers, 2003). When AP balance is randomly perturbed in standing, the limits of stability appear to shrink when there is competition for cognitive resources; hence, when performing a serial 3's subtraction task, a stepping response has been shown to be initiated with the COM further from the BOS margin in both groups, yet especially in the elderly who more frequently used a stepping-strategy to recover balance (Brown et al.,1999). This observation that BOS limits of stability may decrease when cognitive resources are challenged is worth juxtaposing side-by-side to previous finding that the elderly more frequently took two-steps after visually late-cued to terminate gait, with a greater percentage of elderly two-step stopping responses employed unnecessarily with the COM within the anterior-posterior stability boundary relative to young adult two-step stopping responses (86% v. 36%), however rather than a dual task interpretation the additional step was interpreted as being pre-planned with the intension of aiding medial-lateral stability (Tirosh & Sparrow, 2004).

Hence, further research on a larger sample size is needed to asses age-group*turn-strategy preference relationships not only across response conditions, but also within the context of the cognitive resources needed to visually process increasing amounts of environmental information, in order to sort-out associations with the various mixed-turn sub-types (“extra-step” mixed-turns v. “small-amplitude” for both step-turns & spin-turns), as “extra-steps” may imply issues involving containment/arrestment of forward momentum or balance (Cao et al., 1997; Tirosh & Sparrow, 2004; Crenna et al., 2001) or possibly time-sharing of attentional resources (Brown et al.,1999), whereas “small-amplitude” turning may imply issues involving ML balance & sideways falls (Conradsson et al., 2017; Mak et al., 2008). At the same time, the picture might not be so clear, as use of “extra-step” mixed-turns apparently could take on the form of an intentional strategy to aid ML stability when unexpectedly terminating gait (Tirosh & Sparrow, 2004) with greater stride-frequency also being suggested as a strategy to increase the ML margin of stability (Hak et al., 2013). Although further investigation is needed and no statistical conclusion can yet be reached given all mixed-turn subtypes needed to be combined to meet loglinear assumptions, given that 9 of the 12 mixed-turns in the elderly-group*fast-speed*late-cue*mixed-turn were of the “extra-step” variety (with the remaining 3 of 12 falling in the “small-amplitude” sub-group) (Appendix AA), these findings may hint that in healthy elderly at low-risk for falls, early declines in turn performance when gait is hurried & direction uncertain may have more to do with issues in AP stability i.e. arresting the COM within the available response timeless (Cao et al., 1997, 1998), and less to do with ML stability (Conradsson et al., 2017; Mak et al., 2008).

Healthy low-fall-risk seniors without functional impairments or age-related declines in gait speed may benefit from turn approach training targeting containment of forward momentum & preservation of the anterior margin of stability through backward body leaning & minimizing the extent of step/stride-length shortening

In healthy seniors without ADL functional impairments & no age-related decline in walking speed, gait programs to reduce the risk for forward tripping during the turn approach phase, particularly when direction is unknown, may benefit from training which targets slight backward body leaning & preservation of the anterior margin of stability (i.e. anterior-posterior BOS) by minimizing the loss in penultimate or ultimate step-length/stride-length to no greater than approximately 15-20% the baseline value.

In the present study, when direction was known in advance, both age-groups reduced speed (Table 30, Table 32, Figure 15-16) & stride length (right/left combined) (Table 33, Table 35, Figure18-19) only when needing to turn right as opposed to continue straight; additionally and perhaps of clinical relevance when direction unknown (relative to when direction was known in advance) both age-groups reduced speed (more so when walking fast Table 31, Figure 13-14) & stride length (Appendix U). Additionally, a trend was seen for less of an increase in elderly stride-length when walking fast as compared to at preferred speed (irrespective of direction or whether or not direction was known in advance)(Table 34, Figure 17); however, no significant age-related differences were seen in gait speed whether walking at a preferred or fast pace (Table 30, Appendix Q)

Slower speeds & shorter strides when approaching turns have been suggested to be fundamental for successful turning, contribute to preserving a stable base of support (Strike & Taylor, 2009; Dixon et al., 2013; Huxham et al., 2008), reduce forward momentum & instability in both age-groups during figure-eight-walking (Shkurtova et al., 2004), and buy planning time when future direction is unknown. Yet, given the greater extent to which reductions in step-length & speed have been reported in the elderly when approaching a direction change regardless of early v. late cuing, healthy older adults have been described as being more conservative & cautious (Paquette et al., 2008; Paquette & Vallis, 2010). A decrease in elderly stride-length has been suggested to be the consequence of a reduction in push-off power generation and an adaptive strategy used by the elderly to minimize forward & upward perturbations during straight gait (Winter et al., 1990). Additionally, although older adults in the present study were able to significantly modulate gait when walking fast as compared to preferred speed, the present study's finding showing a trend for less of an elderly increase in stride-length at fast-speed relative to young adults has previously been reported during linear walking again likely suggesting an attempt to minimize perturbations acting on the body when accelerating (Shkuratova et al., 2004).

During straight gait, slower speeds & shorter steps used by older adults have been shown to minimize accelerations at the head & pelvis, and given the absence of an age-related difference in harmonic ratios, suggest as a conservative elderly strategy to compensate for physiological declines so as to aid stability/reduce fall risk (Menz, Lord, & Fitzpatrick, 2003). Yet despite the belief that head & pelvic accelerations disturb gaze & posture, in young adults stability on the whole as measured using harmonic ratios has not been found to be greatest (the higher the value the greater the stability in the acceleration signal) when taking slower-shorter steps, but rather at the preferred speed & step-length (and cadence as well), with preferred parameters optimizing head & pelvic stability in the vertical & AP planes while at the same time affording adequate-enough stability in the ML plane (Latt, Menz, Fung, & Lord, 2008).

Moreover, based upon an inverted pendulum model of gait and extrapolation of the COM, a forward loss in balance (i.e. the COM advancing excessively forward relative to the COP) can be precipitated by a sudden exceedingly shorter-than-average-step-length which decreases the anterior margin of stability, requiring a transient increase in length of the ensuing step (if step-time is held constant) in order to compensate & restore the steady-state pattern immediately afterwards (Hof, 2008). A sudden precipitous decrease in step-length during pre-crossing of a late-cued step-over task has been observed to precipitate tripping when walking at a hurried speed, with momentum carrying the COM forward beyond the reduced BOS even despite the attempt of an additional step & the absence of physical contact with an object (Chen et al., 1994). If a comparison is allowed between the need to arrest the forward momentum of the body when making an unanticipated turn, with the need to arrest the forward momentum of the body after advancement of a right swing-limb is momentarily halted when walking along a straight path, it has been found that the capacity to lengthen the AP BOS (toe-to-toe anterior-posterior distance) beyond its baseline value at the subsequent 1st left step following placement of the perturbed right foot (i.e. at the 1st recovery step) allows younger adults to return to their baseline anterior-margin of stability within just 2 recovery steps (hence lowering their risk of falling forward); yet as middle aged-older adults do not enlarge their AP BOS beyond its baseline value at the 1st recovery step require 5 recovery steps to return to their baseline anterior-margin of stability (Suptitz, Catala, Bruggemann, & Karamanidis, 2013).

As either an increase in speed or decrease in stride-length has been reported to enlarge the backward margin of stability to guard against a posterior fall from a slip, gait training for longer strides has been suggested to have a net benefit of enhancing backwards stability as any decrease in the posterior margin caused by a 20% increase in stride-length has been reported to be more than compensate for by a 20% increase in speed (Hak, Houdijk, Beek, & Dieen (2013). Yet any decrease in the risk of falling backward derived from an increase in the posterior margin of stability, would tend to increase the risk of falling forward; hence, the decision of whether to target the posterior v. anterior margin of stability when training has been suggested to be task-dependen t i.e. preserving the anterior/forward margin may need to be prioritized when the risk of a forward trip is high as when descending a curb (Hak et al., 2013). Additionally, in the elderly it has also been reported that at mid-swing, the position of the COM relative to the COP is anterior in those with a past history of falling forward from a trip, yet posterior in those with a past history of falling backward from a slip, suggesting that not only the task but also a patient's fall history may need consideration when deciding to use gait training to enhance either the posterior v. anterior margin of stability (Wright, Peters, Robinson, Watt, & Hollands (2015).

As 99% of turn failures in both young & healthy older adults have been attributed to the inability to arrest the forward momentum of the COM from advancing beyond the turning location within the available response time after a late-direction cue (Cao et al., 1997) for healthy active seniors with no fall history the risk for falling forward from a trip upon approach may be greater than the risk for falling backward from a slip. Additionally, although the odds of hip fracture in the elderly may be greater from a fall while turning as opposed to a fall during straight gait, primarily because of the greater likelihood of landing sideways (Nevitt and Cummings, 1993 Cumming & Klineberg, 1994), there is suggestion that preservation of gait speed in the elderly may lessen the chance of sideways hip impact (thought to increase the risk for hip fracture) as the likelihood of a sideways fall from a slip has been shown to decrease at fast speeds (i.e. greater likelihood of falling forward) but increase as at slower speeds when simulated in young adults (Smeester, Hayes & McMahon, 2001). Furthermore, older adults who sustain a hip fracture from a trip have been shown to have higher pre-injury functional ADL scores compared to those whose hip fractures were attributed to a loss of balance - with a trend also seen when comparing tripping v. slipping hip fractures (Matsui, Harada, Takemura, Terabe, & Hida, 2014). Hence, the risk for suffering a hip fracture from a forward tripping fall, as opposed to a sideways fall, may possibly be greater in those seniors who are most healthy, active & functionally independent and show no age-related decline in gait speed. In addition, findings in the present study may also suggest that AP stability rather than ML issues may be more involved in early turn performance declines in healthy elderly at low-fall risk without age-related declines in gait speed, including both age-groups appeared equally tolerant of the ML disequilibrium required to initiate turns (i.e. no age-related difference was seen in left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed); and when hurried with future direction uncertain, although not considered statistically significant, 9 of the12 elderly mixed-turns were found to be of the “extra-step” variety possibly hinting at more difficulty arresting forward momentum (Cao et al., 1997, 1998; Tirosh & Sparrow, 2005; Crenna et al., 2001), whereas only 3 of the mixed-turns were of the “small-amplitude” variety to possibly suggest ML stability issues (Conradsson et al., 2017; Mak et al., 2008) (Appendix AA). All this taken-together may suggest that gait training specifically for approaching a turning task with healthy older adults at low-fall risk and no decline in gait speed may potentially be best targeted to preserving the anterior margin of stability, more so than the posterior or possibly even ML margin; and while targeting preservation of the anterior margin of stability may be worth considering for those with a history of forward falls from tripping, this strategy does not appear to be advisable for those with a history of backward or sideways slips or falls.

As a systematic increase in both turn angle & backward body leaning has been observed during push-off of the penultimate footfall with direction known in advance, the use of backward body leaning as an anticipatory postural adjustment has already been suggested to slow the forward trajectory, minimize postural disturbance & lessen the risk for falling when approaching turns (Xu et al., 2004). To this the present study would also add that when direction cannot be anticipated, training to minimize the shortening in penultimate or ultimate step-length so as to safeguard the anterior margin of stability may help make it less likely for the forward momentum of the COM pass beyond the turning point. It is being suggested here that any decline in step-length not exceed approximately 15-20% the baseline value so as to lessen shrinkage in the anterior margin of stability and thereby reduce the risk of tripping forward upon approach. Minimizing the lost in step-length/stride-length to no greater-than approximately15-20% baseline appears to be a reasonable estimate given the 12% reduction in final stride-length & step-length (relative to straight gait) previously reported in young adults abruptly turning 90^0 at preferred speed with direction known in advance (Strike & Taylor, 2009); the 14.9% v. 20.6% decrease in turn approach stride length (relative to straight gait) reported in young v. elderly adults walking along a 25 m corridor to change direction during the 6 minute walk test; (Mariani, Hoskovec, Rochat, Bula, Penders & Arminian, 2010); and the 16% v. 21% reduction in final step-length ending in ultimate pivot foot placement (relative to unobstructed walking) previously reported in young v. older adults, respectively, late-cued to circumvent at preferred speed (Paquette & Vallis, 2010). Preserving the AP BOS may be even more critical at fast speeds given negative AP margins of stability (i.e. COM shifts behind the posterior border of the AP BOS) are more likely as gait velocity increases (Suptitz et la., 2013).

In the present study, the percentage decrease in stride-length was small even when comparing a late-cue to turn-right relative to an early cue to continue straight, with the shortening of stride amounting to less-than 5% at either walking speed. Hence, only a 3.6% decrease in stride length was seen at preferred speeds when cued-late to turn-right as opposed to cued-early to continue straight (late-right 1.582 v. early-early straight1.641 LL), and only a 4.2% decrease in stride length was seen at fast speed when cued-late to turn-right as opposed to cued-early to continue straight (late-right 1.850 v. early-early straight1.931 LL) (Appendix T). However, the relatively small percentage of decrease in stride-length found in the present study likely resides in the limitation in instrumentation not allowing Gaitrite data to be recorded for the ultimate pivot footfall. As previously mentioned, when combining speed & cue conditions, in 76% of trials the final recorded stride-length ended with the penultimate footfall & in the remaining 24% of trials the antepenultimate footfall. Additionally, as only two strides of data were recorded per trial, data for the final two strides (i.e. right & left strides) of each trial were combined & averaged to simplify interpretation. Thus, the stride-length data of the present study did not equate with the final approach stride of prior studies, but instead in the majority of trials the stride-length data represents an average of the two strides preceding the final approach stride and hence a comparison is not justified.

In light of visual scanning & processing costs during turn approach, training may benefit from initial practice as more of a closed-motor-skill (static object location known/unknown) progressing to more of an open-motor skill (moving object, trajectory known/unknown); active visual scanning to transition areas where a path divides may be supportive if future direction is uncertain

In light of the potential for visual scanning & processing costs to impact speed/step-length, training for a direction change may benefit from a progression in which a tuning task is initially performed as a closed motor skill in an area containing stationary objects placed first in familiar & then unfamiliar locations; and then later performed as a open motor skill in which rather than direction being unpredictable, the area may contain moving objects having first familiar & then unfamiliar trajectories (i.e. simulating unpredictable movements of a pet). Although visual fixations were not assessed, borrowing from strategies used in approach of complex terrains, active visual scanning to transition areas where a path divides & sequentially fixations to the most salient looming features/objects 2-steps ahead may also support a last minute direction change, yet greater online scanning in closer spatial-temporal proximity to limb movements may be needed as threats & unpredictability increases. Monitoring the loss in step-length/stride-length upon approach to ensure it not exceed approximately15-20% baseline again seems advisable.

An increased demand for active visual sampling of the terrain relative to straight gait has been reported during approach of turns with direction known in advance (Patla et al., 1996; Galna et al., 2012). The axial-segment reorientation onset when approaching turns has a cephalo-caudal sequence (Hollands et al., 2001; Paquette et al., 2008), with head reorientation beginning about 1.1 m (slightly less than stride-length) prior to assuming the new travel path (Prevost et al., 2002; Sreenivasa et al. (2008); yet even before the onset of head reorientation, saccadic flicks into the new travel path lead the way. Not surprisingly, a slower approach speed which reduces the frequency content for head motion has been suggested to be of benefit to both the vestibular-ocular reflex & vestibulo-collic reflex reorientation response (Imai, Moore, Raphan & Cohen, 2001). Relative to preferred speed straight gait, when negotiating a 1m radius circular path, a reduction in speed (approximately 23%) has been reported, along with less dynamic stability (represented as a higher maximum finite-time Lyapunov exponent at several lower extremity joints) from spatial-temporal, kinematic & kinetic gait changes producing inner v. outer limb asymmetries to displace the COM into the turn

(Segal, Orendurff, Czerniecki, Shofer, & Klute, 2008). Although the taking of smaller steps (& a slower speed) during straight gait has been reported to result in the smallest acceleration RMS (root mean square) at the head & pelvis in all planes, and highest harmonic ratios at the head & pelvis in the ML plane (suggesting ML stability), it is worth recalling that walking straight at a preferred speed & step-length has been found to optimize head & pelvic stability in the vertical & AP planes yet still afford satisfactory ML stability (Latt et al., 2008).

But besides a purely biomechanical explanation, some portion of the loss in speed & stride-length when cued-late with direction unknown & when cued-early to turn right may have come from actively fixating gaze/scanning & attention-resources needed to process visual-information to safely stay clear of above-ground physical objects (i.e. hazard cones) bordering the trapezium-shaped dimensions of the turn-zone. For both a closed motor task of circumventing a stationary obstacle and even more so an open motor task of circumventing an obstacle in motion, a decrease in speed in both age-groups has been reported and attributed to greater visual sampling & data processing costs to preserve the personal space safety margin even without a dual-task paradigm, yet the extent of slowing is greater (especially in the elderly) when circumventing during dual-task listening to a message (Gerin-Lajoie et al, 2006). Dual-task costs are known to decrease both speed & stride-length (Al-Yahya et al., 2011; Simoni, Rubbieri, Baccini et al., 2013) and have been suggested to precipitate greater limb stiffness to reduce swing-limb velocity (Weerdesteyn et al., 2005).

Moreover, besides a slower gait, shorter step-lengths particularly across the penultimate & ultimate footfalls have been reported when circumventing an obstacle (without any dual-task paradigm of listening to a message) when the final location/stopping point of the obstacle was uncertain whether stationary (about a 10% reduction) and to an even greater extent when in-motion (about a 14-15% reduction), suggesting that when an obstacle’s final location/path is unknown, there may be even greater online visual sampling & information processing costs needed for integrated monitoring of the current v. targeted COM trajectory (Gerin-Lajoie et al, 2005).

When approaching turns with direction known in advance, regardless of single v. dual-task paradigm, the ability to walk faster and take longer steps across the approach phase have both been associated with a higher saccadic frequency; and relative to both straight gait & single-task turning, a reduction in saccadic frequency in healthy elderly upon approach during dual-task (digit-recall) turning has been suggested to give indication for the attention requirement of saccades when walking (Stuart et al., 2017). Furthermore, in the absence of a dual-task paradigm, when unexpectedly needing to cross over an obstacle dropped less than a step away while walking on a treadmill with gaze fixated on a point two steps ahead (preventing visual scanning prior to object release), although saccades were infrequently needed following object release (just 18% of trials, ≥ 2 saccades each instance, fixation point each instance being the future foot landing spot beyond the obstacle) possibly suggesting that rather than overtly moving the eyes to redirect attention, participants may have instead covertly directed attention towards the obstacle in the peripheral field, caution was expressed that gait tasks & environments with more complex or challenging landing locations other than linear-path treadmill walking may precipitate a greater frequency of visual scanning (Marigold et al., 2007). Therefore, it may not be surprising that in a non-cluttered turn environment with all travel paths defined by floor tape yet free of physical objects, regardless of early v. late cuing (and both before & after the late-cue or transition-stride when early-cued) the majority of the total duration of gaze was spent fixated on environmental locations falling within the current heading rather than at eccentric locations, with the percentage of forward looking gaze carried along by the body (i.e. gaze anchored ahead rather than actively shifted to salient features on the ground) upon approach at about 10% both prior to the late-cue & prior to the transition-stride when cued-early (Hollands et al., 2002).

In the absence of any dual-task paradigm or response time conditions, when approaching a complex multi-surface terrain, forward looking gaze carried along by the body has been found to be much less helpful (employed < 1% of the travel time), with the need for active visual scanning to important features increasing as terrains become more challenging; and there is also suggestion that should the necessity for an unanticipated or rapid change in path arise (at least within the context of complex yet static terrains), visual scans to information-rich transition regions of the ground during the approach phase may allow the brain to then covertly attend with ambient vision to more than one surface - formulating a more comprehensive global-spatial map -to better direct future safe foot landing, and that sequential small portion scans to impending salient features (approximately 2 steps or 1.2 s ahead) - whether through overt active fixations or covert attention shifts within the peripheral vision - provides temporarily stored yet continuously revised spatial-temporal information & trans-saccadic integration for an online internal model of the geography needed to rapidly react when approaching an unpredictable situation (Marigold & Patla, 2007). However, within a multiple-resource model to predict dual-task costs (DTC), the capacity to time-share foveal & peripheral vision presents a greater challenge as two visual information sources become more spatially separated or eccentric to each other (Wickens 2002, 2008; Horrey & Wickens (2004). Thus it may not be surprising that as turn angle increases, even in the absence of a dual-task paradigm, an increase in visual sampling (Patla et al., 1996) & longer onset latency for saccadic eye movement into the new travel path (Hollands et al., 2002) have both been reported. As such it remains to be seen whether the use of covert parafoveal peripheral vision attention shifts to supplement overt active fixations as suggested when negotiating a complex (yet linear) multi-surface walkway (Marigold & Patla, 2007), can be applicable when turning off an eccentric 90^0 path, particularly if tripping hazards are strewn about (Patla et al., 1996).

Hence, with regards to application, in light of the previous concern expressed over an excessive loss in step-length/stride-length potentially precipitating a forward fall (Hof, 2008; Chen et al., 1994; Hak et al., 2013); and the suggestion that active visual scanning & processing costs may partially contribute to a 10-15% loss in step length when circumventing (Gerin-Lajoie et al, 2005), it is suggested that gait training for turns be progressed from a more closed-motor-skill performed in an turn-area containing a slowly expanding number of stationary objects placed first in familiar & then unfamiliar locations (i.e. allowing pre-trial viewing of stationary objects v. blocking viewing with a curtain or large sheet of cardboard until within the final approach steps), to a more open-motor-skill performed in an turn-area containing moving objects having first familiar & then unfamiliar trajectories (i.e. rolling a ball or tumbling a foam bolster first in an anticipated followed by unanticipated direction). Manipulating the location or trajectory of objects within the immediate environment to make turning an unpredictable open-skill, rather than visually cuing with a random direction signal, may be more realistic & applicable to everyday situations. For example, the annual fall injury rate related to dogs & cats has been estimated to be 29.7/100,000 in the overall population, increase with age, result in the highest fracture-rate in elderly 75-84 years, with tripping/falling over pets reported to be the number one circumstance surrounding the fall (66.4% cats, 31.3% dogs) yet falls over inanimate pet items i.e. toy/food-bowl amounting to just 8.8% of falls (Stevens, Teh, & Halleyesus, 2010). As mentioned previously, monitoring the loss in step-length/stride-length to ensure it not exceed approximately15-20% baseline (Strike & Taylor, 2009; Mariani et al., 2010; Paquette & Vallis, 2010; Gerin-Lajoie et al, 2005) again seems justified. Additionally, although visual scanning was not assessed, applying to the present study the same gaze fixation strategies previously reported when approaching to negotiate a complex multi-surface terrain (Marigold & Patla, 2007), yet disregarding any concern as it relates to path eccentricity, active visual scans fixated to transition areas wherein a linear walkway divides may allow covert attention shifts to the surrounding divergent paths within the ambient field, and along with sequential scans to the most relevant imminent features/obstacles approximately 2 steps ahead, may potentially provide a more informative online spatial-map to guide step-length/step-width adaptations (Marigold & Patla, 2007) allowing a safety margin for foot clearance of bordering objects when a last minute direction change is needed. However, if imminent obstacles pose a greater threat to stability (Patla & Vickers, 2003) or an obstacle’s location/path is uncertain (Goodale et al., 2004; Gerin-Lajoie et al, 2005, 2006) greater online scanning closer in proximity of limb movement will obviously be necessary.

Based upon no age-related difference in BOS narrowing when approaching turns, healthy elderly at low-fall risk & no age-related decline in gait speed may be equally as tolerant as young adults to the ML disequilibrium initiated for a direction change. The number of “small-amplitude” mixed-turns suggestive of a ML stability issue being surprisingly low in the elderly even when hurrying with direction unknown may support this view. Juxtaposing spatial-temporal data alongside mixed-turn subtype preferences may help reinforce clinical decisions

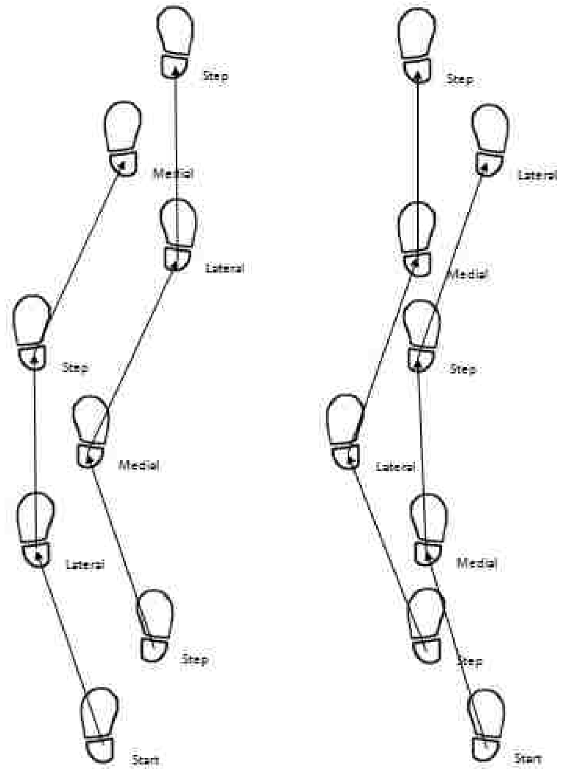
When approaching turns, young & healthy elderly without fall-risk or age-related declines in gait speed may possibly be equally as tolerant as young adults to the ML disequilibrium required to initiate a direction change. Although all four mixed-turn subgroups in the present study had to be combined together as one turn-strategy for the purpose of statistical power, the observed preferences between the two major mixed-turn subtypes (“small-amplitude” v. “extra-footfall” i.e. aka extra-step) may support this view that the healthy participants were tolerant of ML disequilibrium, as even during the most challenging interactive response condition of hurrying with future direction unknown, elderly use of the “small- amplitude” mixed-turn subtype suggestive of a ML stability issue was surprisingly low relative to the number of “extra-step” mixed-turns suggestive of more AP stability involvement (elderly late*fast mixed-turn counts: 3 “small-amplitude” mixed-turns v. 9 “extra-step” mixed-turn). Although further research is needed with a much larger sample size, juxtaposing spatial-temporal data alongside preferences for mixed-turn subtypes may prove helpful in the triangulation process when making clinical decisions with regards to assessment & training approach. Nonetheless, inclusion of other standardized functional balance assessment tools is necessary, even more so as interpretation of mixed-turn subtypes can be misleading.

In the present study, left BOS narrowing was seen in both age-groups when both hurrying to make an anticipated right-turn, or late-cued to turn-right at preferred-speed (Table 39, Table 41, Figure 25- 26). To best appreciate this finding, it is helpful to consider that due to the length of the late-cue mat (0.58 m), the late-cue was delivered upon penultimate foot contact in about 54% of trials, yet upon ante-penultimate foot contact in the remaining 46%. Thus, almost half of late-cue trials would better be described as “quasi”-late, given the cue was delivered upon ante-penultimate foot contact. Moreover, although the present study combined spatial-temporal data for all right-direction turn strategies (step-turns & spin-turns alike), the left BOS narrowing seen when “quasi “ late-cued at preferred-speed and early-cued at fast speed to turn right *(Figure* 28 & 30.) for-the-most-part likely represented anticipatory left stride-width narrowing in approach of right step-turns (Paquette et al.,2008) from use of a medial penultimate foot strategy to assist with regulation of COM acceleration i.e. reduce the COP-COM distance opposite the intended turn direction (Patla et al., 1999; Hollands et al., 2001; Hase & Stein, 1999). When early-cued for right 90^0 step-turns, medial-lateral disequilibrium needed to alter direction and accelerate the COM into the turn has been reported to begin during approach as early as the penultimate footfall with the COM trajectory falling lateral to the COP trajectory at mid-stance particularly at fast speeds (Xu et al., 2004). Given in the present study no age-related difference was seen with regards to the left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed, this may possibly suggest that the healthy elderly group -in whom no significant age-related decline in gait speed was apparent- were equally as tolerant as the young adults to the ML disequilibrium required to initiate turns. Interestingly, it has been suggested that initiation of ML COM acceleration into the turn direction upon approach at the penultimate limb, rather than requiring an increase in muscle contribution to accelerate into the turn, may instead for the sake of efficiency involve more of a decrease in muscle contribution accelerating away from the turn (Dixon et al., 2015).

This finding of no-age related difference in left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed, and any suggestion that it may show both age-groups are equally tolerant to the ML disequilibrium required to initiate turns, obviously needs further study and collaboration. In this particular instance, some indirect support may come from the mixed-turn subtype findings, which although all mixed-turn subgroups needed to be combined in order to meet expected frequency count loglinear assumptions, showed that elderly use of the “small- amplitude” mixed-turn subtype suggestive of a ML stability issue (Conradsson et al., 2017; Mak et al., 2008; Thigpen et al., 2000) was surprisingly low relative to the number of “extra-step” mixed-turns suggestive of more AP stability involvement (Cao et al., 1997, 1998; Tirosh & Sparrow, 2005; Crenna et al., 2001) (elderly late*fast mixed-turn counts: 3 “small-amplitude” mixed-turns v. 9 “extra-step” mixed-turn). As interpretation of an “extra-step” mixed-turn from the standpoint whether it truly represents an AP stability issue (Cao et al., 1997, 1987; Tirosh & Sparrow, 2004; Crenna et al., 2001) v. a ML issue (Conradsson et al., 2017; Mak et al., 2008; Thigpen et al., 2000) must proceed cautiously since an age-related decline in ML stability has been reported (Kavanaugh et al., 2005). Additionally, the taking of “extra-step” mixed-turns can also potentially arise from competition for cognitive resources time-shared with visual scanning & mental processing cost needed to preserve a safety margin distance from nearby objects in the turn area (Gerin-Lajoie et al, 2005; 2006; Stuart et al., 2017) shrinks the BOS stability margin to trigger a step (Brown et al.,1999), or even from an underlying “primary” issue in the frontal plane in the form of an intentional strategy to aid the ML stability marginal (Tirosh & Sparrow, 2004). In this instance with regards to the present study, where no age-related difference was seen in BOS narrowing for the response conditions of both fast*early & late*preferred and lower frequency counts appeared to be tallied for elderly preference of “small-amplitude” mixed-turns relative to “extra-step” mixed-turns for the most constrained response condition of a fast-speed*late-cue, the spatial-temporal data & turn strategy data support each other. Triangulation with other standardized functional balance assessment tools i.e. Multi-Directional-Functional Reach-Test, Berg Balance Scale, DGI (Shumway-Cook & Woollacott, 2012) must always be sought as well when making clinical decisions.

Forward progression alternating zigzag diagonal walking may be of benefit to facilitate use of ML foot strategies to regulate ML COM displacements with progression to include dual-tasking

Gait training for turns may benefit from alternating zigzag diagonal walking at small-angles to the forward progression, reciprocating direction every couple of steps (i.e. four-steps), with the hope of facilitating use of medial & lateral foot placement (& trunk) strategies needed to help initiate & regulate ML COM displacement when approaching turning & possibly contribute to ensuring foot-obstacle clearance. Training using zigzag walking under dual-task conditions may also be clinically relevant.



a. b.

Figure 34. Two examples of zigzag forward progression diagonal walking activities suggested to facilitate use of medial and lateral foot placement strategies needed when approaching step-turns (a) & spin-turns (b). The pattern in each case reciprocates in the other direction every 4 steps so that benefit can be derived for left turns as well.

As already mentioned, the left BOS narrowing observed in both age-groups when both “quasi” late-cued at preferred-speed & early-cued at fast speed fast to turn right (Table 39, Table 41, Figure 25- 26) for-the-most-part likely represented anticipatory left stride-width narrowing in approach of right step-turns from use of a medial penultimate foot strategy to reduce the COP-COM distance opposite the intended turn direction (Paquette et al.,2008; Patla et al., 1999; Hollands et al., 2001; Hase & Stein, 1999). Conversely, it is also believed the right BOS widening seen in the present study when early-cued to turn-right, regardless of speed (Table 36-37,Figure 20-21, Figure 29.), for-the-most-part likely represented anticipatory right stride-width widening in approach of right spin-turns from use of a lateral penultimate foot strategy to better accelerate the COM into the new path direction & help preserve medial-lateral stability within the BOS (Paquette et al.,2008). Thus, for both step-turns & spin-turns, the use of medial & lateral foot placement strategies is seen during the approach phase. Moreover, when these findings are considered with previous observations of systematic preservation of a ML safety envelope from displacement away from obstacles prior to circumventing (Hackney & Cinelli, 2013; Vallis & McFadyen, 2003; Gerin-Lajoie et al., 2005; Gerin-Lajoie et al., 2008) & veering away from corners prior to turning (Taylor & Strike, 2016), taken together would appear to support the inclusion of forward progression zigzag diagonal walking as a precursor activity for turning. Hence, the present study would appear to support the inclusion of zigzag walking to possibly facilitate the use of both medial & lateral foot placement strategies needed to both regulate COM displacement and allow foot-obstacle clearance when approaching step-turns & spin-turns (Figure 34.). Zigzag walking may also be beneficial to regulation of the ML disequilibrium reported to be initiated across the penultimate footfall during the turn approach phase (Xu et al., 2004). As step-width under dual-task conditions has been reported to both increase (Klein et al., 2015), and either increase or decrease depending upon the task with associations seen between the magnitude of step-width change & fall risk (Nordina et al., 2010), practicing zigzag walking under dual-task conditions may also be of benefit. The inclusion of zigzag walking agility drills with cognitive-motor interference has already been advocated for in exercise-based fall prevention programs (Donath, van Dieen, & Faude, 2015).

When hurried & a future change in path is uncertain, a concurrent precipitous shortening of stride & narrowing in BOS upon approach of turns may increase the risk for tripping over one's own feet especially in the elderly if attention is distracted

When response-time to turn is constrained either by a hurried fast-speed or uncertainty about turn direction, BOS narrowing from use of a medial foot strategy in strides ending in either the penultimate footfall for step-turns or ultimate footfall for spin-turns, if concurrent with a precipitous loss in stride-length, could potentially make the risk for tripping over one's own feet greater when approaching turns as would otherwise be expected when just continuing along a straight path. The risk for tripping over one's own feet may be greatest when hurrying in approach of an unanticipated extra-footfall-mixed-spin-turn. Further study is warranted not only for the risk of tripping from limb-entanglement given step-length & step-width have been shown not to vary with each other, but also to determine if the BOS changes reported in this study are reproducible across directions & speeds in a larger sample size.

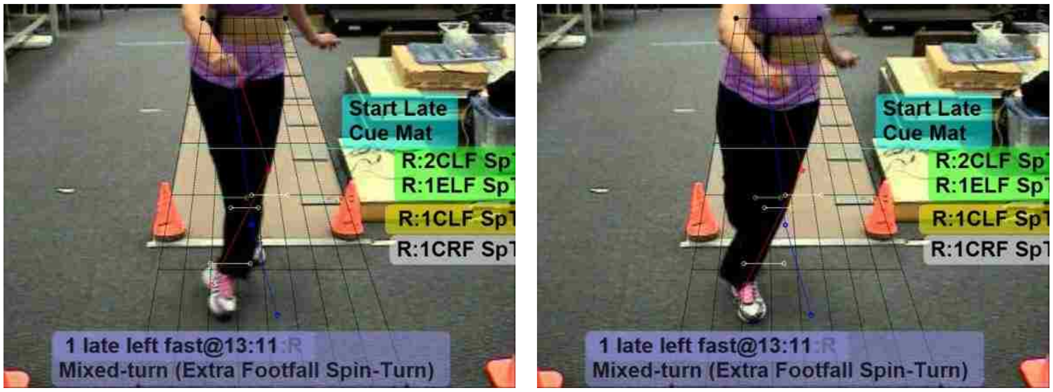
In addition to medial displacement being used at the penultimate footfall during step-turns (i.e. a medial-foot strategy), medial displacement of the ultimate-pivot foot has been previously observed after unexpectedly cued and executing a spin-turn, with the suggestion of it serving the same purpose of reducing frontal plane COM displacement/acceleration opposite the turn (Hase & Stein, 1999). Although the present study was only able to record Gaitrite data ending in the penultimate (*Figure* 28-29.) but not ultimate (pivot) foot, video analysis was nonetheless able to capture both footfalls. Thus, not only does the video analysis support the Gaitrite findings showing both the late-cue & fast-speed use of a medial penultimate foot strategy upon approach of right step-turns (*Figure 30*.), but the video analysis also appears to suggest the use of a medial ultimate pivot foot strategy upon approach of both late-cue & fast-speed right spin-turns (*Figure 31*). The use of a medial ultimate pivot foot strategy in both age-groups when viewed on video appeared most robust from the interaction of a late-cue*fast-speed (*Figure 32-33*), regardless of right v. left direction.

In the present study, a loss in stride-length when either anticipating the right turn (Table 33, Table 35, Figure 18-19) or “quasi” late-cued irrespective of direction (Appendix U), was found in both groups to parallel the left BOS narrowing seen when both hurrying to make an anticipated right-turn or “quasi” late-cued to turn-right at preferred-speed (Table 39, Table 41, Figure 25- 26). A concomitant decrease in both step-width & length has previously been reported in the elderly across the step ending in penultimate foot placement after being early-cued for 40^0 step-turns at preferred speed, although the young adults in that study only displayed step-width narrowing but no shortening (Paquette et al., 2008). Given the present study assessed the final two recorded strides of spatial-temporal data yet made no attempt to control the foot initiating gait, stride-sequence, nor pivot-foot across, the BOS findings reported in the present study do not represent successive right BOS widening followed by left BOS narrowing (or vice versa) in the same trial, nor do the right/left BOS findings represent a change relative to each other occurring in the same trial. Additionally, data for right & left stride-length were combined and averaged. Thus, the present study cannot say with any precision whether the left BOS narrowing & stride-length shortening were concurrent, but if so, such a combination may potentially precipitate a tripping episode. Any risk for tripping over one’s feet would appear to have the greatest potential when walking fast to turn-right at which point the present study found left BOS to be narrowest (Table 41) & when late-cued at which time the present study found combined right/left stride length to be shortest regardless of direction (Table 35).

Concurrent narrowing of BOS & loss of stride-length ending in pivot foot placement appeared on video to be most robust from the interaction of a late-cue*fast-speed, sometimes to the extent of crossing-limbs even prior to executing the right or left turn. It is not at all surprising that BOS narrowing from use of a medial foot strategy would be most robust from the interaction of a late-cue & fast speed, whether at the penultimate or ultimate footfall. When late-cued to turn, an increase in medial penultimate foot placement has already been reported (Hollands et al., 2010); and as opposite direction trunk lean i.e. an in effective trunk strategy (Houck et al., 2006) & a decrease in ML GRF production into the direction yet increase in time-to-peak (Kim et al., 2014) have all been reported, a reduction in the COP-COM distance at the penultimate footfall during step-turns direction (Patla et al., 1999;; Paquette et al., 2008) or ultimate footfall during spin-turns Hase & Stein, 1999 in order to reduce ML COM acceleration opposite the turn would appear to be a high priority strategy. Additionally, when walking fast to turn, both greater ML GRF& centripetal force into the turn direction is required (Xu et al., 2004; Orenduff et al. 2006; Fino et al. 2015) again making it essential to minimize ML COM accelerations away through use of a medial foot strategy upon approach.

The detection of narrowing in left BOS when late-cued to turn at preferred speed is surprising given the low percentage of trials in which a post-late-cue footfall was recorded [1 post-late cued footfall: right-turn trials 11% (15%preferred, 7% fast) & straight trials 22% (preferred 32%, fast 12%)] and may speak to its importance when turn response time is constrained (Appendix C). Yet as the percentage of trials containing 1 post-late-cue footfall was even smaller at fast speed, likely explains why left BOS narrowing was only detected at preferred speed when late-cued to turn. The finding of the present study that when early-cued to turn-right (as opposed to continue straight), left BOS narrowing was not seen upon approach at preferred walking speeds as previously reported (Patla et al., 1999; Paquette et al., 2008) but only at fast speed is intriguing. Given the present study may have been the first to assess spatial-temporal gait changes when approaching turns across the interaction of speeds & direction-cue response time constraints, it also appears be the first to report that when direction is known in advance, BOS narrowing (i.e. penultimate foot medial placement approaching step-turns or ultimate foot medial placement approaching spin-turns) may be more identifiable when one is in a hurry as opposed to walking at preferred speed. Hence, although during continuous straight gait, step-width may not decrease at faster than preferred speeds (Collins & Kuo, 2013; Sekiya et al., 1997; Latt et al., 2008; Helbostad & Moe-Nillsen, 2003), during the still linear approach phase before turning off a straight path, BOS across either of the final two approach footfalls may be at its narrowest with minimum ML foot separation at its least when walking at a fast rather than natural speed, which could potentially increase the risk for tripping over one's own-feet when in a hurry.

In the same study finding excessive hurrying to be the primary cause for elderly falls, the sixth most frequent reason was tripping-over-one's-own-feet/for-no-apparent-reason at 10% (Berg et al., 1997). In independent living elderly considered to be at high fall risk (either for balance issues, an injurious fall/or two non-injurious falls over the past year), a combination of tripping/catching one’s foot/ being clumsy/tangling one’s feet has been reported to be the number two reason on the list attributed to falling at 28.5% (second only to losing balance, being unsteady or being wobbly at 31.5%) and the number one reason on the list for a moderate-severe injury at 29.2% (Stevens, Mahoney & Ehrenreich, 2014). A tripping event in general (not specifically over one’s own feet) has been reported to be the cause of about 36% of hip fractures (Cumming & Klineberg, 1994); and when elderly who had experienced a fall (not necessarily a trip) within the prior year were asked to choose as many relevant reasons, although tripping over something (i.e. a cord, curb) was tied as the third/fourth most frequent cause at 19%, the sixth most frequent reason reported was tripping-over-ones-own-feet / for-no-apparent-reason at 10% .(Berg et al., 1997). Yet although concern for tripping has already been expressed from the standpoint of either inadequate minimum ML foot separation/clearance when actually executing early-cued preferred-speed spin-turns (Taylor et al., 2005), or from the greater variability in minimum ML foot separation seen when executing late-cued non-preferred direction (cross-over) stationary 180^0 turns (Meinhart-Shibata et al., 2005), the risk for tripping over one’s own feet upon the approach phase prior to turn execution has not received much attention in the literature for either turn-strategy. Given when unexpectedly terminating forward gait, older adults more frequently require an extra-yet-often short second-step compared to young adults (Tirosh & Sparrow, 2005), a second short step is more often required when walking fast as opposed to at preferred speed (Crenna et al., 2001), and peak breaking GRF is greatest at the ultimate lead-limb when not needing an extra-step to stop & increases with faster cadence (Bishop et al., 2004), a shortening in step/stride-length (Chen et al., 1994) concurrent with narrowing of BOS may present in the elderly the greatest risk for tripping over one’s own feet when hurrying in approach of an unanticipated direction change, which after the taking of the extra-step, would then most expeditiously be executed with the limb cross-over of a spin-turn i.e. an extra-footfall-mixed-spin-turn (Figure 35).



a. b.

Figure 35. Photo sequence showing an elderly female (a.-b.) approaching a left turn after receiving a late-direction-cue walking at fast speed. The concurrent loss in both step-length & change in step-width appeared most robust when late-cued at fast speed, with medial placement of the pivot foot at times to the extent of limb-crossing even prior to executing the turn, regardless of right v. left direction. A precipitous change in BOS & loss in stride-length could potentially make the risk for tripping over one's own two feet that much greater when approaching turns as compared to continuing straight. Given older adults more often take a short extra step when unexpectedly terminating gait (Tirosh & Sparrow, 2005), and a short extra step in more often taken at fast speed (Crenna et al., 2001), concurrent narrowing of BOS & shortening of stride-length in the elderly may present the greatest risk for tripping over one's own feet when hurrying in approach of an unanticipated extra-footfall-mixed-spin-turn as shown here when turning left.

The age-related trend in the present study for less of an elderly increase in stride-length at fast walking speed (Table 34, Figure 17), though not peculiar for right-turns only (i.e. was observed during straight trials as well) is nonetheless consistent with age-related stride-length differences previously reported during fast-straight gait (Shkuratova et al, (2005); and is not at odds with past preferred-speed studies showing a greater decrease in elderly (compared to young adult) step-length upon approach when early-cued to turn (Paquette et al., 2008), late-cued to circumvent (Paquette et al., 2010), late-cued for obstacle crossing (Chen et al., 1994), and in advance of curb descent in which concern was also raised that a loss in step-length if coupled with attention being distracted could potentially precipitate a fall in the elderly (Lythgo et al. , 2007). Thus, it is not unreasonable to suggest the potential risk of tripping over one's own feet from a concurrent decrease in left BOS and stride-length could pose a greater problem for older adults who appear to be more susceptible to cognitive-motor gait issues (Al-Yahya et al., 2011); and this potential risk for tripping over one's feet when approaching turns may be most applicable when gait is hurried as step-width variability during straight walking has been reported to show a positive relationship with speed in older adults (Brach et al., 2001).

These spatial-temporal findings in the present study of a narrowing in left BOS at the penultimate foot presumably when a right step-turn is hurried or unanticipated (and likewise at the ultimate-pivot foot for right spin-turns as captured on video), and whether a contemporaneous loss of stride-length has potential to increase the risk for tripping over one's own feet, need to be further explored. This would especially appear to be especially warranted given step-length & step-width have been shown not to vary with each other (Latt et al., 2008); and gait variables related to propulsion v. stability have been suggested to be regulated by different neuro-circuitries (i.e. step-length being under greater cortical influence v. BOS being more sensory feedback based) with each being a separate independent component (AP direction v.

ML direction) within step-variability (Socie et al., 2013; Morris et al., 2007; Collins & Kuo, 2013).

Additionally, the trend in the present study showing young adults but not the elderly increase right BOS when walking fast (relative to preferred speed) (Table 36, Table 38, Figure 22) is very difficult to interpret as straight gait BOS in young adults has been shown to decrease as speed increases from slow to more preferred levels (Orendurff et al., 2004; Klein et al., 2014). It is tempting to suggest this trend on the part of young adults possibly represents either more robust use of a step-out foot strategy (Paquette & Vallis, 2010), greater stability & tolerance against ML perturbations (Kavanaugh et al., 2005) caused by larger horizontal accelerations from an increase in the COP-COM distance (Winter (1995) or from rapid limb movements (Hughey & Fung, 2005), smaller ML safety margin relative to nearly objects (Hackney & Cinelli (2013), faster sensori-motor processing (Woollacott & Shumway-Cook, 2002), greater metabolic capacity (Lenoir et al. (2006), or even an intentional strategy to prophylactically guard against tripping over-one’s-own-feet from limb entanglement when approaching turns. However, these explanations do not seem justified as the increase in right BOS in young adults at fast speed was not specific to right-turns only but also seen for straight trials. This trend in young adults but not the elderly for an increase in right BOS when walking fast (relative to preferred speed) regardless of continuing straight or turning-right also warrants further investigation to see if it is reproducible in a larger sample size.

Unanticipated gait termination/deceleration drills may be of benefit to the approach phase of turning

Given the similarity in the distal-to-proximal braking synergy employed when unexpectedly terminating gait and unexpectedly needing to turn, fall prevention training programs may benefit from the inclusion of gait termination drills to better restrain forward momentum & displacement of the COM upon approach.

As previously mentioned, 99% of turn failures are believed to due to the inability to arrest forward momentum within the available response-time, and reduced ability to truncate push-off of the penultimate “late-cue” limb has been suggested as the primary cause of elderly difficulty decelerating (Cao et al., 1997; 1998). A similar distal-to-proximal extensor “braking” muscle synergy has been observed in the penultimate “late-cue” (aka trail-limb) when both abruptly terminating straight gait as well as abruptly decelerating when unexpectedly cued to turn, with the suggestion of a similar neural mechanism for both rapid stopping & turning (Hase & Stein, 1998,1999). The prominent decelatory function played by the penultimate limb when approaching early-cued turns has already been established (Glaister et al., 2008).

While a decrease in the ML (& vertical) GRF at the ultimate footfall when turn direction was unanticipated (as opposed to anticipated) when sprinting has been shown (Kim et al., 2014), the principal investigator is unaware of early v. late-cue turn-related studies comparing AP GRFs. However, unexpected gait termination research has verified that a late-cue (as opposed to early-cue) to stop constrains the ability to reduce propulsion forces in the penultimate cue/trail-limb (Tirosh & Sparrow, 2004). Additionally, when unexpectedly terminating gait, peak breaking GRF has been found to increase with a cadence-based increase in speed, and be greatest at the ultimate lead-lead when not needing an extra-step to stop as opposed to needing an extra-step (Bishop et al., 2004). Not surprisingly, a second short step is more frequently required when walking fast as opposed to at preferred speed (i.e. one stride cycle as opposed to just one step); but a velocity-dependent modulation of the distal component of the braking synergy has been shown to differ across limbs during unexpected gait termination, as although an increase in activity of the proximal braking component of both limbs was seen during the shorter available response times at faster speeds (i.e. the hamstrings in the penultimate trial-limb, whereas the quadriceps in the ultimate lead-limb) the distal soleus braking GRF in the ultimate-lead-limb was boosted yet suppressed in the penultimate-cue-limb - which if not would otherwise be counter-productive to deceleration once the COM is beyond its COP during latter stance (Crenna et al., 2001). Thus, given the similarity between rapid stopping & turning (Hase & Stein, 1998,1999), through the practice of unanticipated stopping/deceleration drills, strategies may emerge to better restrain the forward advancement of the COM relative to the COP, including those already described such as anticipatory backward body leaning (Xu et al., 2004) or preservation of the anterior margin of stability by minimizing the loss in step/stride-length (Hof, 2008; Hak et al., 2013; Suptitz et al., 2013; Chen et al., 1994). Such strategies may potentially leading to less velocity-dependent suppression of the distal soleus braking GRF at the penultimate-cue-limb when unexpectedly cued to turn while walking hurriedly. It is for these reasons the present study is suggesting that unanticipated linear deceleration/gait termination drills, progressing from preferred to faster speeds with the goal of abruptly stopping within 1-2 steps, be introduced in the early phases of a turn training program.

Practicing turns at fast speed with direction known may benefit preferred speed performance when direction is unknown

Practicing turns off a straight path with direction known in advance at a fast walking speed may possibly transfer over to improving performance when unexpectedly needing to turn at a preferred speed.

As already mentioned, the present study appears to be the first to investigate the interaction of both speed & cue-delivery time on approach gait adaptations & turn performance. Hence, the most original finding coming from the present study may be the cue*direction*speed interaction which revealed both age-groups not only narrowed left BOS when cued early to turn right walking fast, but also when cued late to turn right at preferred speed. This 3-

way interaction, the only one of the entire study, may have clinical implications for gait training purposes as it may suggest that benefits derived from practicing turns off a straight path with direction known in advance but at a fast speed, could possibly transfer over to improving performance when unexpectedly needing to turn at a preferred speed. This may be particularly relevant given the preceding discussion showing similarity in distal-to-proximal braking muscle synergy when unexpectedly terminating gait & decelerating for an unexpected direction change (Hase & Stein, 1998, 1999).

In young adults terminating gait across preferred v. fast cadence-modulated speeds, no difference has been reported in the kinetic measure of rate of deceleration force generation in the ultimate-lead-limb when early-cued (prior to the trial) at a fast cadence compared to late-cued at a preferred cadence suggesting commonality between the two different speed*cue response conditions (Bishop et al., 2004). Additionally, in youths (mean 14.4 years) terminating gait across preferred v. fast speeds without manipulating cadence, no difference has been found for the kinematic measure of peak hip & knee angles during terminal stance in the ultimate-lead-limb when early-cued at a fast cadence compared to late-cued at a preferred cadence, prompting the suggestion that performance of anticipated gait termination at fast speed may be clinically useful as a predictor of unanticipated gait termination at a preferred speed (Ridge et al., 2016).

When the above previous findings of similarity between anticipated gait termination at a fast-speed with unanticipated gait-termination at a preferred speed for both a kinetic variable (Bishop et al., 2004) & kinematic variable (Ridge et al., 2016) is combined with the finding of the present study showing that both age-groups narrowed left BOS when both early-cued to turn right at fast-speed & late-cued to turn right at preferred-speed, and it recalled that a similar neural mechanism has been proposed for both unanticipated sudden stopping & turning off a straight path (Hase & Stein, 1998,1999), it seems reasonable to speculate that practicing turns off a straight path with direction known in advance (a closed-motor skill) at a fast walking speed may possibly bring-about positive transfer-of-learning on performance when unexpectedly needing to turn (an open-motor skill) at a preferred speed.

Limitations of the study

The present study had numerous limitations including: being underpowered; not correcting for family-wise error; interpreting significant interactions with marginal means & plots; normality violations; many intrinsic confounding variables were not assessed; cannot generalized findings to other elderly groups other than those with low-fall risk; gait data for all turn strategies were combined; limitation of instrumentation did not allow spatial-temporal data to be recorded for the important pivot foot; averaging of strides did not permit identification of footfall undergoing most adaptation; too few strides may impact reliability of gait data; analysis was limited to a very basic spatial-temporal & categorical level; and a testing or learning effect though unlikely may have potentially threatened internal validity.

Study was underpowered

To begin with, the study used a convenience sample but more importantly was under-powered with an n = 20 (10 young adults & 10 healthy older adults). This likely contributed to the absence of any significant relationships between age-group & turn strategy preferences, and the paucity of age-related differences (only trends) in spatial-temporal gait adaptations. For the chi-square test of independence of the relationship between age-group & turn strategy preference, post-hoc power computed with G*Power v. 3.17 for Cramer’s V = 0.14 (Table 15); and for the mixed-design ANOVAs comparing age-group differences in spatial-temporal gait adaptations, as reported in the Test of Between Subject Effects computed with SPSS v. 18, power observed was < 0.80 for all dependent variables except stride-length [power observed: right/left combined stride-length = 0.88 (Table 33), gait speed 0.46 (Table 30), left BOS 0.31 (Table 39), right BOS 0.25 (Table 36)].

No correction for family-wise error

Another potential limitation is that no correction was made for the family-wise error rate of multiple comparisons. For each of the four spatial-temporal dependent variables, the 2x2x2x2 mixed-ANOVA had 15 comparisons, which if a Bonferroni correction were performed [$1-(1-\alpha)^{1/n} = 1-(1-0.05)^{1/15}$], would establish p = .0034. However, Perneger (1998) has argued that while such corrections have merit in an exploratory study in which there are no prior established relationships upon which to base an educated hypothesis (unlike the present quasi-experimental study), Bonferroni corrections are best avoided when evaluating results in which hypotheses have been stated given they restrict meaningful data interpretation.

Significant interactions interpreted with marginal means & plots instead of post-hoc comparison procedures

Additionally, when interpreting between which pair of means the difference resided for any significant interaction as reported in the Tests of Within-Subjects Contrasts table, rather than standard post-hoc multiple comparison procedures, the approach taken in the present study involved looking at estimated marginal means & interaction plots (i.e. slopes, differences between points). Portney & Watkins (2009) note that given post-hoc tests are formulated from overall group differences and not within-subject comparisons, standard post-hoc multiple comparison procedures are not usually employed for repeated measures analyses as they are not logically compatible. Moreover, Field (2009) omits any discussion of multiple comparison tests when interpreting significant interactions as reported in the Tests of Within-Subjects Contrasts for mixed-ANOVA. Instead Field (2009) advises the approach adopted in the present study, namely, examination of the estimated marginal means and the use of interaction plots paying attention to the steepness of the line slopes & the vertical distance separating the x-axis comparison points of any two lines. Nonetheless, an attempt was made to also manually compute Tukey’s HSD for significant interactions of interest pertaining to the four dependent gait variables with the mean square error term used corresponding to the error for that specific interaction (Appendix Q, Appendix T, Appendix W, and Appendix Z). However, in each instance manual computation using Tukey’s HSD to assess between which pair of means the significance resided did not agree with the significant interaction as reported in the Tests of Within-Subjects Effects nor the interpretation by the principal investigator of the interaction plot.

Violations of normality

A still further statistical limitation involves violation of the assumption of normality as for all four spatial-temporal dependent variables, although the assumption of homogeneity of variance was met for all 8 conditions and sphericity was not an issue given each repeated measures variable had only 2-levels, normality was violated in 1-4 of the 16 possible conditions as determined by either a significant Shapiro-Wilk or Kolmogorov-Smirnov test (Appendix P, Appendix S, Appendix V, Appendix Y). However, despite the violations of normality, according to Field (2009) when group sizes are identical as in the present study (young n=10, elderly n=10), ANOVA is believed to be reasonably robust to violations both of normality and even homogeneity of variance.

Intrinsic confounding variables not assessed

Another potential limitation involves the multitude of potential intrinsic confounding variables which were not assessed but may threaten interpretation of the findings, among them being age-related declines in muscle strength, range of motion, somato-sensory & vestibular function, and vision i.e. acuity, contrast, depth perception (Shumway-Cook & Woollacott, 2012). Nonetheless, among the exclusion criteria were uncorrected visual impairment, and known vestibular involvement or dizziness with head movements. Additionally, although the elderly did not perform quite as well as young adults on the DGI (Table 4), functional balance in the older adult group was still above the inclusion criteria score to put them at low fall-risk (Table 1), and no significant age-related difference was seen in preferred gait speed or for that matter even fastest-comfortable gait-speed (Table 30, Appendix Q) which for fast gait might otherwise be expected to be slower in the elderly (Shkuratova et al., 2004)

External validity as findings cannot be generalized to other elderly groups having different characteristics than those who participated, particularly those elderly at risk for falls

Another limitation is that the findings in the present study with regards to healthy older adults cannot be generalized to all elderly groups particularly those considered to be at high-risk for falls (especially sideways & backwards), show age-related declines in gait speed (whether at a preferred or fast pace), or cognitive deficits. The elderly participants in the present study ranged in age from 65-75 years, described themselves as being healthy, and were judged to have intact cognitive ability based upon the MMSE, functional balance to suggest low-fall risk based upon the DGI, and balance confidence to suggest being non-fallers based upon the ABC scale (Table 1, Table 4). Additionally, as mentioned, although in the present study a trend was seen suggesting the elderly group had less of an increase in stride-length at the faster walking speed, no age-related difference was seen in gait speed either at the preferred or fast pace (Table 30, Appendix Q). When this lack of an age-related decline in gait speed is combined with the present study's finding of left BOS narrowing when approaching right-turns whether cued-early for direction at fast-speed or cued-late at preferred-speed (Table 39, Table 41, Figure 25- 26), this may possibly suggest that the healthy elderly adults were equally as tolerant as the young adults to the ML disequilibrium required to initiate turns. Hence, when solely confined to healthy elderly adults with no significant age-related decline in gait speed (as in the present study) & no functional impairments, judged to be at low-fall risk particularly to a backwards slip (Wright et al., 2015), the principal investigator is of the opinion that when combining the present study's findings with that of previous research -[showing that the over-whelming majority of turn failures in healthy young & elderly adults are due to an inability to arrest the forward momentum (Cao et al., 1997), the likelihood of a sideways fall decreases with gait speed (Smeester et al., 2001), and that older adults suffering a hip fracture from a trip have been found to have higher pre-injury functional ADL scores than those whose fractures were due to a loss of balance]- preservation of the anterior margin of stability by minimizing the loss in step/stride-length (Hof, 2008; Hak et al., 2013; Suptitz et al., 2013) and backward body leaning (Xu et al., 2004) may best be targeted for gait training for approaching turns in otherwise healthy elderly adults. Different strategies appear to be needed for those deemed to be at high risk for sideways ML instability or backward direction falls from a slip ((Wright et al., 2015; Hak et al., 2013; Latt et al., 2008).

Spatial-temporal data for all strategies combined

A still further limitation is that Gaitrite data for both right-step-turns & right-spin-turns (and for that matter mixed-turns as well) were combined in the present study to simplify the analysis for all comparison with straight-gait. Obviously this complicates interpretation of BOS changes. It is for this reason interpretation of BOS findings were grounded in previous research showing that during the approach phase (not execution phase) step-width narrows for step-turns but widens for spin-turns (Paquette et al., 2008). Moreover, it is important to note that in that same study, although only the elderly reduced both step-velocity & step-length across the final three approach steps, no difference was seen in the change in either step-velocity or step-length when comparing step-turn v. spin-turn strategies for either age-group (Paquette et al., (2008). However, when late-cued to avoid an obstacle placed one-stride ahead, for the step ending in placement of the ultimate pivot foot (which in the present study could not be recorded), not only was the reduction in both step-length & step-velocity greater in the elderly, but the elderly also used a shorter step when circumventing with a step-out as opposed to cross-over maneuver (Paquette & Vallis, 2010). Thus whether step-length changes upon approach differs between turn strategies may require further clarification and be another area worth exploring.

Limitation in instrumentation not recording spatial-temporal data for pivot foot & few post-late-cue footfalls

The present study experienced a limitation in instrumentation. As the last 55 cm of the Gaitrite carpet lacked sensors, (i.e. an instrumentation limitation), no ultimate footfalls were recorded (penultimate 76%, ante-penultimate 24%). Moreover, given the late-cue was delivered upon penultimate footfall contact in 54% of trials & upon ant-penultimate footfall contact in the remaining contact 46% of trials, few late-cue trials contained even just 1 post-late-cue footfall, especially at fast speed & for right-turns [% of late-cue trials containing 1 post-late cue FF: right-turns 11% (15%preferred, 7% fast) & straight 22% (preferred 32%, fast 12%)(Appendix C). Thus not only does the paucity of trials containing even 1 post-late-cue footfall leave a lot to be desired regarding information on reactive strategies (i.e. may possibly explain why no change in right BOS was seen when late-cued to turn-right), but spatial-temporal data is missing for the all-important ultimate pivot foot which not only contributes most to ML acceleration of the COM when turning (Glaister et. al., 2008) but where adaptations in ML foot placement would need to be reserved for an unexpected sudden direction change (Hollands et al., 2001; Hase & Stein, 1999).

Averaging successive steps/strides did not allow precise identification of which footfall underwent most spatial-temporal change

A still further limitation is that the Gaitrite data for all spatial-temporal variables data was averaged across a window period restricted to the final 1 or 2 strides. Thus for each trial, the dependent variable for both speed &step-length were the average of one right & one left stride though not necessarily in that order as neither the initiating foot or stride-sequence (Appendix D) was standardized. Additionally, although the left & right heel-to-heel BOS dependent variables were not averaged, the Gaitrite computed each across two steps (i.e. one stride) with left BOS computed across the right stride & right BOS computed across the left stride (CIR Systems, Inc, 2013). The point here is that unlike prior turn approach-phase research which compared spatial-temporal changes (in terms of step-length, step-width, step-velocity) incrementally across a series of final footfalls and could pin-point across which step the greatest adaptations took place (Paquette et al., 2008) the present study was handicapped and could not be so precise as to the location (i.e. footfall) where the change took place nor how sudden it happened (i.e. spread out cross more than one footfall or confined to just one footfall).

Too few strides per trial may impact reliability of gait data

Somewhat related to this last limitation about the spatial-temporal variables being averaged across a window of 1 or 2 strides is concern about reliability. According to Hollman et al. (2010) excellent reliability for mean velocity during normal walking requires using 4 strides of data; however, to achieve the same level of excellent reliability for mean velocity during dual-task walking, the number of strides increases to 9, Although a traditional dual-task paradigm was not employed in the present study, concern about visual sampling needed to preserve a personal space safety margin relative to tripping hazards in the turn area vicinity (Gérin-Lajoie et al., 2005) & associated data processing costs potentially affecting gait (Gérin-Lajoie et al., 2006; Stuart et al.,2017) were considered in interpreting the decline in speed & step-length. Be that the case, the potential is there for reliability issues, however, these stride number recommendations are within the context of steady-state straight gait, not when approaching turns.

Measurement & analysis limited to a very basic spatial-temporal level & turn-strategy analysis limited to a video-based categorical level

Another limitation involves the level of analysis being technologically restricted to a spatial-temporal level for the gait data, and restricted to a descriptive level for the turn strategy data based solely upon a frontal view of the lower half of the body. Thus although the present study was able to gather some limited information on use of one of the two major strategies used when approaching turns, namely a foot strategy, no assessment could be made of the second major strategy of trunk/hip roll lean (Patla et al., 1999; Hollands et al., 2001). Additionally, the findings were interpreted in the light of prior research performed on a much higher level of kinematic (Xu et al., 2004), kinetic Glaister et. al., 2008), EMG (Hase & Stein, 1999), eye movement tracking (Marigold & Patla, 2007), yet the present study did not measure any parameters at these other levels including COM acceleration, margin of stability, GRF or visual gaze. Nonetheless, although the analysis of gait was very limited in its scope, the Gaitrite has been found to be both reliable & valid for measuring spatial-temporal parameters (McDonough, Batavia, Chen, Kwon, & Ziai, 2001; Lord, Rochester, Baker & Nieuwboer, 2008; Bilney, Morris, and Webster, 2003). Similarly, while there are more advanced methods available to assess turn strategy preferences, video analysis still appears to be the gold-standard at this time (Golyski & Hendershot, 2017) and the principal investigator of the present study who performed the video analysis was found to be a reliable rater based upon the approach of using Kinovea[a] software and the operant definitions established for step-turns, spin-turns, and mixed-turns for the purposes of this study. (Appendix A).

Internal validity possibility threatened by a testing or learning effect

Finally, the last major limitation to mention involves anticipation of the late-cue to turn and the possibility of a testing or leaning-effect from trial repetition threatening internal validity (Portney & Watkins, 2009). Although it is acknowledged participants soon learned the approximate location along the walkway of when to expect either the early-cue (usually within the first step on the Gaitrite) or late-cue for direction (about 2 steps before the Gaitrite's end), and that if the early-cue was not delivered then by default to expect a late-cue, future turn direction (i.e. whether to continue straight, or turn right or left) was randomized and remained uncertain. Thus, for the separate preferred & fast speed block of 18 trials, three trials for each of the three different direction cues (left, straight, right) under both temporal constraints (early, late) were performed with randomization.

Interestingly, there is suggestion from a early v. late-cue fast walking (no preferred speed condition) turn-related study comparing just two but nonetheless random directions (straight v. left step-turns) that when late-cued, errant anticipation of direction (i.e. mistakenly anticipating a turn-left signal when instead late-cued to continue straight) may cause performance (with regards to hip abductor moment & angle) to mimic if not over-mimic that seen when early-cued for the opposite direction i.e. performance when late-cued to continue straight, resembles that when early-cued to turn-left; or on the flip-side when late-cued to turn-left, resemble that when early-cued to stay straight (Houck et al.,2006). Thus, although repetition may have brought-about kinetic & kinematic anticipation or learning for early-cue performance, randomization appeared to prevent any learning to support late-cue performance. Additionally, there is also indication from a visual-motor control perspective that when young adults negotiate across an environment containing footprint targets posing no threats to stability, despite the absence of any randomization, the number of steps-ahead upon which they gazed did not differ based upon trial number, suggesting the absence of a learning-effect or mental mapping, as visual information acquired in one trial did not appear to carry-over to direct gait changes in subsequent trials (Patla & Vickers, 2003). Thus, in light of the randomization process employed in the present study, and when considering the absence of a testing-effect in the two studies just cited above, one from a kinematic/kinetic perspective with randomization (Houck et al., 2006), and the other from a visual-motor control perspective (Patla & Vickers, 2003), the likelihood of a learning effect threatening internal validity in the present study seems remote.

Closing

About one-third of those 65 years of age or older are known to fall each year (Tinetti, Speechley & Ginter, 1988; Masud and Morris, 2001). Although just 1-2% of falls result in hip fracture (Berg et al., 1997; Tinetti et al., 1988), hip fracture injuries are potentially life threatening (Marottoli et al., 1994; Haleem et al., 2008), often debilitating (Marottoli et al., 1994; Magaziner et al., 2000), and costly (Carroll et al., 2005; Shi et al., 2009). The odds-ratio for a hip fracture injury from a fall when turning is approximately 8 x greater than a fall when continuing along the same trajectory, and believed to be due to the greater chance of falling sideways and impacting the hip (Cumming &

Klineberg, 1994) given previous research had reported the odds for hip fracture (verse no-fracture) following a sideways or straight-down fall to be over 3 x as much (Nevitt & Cummings; 1993).

However, while type of walking task (i.e. turns v. straight) may have a bearing on fall direction, so too does speed. When falls were simulated in young adults, a slip (anterior foot translation from low friction) while walking slow usually lead to a sideways or backward fall with greater likelihood for hip impact; yet a slip walking fast was reported to usually lead to a forward impact fall similar to a trip (mid-swing resistance), although unlike slips, trips were found to lead to forward falls at all speeds (Smeester et al., 2001). Moreover, one prospective study exclusive to elderly females has reported average walking speed to be slower in eventual fallers who suffered hip fracture as compared to eventual fallers who did not [0.94(.22) v. 1.03(.24) m/s], and while no association was seen between walking speed and the risk of the fall to produce hip fracture (Nevitt & Cummings, 1993) both speeds appeared below average [i.e. 1.25(.21) m/s (Shkuratova et al.; 2004; 1.16(.21) m/s (Menz et al., 2004)]. It is not surprising pre-injury functional ADL scores have been reported to be lower in those whose hip fractures were caused by a loss of balance as compared to those whose hip fractures were trip-related- although no mention was made of speed (Matsui et al., 2014). Interestingly, independent of the discussion of hip fracture, excessive hurrying has been reported to be the number-one reason for falls in general (Berg et al., 1997).

In the often-referenced study by Cummings & Kleinberg (1994) reporting the 7.9 x greater likelihood (5.4 x greater when omitting those with Parkinson or Stroke) for hip fracture when falling while turning relative to gait in one direction, it may be important to note that a distinction was not clearly made between walking-turns made off a straight path as opposed to turns made “in-place” with little forward momentum. A closer examination of the terminology actually used by Cumming & Kleinberg (1994) indicates that turns were really described as “turning-around”, and categorized as “postural change” while grouped together with “in-place” tasks including “bending-over” & “sitting-down”. Moreover, examples of activity phrases which were coded by Cummings & Kleinberg (1994) as taking-place while turning included: “turning around to pick-up a shovel while sweeping leaves”, “turning around to close a window when in a bathroom”, & “turning abruptly when inserting eye drops”. Thus, the turning tasks associated with both hip fracture & sideways direction falls as reported by Cumming & Kleinberg (1994) may have been more “in-place” and less capable of generating unmanageable forward velocity & forward momentum.

While the chance for sustaining a hip fracture (verse no fracture) from a sideways fall may be greater, forward direction falls still account for about 15% of all hip fractures (56% sideways, 17% backwards and 14% forward) (Nevitt & Cumming, 1993). Moreover, in a recent longitudinal study of healthy elderly females not limited to hip fracture injuries, of the sideways falls reported, 30% had a concomitant backward component, while 25% of sideways falls had a forward component; and in general a forward fall direction was most prevalent in those who reported hurrying, tripping, & wrist/hand impact (Crenshaw, Bernhardt, Archenbach, Atkinson, Khosla, Kaufman & Amin, 2017). Furthermore, as falls in healthy elderly have been shown to be most often caused by a trip rather than a slip or loss of balance (trip 34%, slip 25%, loss-of balance 9%) (Berg et al., 1997), it is not surprising that trips account for a sizable percentage of hip fractures when viewed alongside those caused by either slips or postural change i.e. postural change includes turns (trip 36%, postural change 18%, slip 10%) (Cumming & Kleinberg, 1994).

When moving away from a discussion of turn failure in terms of falls & hip fracture, to a discussion of non-fallers in which failure is operationally defined in terms of kinematic performance [i.e. either as the COM passing beyond the turning location; a drop in turning speed ≥ 30%; foot placement lateral to the 1 m wide turning path or making contact with poles placed at either end], the overwhelming majority (99%) of late-cue turn failures in both age-groups are attributed to the first i.e. inability to arrest forward momentum of the COM, although older adults required a longer response time (523 v. 408 ms) and distance (68 v. 53 cm) to achieve the same 50% success-rate due to less of a reduction in the duration of stance-(cue) limb push-off (Cao et al., 1997, 1998). With the clinical relevance of a sideways fall direction increasing the likelihood of direct hip impact with fracture, turning (albeit with no distinction between walking-turns v. in-place-turns) being strongly associated with hip fracture & sideways falls in the elderly, yet walking speed affecting fall direction, the present study sought to fill a gap in which previous research had not compared walking turn performance in young & healthy older adults within the same study and across the same response-time conditions of speed interacting with direction-cue-time constraints.

The somewhat contradictory conclusions that 99% of turn failures in healthy young & elderly adults are due to the inability to arrest forward momentum (Cao et al., 1997) yet sideways falls with hip fracture are more likely when turning (Cumming & Klineberg, 1994), was appreciated in light of the two independent components of gait: AP propulsion/ deceleration & ML frontal balance (Socie et al., 2013; Morris et al., 2007; Collins & Kuo, 2013). Thus, on a postural control/biomechanical level, when viewing turning in a most simplistic manner, a turn-approach phase of deceleration in the AP plane -similar to rapid gait termination (Hase & Stein, 1998; 1999) - is followed by an execution phase of acceleration in the ML plane (Patla et al., 1991; Patla et al., 1999; Hollands et al., 2001). Although an age-related decrease in ML stability has been reported (Kavanaugh et al., 2005), healthy elderly also more frequently require an additional second & often short-step to suddenly arrest the forward progression of straight gait being less proficient at modulating propulsive forces to restrain AP COM velocity (Tirosh & Sparrow;

2004). Moreover, when approaching direction changes at preferred speeds, in the AP plane the elderly appear more cautious of stability in decreasing both step-velocity & length regardless of early v. late cuing; however, in the ML plane whereas both groups show similar anticipatory step-width modifications when turning with direction known in advance (Paquette et al., 2008), the elderly show less of a reactive increase in pivot foot step-width when circumventing with direction unknown & unlike young adults also require use of a lateral trunk-roll strategy to displace the COM (Paquette & Vallis, 2010). Thus, when response-time to turn off a straight path is most constrained by the interaction of a fast-speed & late-direction cue, will healthy elderly at low-fall risk (based upon functional gait assessment using the DGI) necessarily show indication for more of an age-related issue involving the ML execution phase rather than the AP approach phase?

In addition to a biomechanical/postural control perspective originally considered to assess age-related differences based upon response time constraints, it became apparent that designating the trapezium-shaped turning area with hazard cones at all four corners may have inadvertently also imposed ML -more so than AP- spatial constraints (entrance width 73 cm v. depth 95 cm)(Figure 8), and a need for greater visual scanning & information processing cost to preserve a ML safety margin distance all of which may have affected the stepping & turning patterns (Patla & Vickers, 2003; Gerin-Lajoie et al, 2005, 2006; Stuart et al., 2017) not common to the relatively object-free testing environments used in most prior turn studies (Patla et al., 1991; Patla et al. 1999; Hase & Stein, 1999; Hollands et al., 2001;Thigpen et al., 2001; Taylor et al., 2005; Hollands et al., 2010; Hollands et al., 2014; Xu et al., 2004, 2006; Fuller et al., 2007; Paquette et al., 2008; Strike & Taylor, 2009; Akram et al., 2010; Mari et al., 2012; Mak et al., 2008). As such although a dual-task paradigm was not employed nor gaze assessed, finding meaning in the results was thought to take more than a purely biomechanical/postural-control interpretation. From this standpoint, given the wider-BOS of step-turns, which makes them more desirable at fast speeds (Akram et al., 2010), may possibly incline them to be less so desirable in a ML spatially constrained area. Conversely, given the narrower-BOS of spin-turns, which renders them less desirable when future direction is uncertain (Patla et al., 1991; Hase & Stein, 1999) & at fast-speed (Akram et al., 2010), may potentially increase their worth in a ML spatially constrained area.

Spatial-temporal AP braking/propulsion (stride-length & speed though grounded more in attention than propulsion) & ML stability/balance (left/right H-H BOS) measures (Hollman et al., 2011; Collins and Kuo, 2013; Al-Yahya et al. (2011) were collected with the Gaitrite. Categorical video-based turn strategy data for wide BOS/space-consuming step-turns, narrow BOS/space-efficient spin-turns-(Patla et al., 1991; Hase & Stein, 1999; Taylor et al., 2005) & two mixed-turn subtypes (Thigpen et al., 2000) with one thought more grounded in AP stability/braking/propulsion “extra-step” turning (Tirosh &

Sparrow, 2005; Crenna et al., 2001) & the other more grounded in ML/balance “small-amplitude” turning (Conradsson et al., 2017; Mak et al., 2008; Leach et al., 2016).

Across speeds (preferred v. fast) & direction-cue-time-constraints (early-cue v. late-cue) a 2x2x2x2 mixed-ANOVA analyzed age-related differences for the spatial-temporal data comparing right-turns to straight walks & 2x2x2x3 loglinear analysis assessed relationships for right-turn strategies [step-turn, spin-turn, mixed-turn-with all mixed-turn subtypes needing to be combined to meet the assumption for expected frequency ($p < 0.05$)]. In view of the absence of sensors across the last 55 cm of the Gaitrite, spatial-temporal data could not be obtained for the turn pivot foot & few post late-turn-direction cue footfall trials were obtained confounding assessment of anticipatory v. reactive gait adaptations.

Spatial-temporal findings in the AP plane surprisingly revealed no major age-related differences (Paquette et al., 2008; Paquette & Vallis, 2010) outside of an expected trend for less of an elderly increase in stride-length at fast-speed (Shkuratova et al., 2005) although no differences in speed at either the preferred or fast pace. The groups showed similar modulation in propulsion/braking as both slowed & took shorter strides to a greater extent when late-cued regardless of direction (Paquette & Vallis, 2010) with the rate of slowing greater at the fast speed; and also slowed & took shorter strides when cued-early to turn-right relative to staying straight (Paquette et al., 2008). In the ML plane again surprisingly no major age-related differences were seen (Paquette & Vallis, 2010) except a trend showing only young adults increased right BOS at fast speed although the change was not viewed as an anticipatory adaptation given it was not specific to right turns. However, perhaps even more surprising, both groups showed similar anticipatory & reactive tolerance to initiating frontal plane disequilibrium upon approach as they widened right BOS when cued early to turn-right relative to staying straight, both narrowed left BOS when cued early to turn right walking fast but when cued late to turn right at preferred speed (the only three-way interaction of the study).

Turn strategy findings as well surprisingly revealed no major age-group based relationships across response-time conditions. Both groups preferred mixed-turns the least, yet showed equal preference for spin-turns v. step-turns (spin-turns 43.8%, step-turns 42.1%, mixed-turns14.2%). Yet a speed*turn-strategy relationship revealed that relative to mixed-turns, preference for spin-turns decreased 3-fold walking fast as compared to at preferred speed supporting the view of greater biomechanical challenge (Akram et al., 2010), while no relationship was seen between step-turns & speed. A cue*turn-strategy relationship showed that relative to mixed-turns, preference for spin-turns decreased 4-fold when late-cued for direction as compared to early; and whereas speed previously had no association with step-turns, surprisingly when late-cued step-turns decreased 5.5-fold suggesting a different interpretation besides a purely biomechanical one (Patla et al., 1991; Hase & Stein, 1999; Akram et al., 2010). Finally, and perhaps most interesting, of all 24 cells of the loglinear cross-tabulation table, the cell corresponding to observed frequency counts for elderly mixed-turns at the most constrained response condition of fast-speed*late-cue, was the only cell to achieve a significant standardized residual at +2.4. Inspection of the Age*Speed*Cue*Turn-Strategy cell count & residual table (Table 6) and bar-chart (Figure 9) supports this finding as, despite both groups performing less mixed-turns relative to both step-turns & spin-turns across 3 of the 4 speed*cue conditions, when response-time was most constrained by a fast*late interaction, the elderly observed mixed-turn count out-numbered, at least numerically-speaking, that for either step-turn or spin-turn. Although no statistical analysis of observed frequency counts for mixed-turn subtypes was possible, with all needing to be combined to meet loglinear assumptions, the “extra-footfall” step-turn sub-group made the greatest contribution to frequency counts in this fast*late mixed-turn cell & was most biased towards the elderly Appendix AA). Given it is an “extra-step” variety, although no statistical conclusion can be reached, may nonetheless possibly hint at an elderly AP rather than ML stability issue for this most response-time constrained interaction (observed count: elderly 7 v. young 1).

The most important findings to come out of the present study are that: in healthy older adults at low-fall-risk and no age-related declines in either preferred or fast paced gait speed when turning across an interaction of response-conditions of speed & direction-cue delivery times show similar spatial-temporal gait anticipatory adaptations in the AP plane of propulsion/deceleration [i.e. similar decreases in stride-length & speed upon approach when late cued or early-cued to turn (outside of less of an elderly increase in fast speed stride-length)]; and despite just concern about an age-related decrease in ML stability (Kavanaugh et al., 2005) given the strong association between hip fracture, sideways falls & turns (Nevitt & Cummings;1993; Cumming & Klineberg, 1994) , both groups also surprisingly showed similar anticipatory & reactive ML plane stability/balance from a spatial-temporal perspective (i.e. similar BOS widening when early-cued to turn, and even similar BOS narrowing when both early-cued walking fast & late-cued at preferred-speed).

Moreover, from a turn strategy perspective, across response-time conditions, both age-groups showed similar ML stability in preference for both step-turns & even smaller BOS spin-turns over mixed-turns, which have previously been reported to be an early-marker of elderly turn-performance decline, particularly those with self described balance issues (Thigpen et al., 2010; Fuller et al., 2007). As expected, at faster speeds both groups had less preference for the more ML biomechanically challenging spin-turns (Patla et al., 1991; Hase & Stein et al., 1999; Strike & Taylor, 2005) while preference for less challenging wide BOS step-turns was unchanged (Akram et al., 2010). Yet when late-cued, not only did the ML biomechanically challenging spin-turns decline as previously seen when walking fast, but in this instance of being late-cued a decline was also seen in preference for the more stable (Patla et al., 1991; Hase & Stein, 1999) yet ML space-inefficient step-turns, suggesting other potential explanations besides purely biomechanical (Taylor et al., 2006) including inadequate response-time to visually scan/process/plan & preserve an adequate ML foot-obstacle safety margin distance to offset the required wide step-out (relative to the potential tripping hazard imposed by the cones on either side of the turn-zone entrance) (Patla & Vickers, 2003; Gerin-Lajoie et al, 2005, 2006; Stuart et al., 2017). As such, though the wide-base BOS of step-turns may be an asset to biomechanical efficiency, in an environment with ML spatial constraints, the same wide-BOS may potentially be a liability to tripping when uncertainty of direction (i.e. a late-cue) denies the opportunity to preserve ML personal-space (Hackney & Cinelli, 2013; Vallis & McFadyen, 2003; Gerin-Lajoie et al., 2005, 2008), hence the potential necessity & regular use of spin-turns in healthy elderly individuals with low-fall risk. Interpreting turn-performance within the context of any existing spatial-constraints has recently been suggested as in a recent Parkinson-related study involving early-cued stationary in-place 360^0 turning atop floor squares of different sizes, even the healthy elderly control group required a greater number of combined forward/backward steps as the in-place turning area decreased, although turn-strategy preferences were not assessed (Fietzek et al., 2017).

Thus, while both groups showed similar gait adaptations in both AP plane propulsion/deceleration & ML plane stability/balance adaptations (outside of a trend for less elderly stride-length at fast speed), and even similar ML plane stability/balance in turn-strategy preferences for step-turns & spin-turns over the early performance-decline marker of mixed-turns (Thigpen et al., 2000), the only noteworthy age-related finding involved preferences between mixed-turn subtypes which though not statistically testable could be simply counted. In particular, the only cell with a significant residual in the loglinear cross-tabulation table revealed the elderly did seven extra-footfall step-turns whereas young adults did just one (Appendix AA). As “extra-step” mixed-turns may point more to an issue with AP stability (Tirosh & Sparrow, 2005; Crenna et al., 2001) in contrast to “small-amplitude” mixed-turns which more likely imply a ML stability issue (Conradsson et al., 2017; Mak et al., 2008), this finding of a numerically (although for the present statistically un-testable) larger observed frequency count of extra-step mixed-turns (as compared to the “small-amplitude” variety) used by the elderly when response-conditions (fast-speed & late-cue) were most imposing [i.e. excessive hurrying (Berg et al., 1997; Crenshaw et al., 2017; Chen et al., 1994) increasing forward momentum, yet less available response time to arrest it (Cao et al., 1997)], may suggest that for these healthy elderly adults with low-fall-risk & no age-related declines in preferred or fast paced gait-speed, ML stability during execution of step-turns & even spin-turns for-that-matter may have been less challenged than was AP stability upon approach, especially given the extra-second-step taken to abruptly halt forward progression when response time is constrained has been shown to often be of short-length (Tirosh & Sparrow, 2004; Crenna et al., 2001). Thus, within the limitations of this study (which are many), the AP & ML spatial-temporal gait & turn-strategy measures used may possibly suggest that for healthy elderly with low-fall risk & no age-related declines in preferred/fast gait speed, fall-prevent training as it possibly relates to hip fracture (Smeester et al., 2001) when turning may best be served by not just being tunnel-visioned into concerns about ML sideways falls (Nevitt and Cummings, 1993; Cumming & Klineberg, 1994) during the turn execution, but also targeting the potentially greater risk of an AP forward fall (Cao et al., 1997, 1998) upon approach. Preserving the anterior-margin of stability upon turn approach, by possibly guarding against excessive loss in step/stride-length (Hof, 2008; Hak et al., 2013; Suptitz et al., 2013; Chen et al., 1994), encouraging backward body leaning (Xu et al., 2004; Hase &Stein, 1999); and inclusion of deceleration/gait termination drills (Hase & Stein, 1998, 1999; Tirosh & Sparrow, 2005; Crenna et al., 2001; Bishop et al., 2004; Ridge et al., 2016) are being offered as strategies for consideration.

Lastly, the finding that the “extra-footfall” step-turn sub-group made the greatest observed count contribution & was most biased towards the elderly (observed count: elderly 7 v. young 1) (Appendix AA), would be in agreement with the previous finding showing that relative to young adults, the elderly more often take an extra-step when making an unexpected rapid lane-shift, especially when shifting lanes would necessitate crossing-limbs rather-than side-stepping (Gilchrist 1998). If difficulty is already experienced in trying to arrest forward AP momentum of the COM upon turn approach (Cao et al., 1997; 1998), it would be logical to expect even further difficulty with the ML biomechanically challenging spin-turns which not only have a narrower BOS, but unlike step-turns also necessitate a reversal in ML GRFs & ML ankle moments (Patla et al 1999; Hase & Stein, 1999; Taylor et. al. 2005; Xu et al., 2006) relative to straight gait. Thus, it is left to future research on a much larger sample-size to assess whether early turn-performance deficits, can be statistically identified in healthy elderly with low-fall risk & no age-related declines in gait speed based upon turn-strategy preferences between mixed-turn sub-groups, building upon our previous understanding of mixed-turns (Thigpen et al., 2000) particularly as it relates to early markers to distinguish between AP v. ML stability issues.

Final Answers to Research Questions

RQ1. Is there a relationship between the factors age-group, speed, cue-time constraint, & turn strategy preference (step-turn, spin-turn, mixed-turn) when turning right?

No, although expected frequency counts were too small to assess preferences for mixed-turn sub-groups, there may be some preliminary indication that when response-time constraints (fast-speed & late-cue) are greatest healthy elderly do more "extra-footfall" step-turns possibly pointing to an issue with AP stability in arresting forward momentum upon turn approach. However, further research is required on a larger sample size to allow loglinear assumptions to be met so that preferences between the four different mixed-turn subgroups can be assessed (i.e. extra-footfall mixed-turns (extra-footfall step-turns, extra-footfall spin-turns) & small-amplitude-mixed-turns (small-amplitude step-turns, small amplitude spin-turns).

If not are there lower–order_interactions between these variables? Yes.

Is there a relationship between age-group (young, elderly) & turn strategy preference (step-turn, spin-turn, mixed-turn)?

No, both age-groups showed similar ML stability in preference for both step-turns & even smaller BOS spin-turns over mixed-turns (spin-turns 43.8%, step-turns 42.1%, mixed-turns14.2%), which have previously been reported to be an early-marker of elderly turn-performance decline, particularly those with self described balance issues (Thigpen et al., 2010).

Is there a relationship between speed (preferred, fast) and turn strategy preference?

Yes, relative to mixed-turns, preference for spin-turns decreased 3-fold when walking fast as compared to at preferred speed, supporting the view of greater ML biomechanical challenge for spin-turns (Akram et al, 2010). No relationship was seen for step-turns and speed.

Is there a relationship between direction cue time constraint (early, late) and turn strategy preference?

Yes, relative to mixed-turns, preference for both step-turns & spin-turns decreased 5.5-fold & 4.0-fold, respectively, when cued-late for direction as compared to when cued-early. Both groups had less preference for biomechanically challenging spin-turns. Yet when late-cued, not only did the biomechanically challenging spin-turns decline as previously when walking fast, but so did step-turns possibly suggesting an explanation other-than purely biomechanical, such as inadequate time to visually scan, process & preserve ML foot-obstacle clearance (Patla & Vickers, 2003; Gerin-Lajoie et al, 2005, 2006; Stuart et al., 2017) for the wide “step-out” relative to nearby potential tripping hazards. Hence, although the wide-BOS of step-turns may aid ML biomechanical efficiency (Patla et al., 1991; Hase & Stein, 1999;

Taylor et al., 2005), when future direction is unknown & physical objects impose ML spatial constraints, the same wide-BOS may potentially be a liability making preference for narrow-BOS spin-turns just as likely.

RQ2. Do young v. older adults demonstrate different spatial-temporal gait modifications (speed, combined right/left stride-length, Right H-H BOS, Left H-H BOS) across the final-four recorded approach footfalls based upon the interaction of walking test speed (preferred v. fastest-comfortable), cue constraint (early v. late cuing), and direction (straight v. right-turns)?

When turning across an interaction of response time conditions of speed & direction-cue delivery times, healthy older adults at low-fall-risk & no age-related declines in either preferred or fast paced gait speed show similar spatial-temporal gait anticipatory adaptations in the AP plane of propulsion/deceleration [i.e. similar decreases in stride-length & speed upon approach when late cued or early-cued to turn (outside of a trend for less of an elderly increase in fast speed stride-length)]; and despite just concern for an age-related decrease in ML stability (Kavanaugh et al., 2005), both groups also surprisingly showed similar anticipatory & reactive ML plane stability/balance from a spatial-temporal perspective i.e. similar BOS widening when early-cued to turn, and even similar BOS narrowing when both early-cued walking fast & late-cued at preferred-speed.

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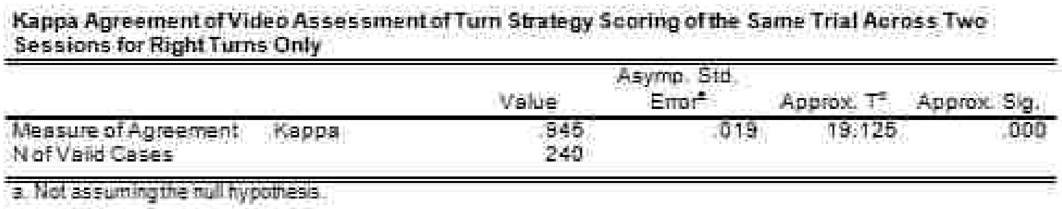
APPENDIXES

Appendix A

KAPPA AGREEMENT OF TURN STRATEGY ASSESSMENT

Turn Strategy Scoring of the Same Trial Across Two Sessions for Right Turns Only

		Turn Strategy Scoring - Session One			
		Step-Turn	Spin-Turn	Mixed -Turn	Total
Reassessment of Turn Strategy Scoring - Session Two	Step-Turn	99	0	2	101
	Spin-Turn	0	104	1	105
	Mixed -Turn	3	2	29	34
Total Counts		102	106	32	240



Kappa Agreement of Video Assessment of Turn Strategy Scoring of the Same Trial Across Two Sessions for Right Turns Only

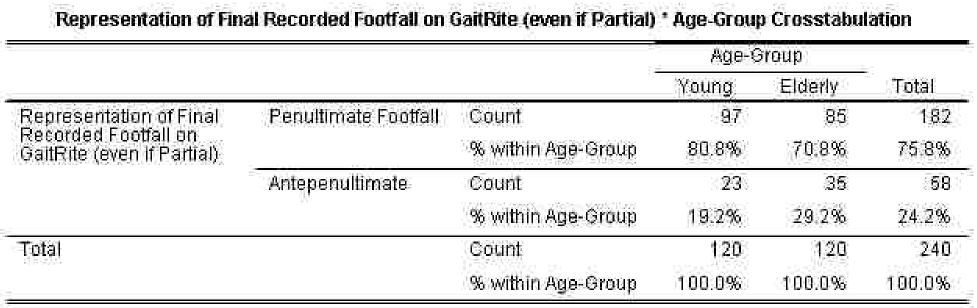
		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	.945	.019	19:125	.000
N of Valid Cases		240			

a. Not assuming the null hypothesis.

The Kappa intra-rater reliability (K) for scoring Turn Strategy Performance across two sessions based upon three categorical levels (Step-Turn, Spin-Turn, Mixed-Turn) was K = 0.945 ($p < 0.000$), 95% confidence interval (0.908, 0.982). K > 0.80 is considered excellent agreement (Portney & Watkins, 2009)

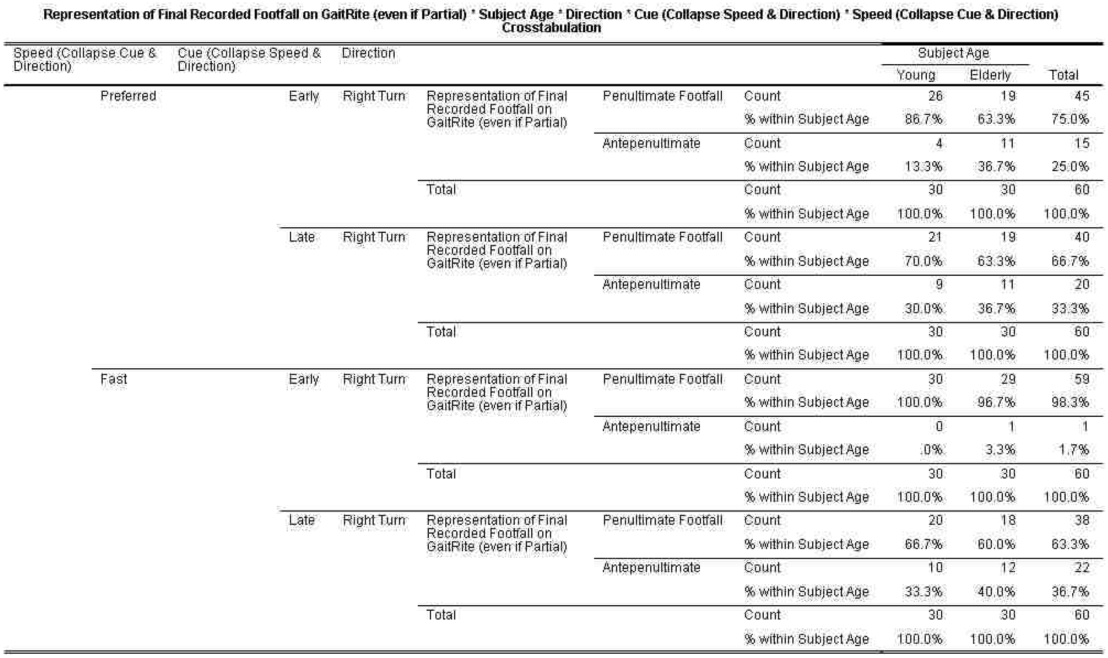
Appendix B

Representation of Final Recorded Footfall



Representation of Final Recorded Footfall on GaitRite (even if Partial) * Age-Group Crosstabulation

			Age-Group		
			Young	Elderly	Total
Representation of Final Recorded Footfall on GaitRite (even if Partial)	Penultimate Footfall	Count	97	85	182
		% within Age-Group	80.8%	70.8%	75.8%
	Antepenultimate	Count	23	35	58
		% within Age-Group	19.2%	29.2%	24.2%
Total		Count	120	120	240
		% within Age-Group	100.0%	100.0%	100.0%

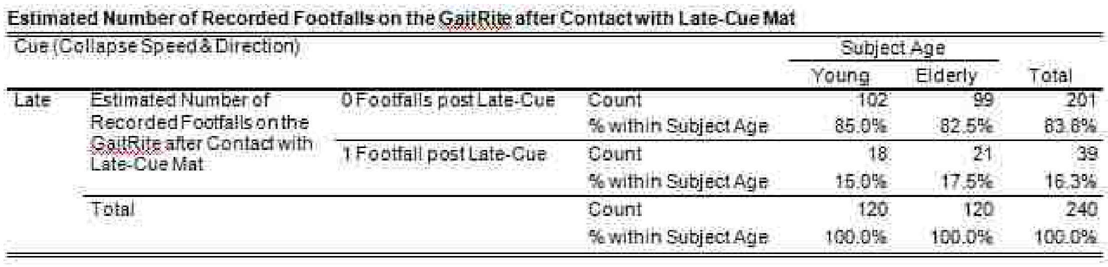


Representation of Final Recorded Footfall on GaitRite (even if Partial) * Subject Age * Direction * Cue (Collapse Speed & Direction) * Speed (Collapse Cue & Direction) Crosstabulation

Speed (Collapse Cue & Direction)	Cue (Collapse Speed & Direction)	Direction				Subject Age		
						Young	Elderly	Total
Preferred	Early	Right Turn	Representation of Final Recorded Footfall on GaitRite (even if Partial)	Penultimate Footfall	Count	26	19	45
					% within Subject Age	86.7%	63.3%	75.0%
				Antepenultimate	Count	4	11	15
					% within Subject Age	13.3%	36.7%	25.0%
			Total		Count	30	30	60
					% within Subject Age	100.0%	100.0%	100.0%
	Late	Right Turn	Representation of Final Recorded Footfall on GaitRite (even if Partial)	Penultimate Footfall	Count	21	19	40
					% within Subject Age	70.0%	63.3%	66.7%
				Antepenultimate	Count	9	11	20
					% within Subject Age	30.0%	36.7%	33.3%
			Total		Count	30	30	60
					% within Subject Age	100.0%	100.0%	100.0%
Fast	Early	Right Turn	Representation of Final Recorded Footfall on GaitRite (even if Partial)	Penultimate Footfall	Count	30	29	59
					% within Subject Age	100.0%	96.7%	98.3%
				Antepenultimate	Count	0	1	1
					% within Subject Age	.0%	3.3%	1.7%
			Total		Count	30	30	60
					% within Subject Age	100.0%	100.0%	100.0%
	Late	Right Turn	Representation of Final Recorded Footfall on GaitRite (even if Partial)	Penultimate Footfall	Count	20	18	38
					% within Subject Age	66.7%	60.0%	63.3%
				Antepenultimate	Count	10	12	22
					% within Subject Age	33.3%	40.0%	36.7%
			Total		Count	30	30	60
					% within Subject Age	100.0%	100.0%	100.0%

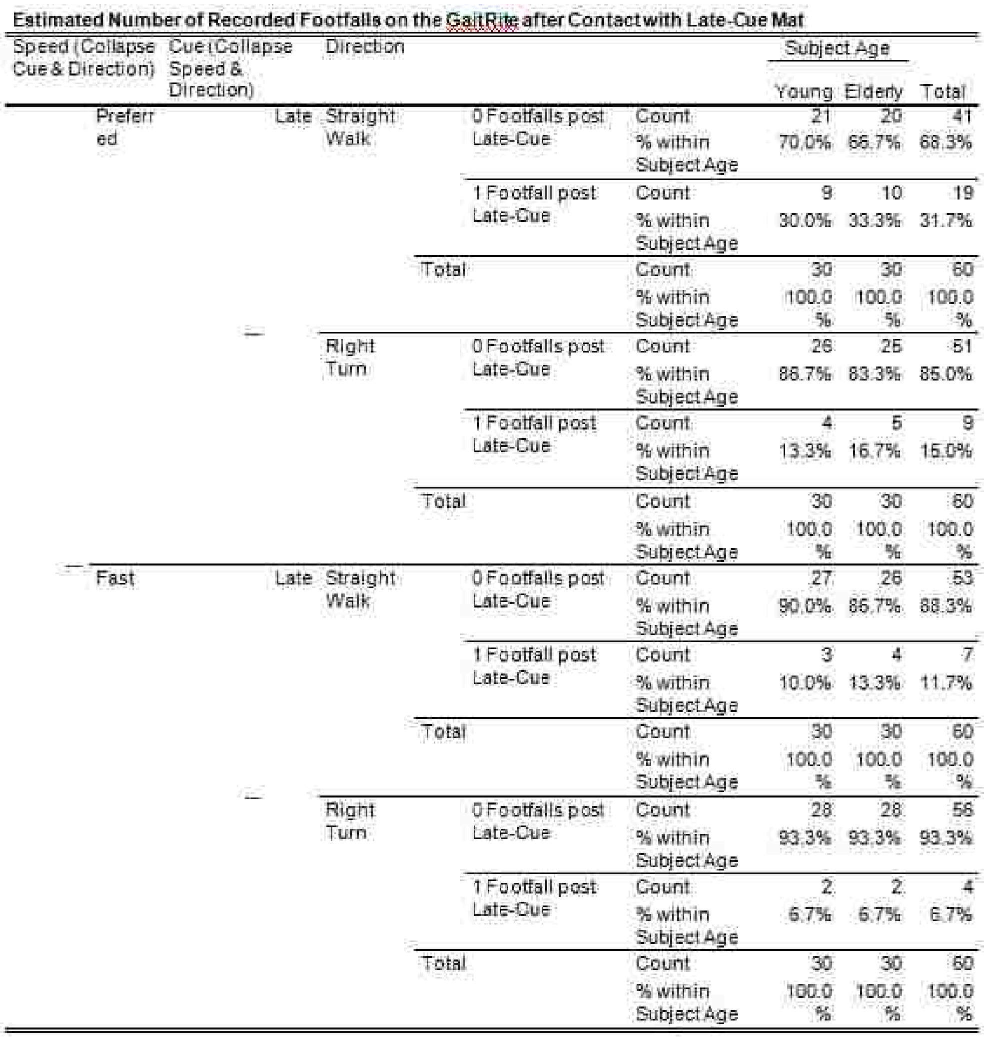
Appendix C

Estimated Number of Footfalls Recorded Post-Late-Cue and Pivoted on Nth Footfall Post-Late-Cue (Right-Turns-Only)



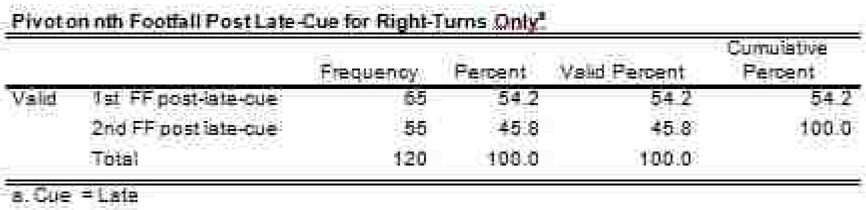
Estimated Number of Recorded Footfalls on the GaitRite after Contact with Late-Cue Mat

Cue (Collapse Speed & Direction)				Subject Age		
				Young	Elderly	Total
Late	Estimated Number of Recorded Footfalls on the GaitRite after Contact with Late-Cue Mat	0 Footfalls post Late-Cue	Count	102	99	201
			% within Subject Age	85.0%	82.5%	83.8%
		1 Footfall post Late-Cue	Count	18	21	39
			% within Subject Age	15.0%	17.5%	16.3%
	Total		Count	120	120	240
			% within Subject Age	100.0%	100.0%	100.0%



Estimated Number of Recorded Footfalls on the GaitRite after Contact with Late-Cue Mat

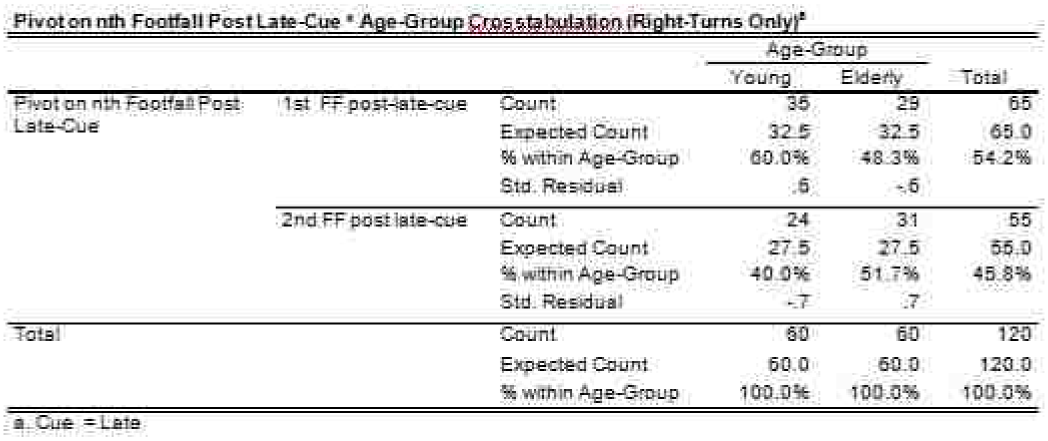
Speed (Collapse Cue & Direction)	Cue (Collapse Speed & Direction)	Direction			Subject Age		
					Young	Elderly	Total
Preferred	Late	Straight Walk	0 Footfalls post Late-Cue	Count	21	20	41
				% within Subject Age	70.0%	66.7%	68.3%
			1 Footfall post Late-Cue	Count	9	10	19
				% within Subject Age	30.0%	33.3%	31.7%
			Total	Count	30	30	60
				% within Subject Age	100.0%	100.0%	100.0%
		Right Turn	0 Footfalls post Late-Cue	Count	26	25	51
				% within Subject Age	86.7%	83.3%	85.0%
			1 Footfall post Late-Cue	Count	4	5	9
				% within Subject Age	13.3%	16.7%	15.0%
			Total	Count	30	30	60
				% within Subject Age	100.0%	100.0%	100.0%
Fast	Late	Straight Walk	0 Footfalls post Late-Cue	Count	27	26	53
				% within Subject Age	90.0%	86.7%	88.3%
			1 Footfall post Late-Cue	Count	3	4	7
				% within Subject Age	10.0%	13.3%	11.7%
			Total	Count	30	30	60
				% within Subject Age	100.0%	100.0%	100.0%
		Right Turn	0 Footfalls post Late-Cue	Count	28	28	56
				% within Subject Age	93.3%	93.3%	93.3%
			1 Footfall post Late-Cue	Count	2	2	4
				% within Subject Age	6.7%	6.7%	6.7%
			Total	Count	30	30	60
				% within Subject Age	100.0%	100.0%	100.0%



Pivot on nth Footfall Post Late-Cue for Right-Turns Only[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1st FF post-late-cue	65	54.2	54.2	54.2
	2nd FF post late-cue	55	45.8	45.8	100.0
	Total	120	100.0	100.0	

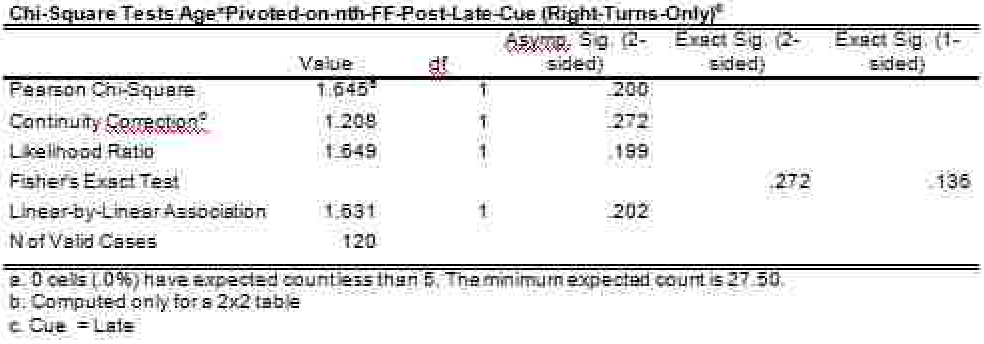
a. Cue = Late



Pivot on nth Footfall Post Late-Cue * Age-Group Crosstabulation (Right-Turns Only)[a]

			Age-Group		Total
			Young	Elderly	
Pivot on nth Footfall Post Late-Cue	1st FF post-late-cue	Count	36	29	65
		Expected Count	32.5	32.5	65.0
		% within Age-Group	60.0%	48.3%	54.2%
		Std. Residual	.6	-.6	
	2nd FF post late-cue	Count	24	31	55
		Expected Count	27.5	27.5	55.0
		% within Age-Group	40.0%	51.7%	45.8%
		Std. Residual	-.7	.7	
Total		Count	60	60	120
		Expected Count	60.0	60.0	120.0
		% within Age-Group	100.0%	100.0%	100.0%

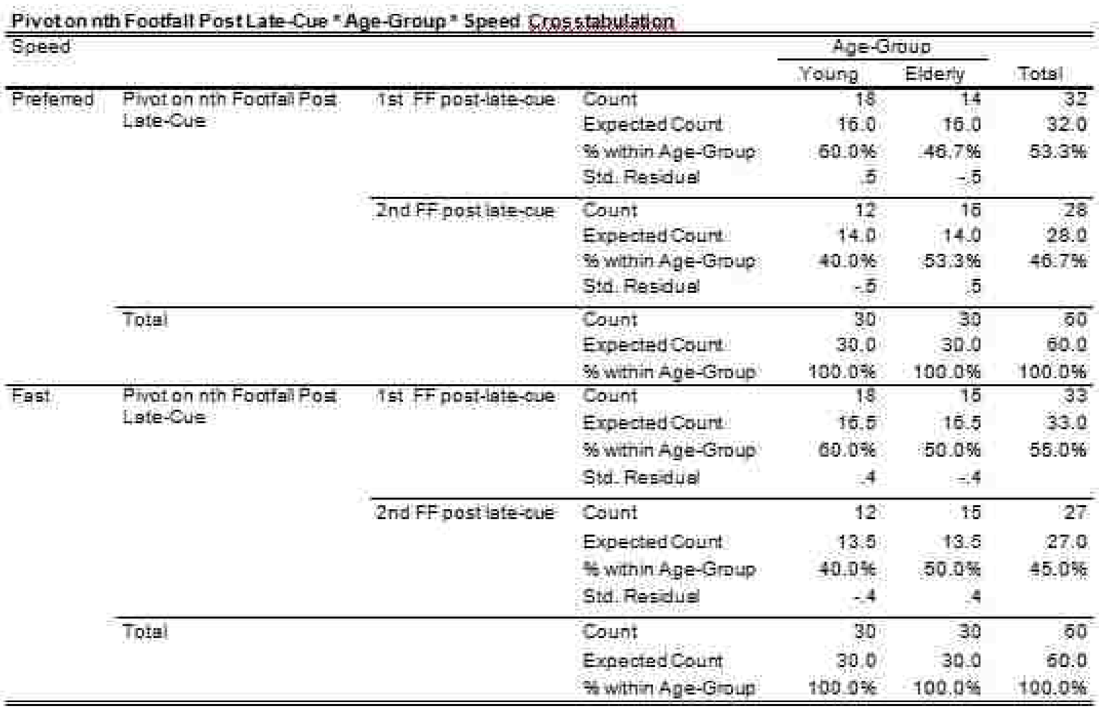
a. Cue = Late



Chi-Square Tests Age*Pivoted-on-nth-FF-Post-Late-Cue (Right-Turns-Only)[c]

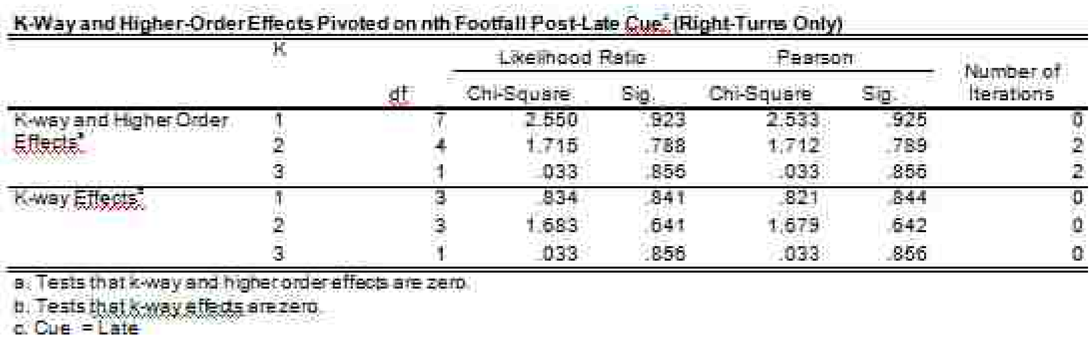
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.645[a]	1	.200		
Continuity Correction[b]	1.208	1	.272		
Likelihood Ratio	1.649	1	.199		
Fisher's Exact Test				.272	.136
Linear-by-Linear Association	1.631	1	.202		
N of Valid Cases	120				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 27.50.
b. Computed only for a 2x2 table
c. Cue = Late



Pivot on nth Footfall Post Late-Cue * Age-Group * Speed Crosstabulation

Speed				Age-Group		
				Young	Elderly	Total
Preferred	Pivot on nth Footfall Post Late-Cue	1st FF post-late-cue	Count	18	14	32
			Expected Count	16.0	16.0	32.0
			% within Age-Group	60.0%	46.7%	53.3%
			Std. Residual	.5	-.5	
		2nd FF post late-cue	Count	12	16	28
			Expected Count	14.0	14.0	28.0
			% within Age-Group	40.0%	53.3%	46.7%
			Std. Residual	-.5	.5	
	Total		Count	30	30	60
			Expected Count	30.0	30.0	60.0
			% within Age-Group	100.0%	100.0%	100.0%
Fast	Pivot on nth Footfall Post Late-Cue	1st FF post-late-cue	Count	18	15	33
			Expected Count	16.5	16.5	33.0
			% within Age-Group	60.0%	50.0%	55.0%
			Std. Residual	.4	-.4	
		2nd FF post late-cue	Count	12	15	27
			Expected Count	13.5	13.5	27.0
			% within Age-Group	40.0%	50.0%	45.0%
			Std. Residual	-.4	.4	
	Total		Count	30	30	60
			Expected Count	30.0	30.0	60.0
			% within Age-Group	100.0%	100.0%	100.0%



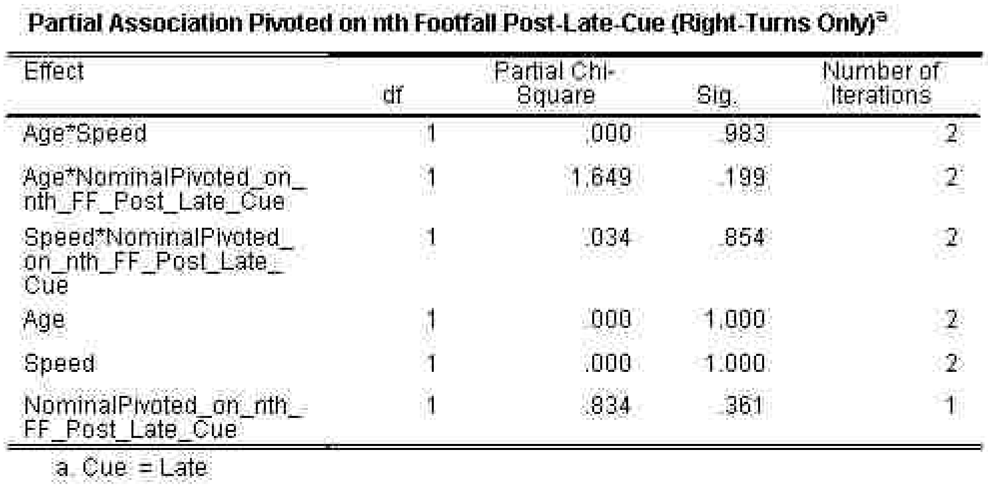
K-Way and Higher-Order Effects Pivoted on nth Footfall Post-Late Cue[c] (Right-Turns Only)

	K	df	Likelihood Ratio		Pearson		Number of Iterations
			Chi-Square	Sig.	Chi-Square	Sig.	
K-way and Higher Order Effects[a]	1	7	2.550	.923	2.533	.925	0
	2	4	1.715	.788	1.712	.789	2
	3	1	.033	.856	.033	.856	2
K-way Effects[b]	1	3	.834	.841	.821	.844	0
	2	3	1.683	.641	1.679	.642	0
	3	1	.033	.856	.033	.856	0

a. Tests that k-way and higher order effects are zero.

b. Tests that k-way effects are zero.

c. Cue = Late



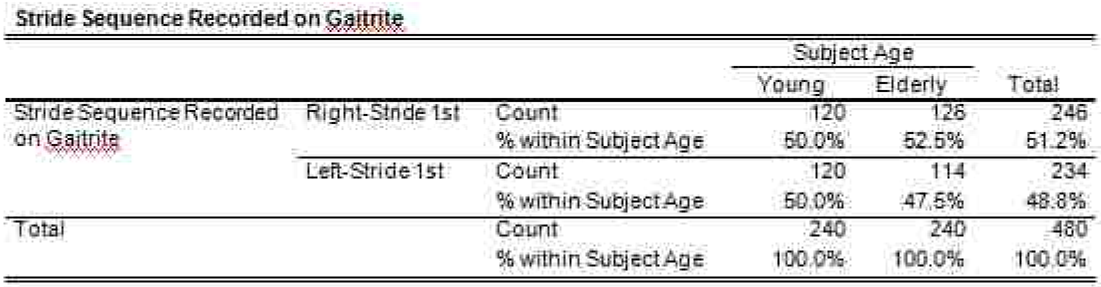
Partial Association Pivoted on nth Footfall Post-Late-Cue (Right-Turns Only)[a]

Effect	df	Partial Chi-Square	Sig.	Number of Iterations
Age*Speed	1	.000	.983	2
Age*NominalPivoted_on_nth_FF_Post_Late_Cue	1	1.649	.199	2
Speed*NominalPivoted_on_nth_FF_Post_Late_Cue	1	.034	.854	2
Age	1	.000	1.000	2
Speed	1	.000	1.000	2
NominalPivoted_on_nth_FF_Post_Late_Cue	1	.834	.361	1

a. Cue = Late

Appendix D

Right v. Left Stride Approach Sequence across Trials



Stride Sequence Recorded on Gaitrite

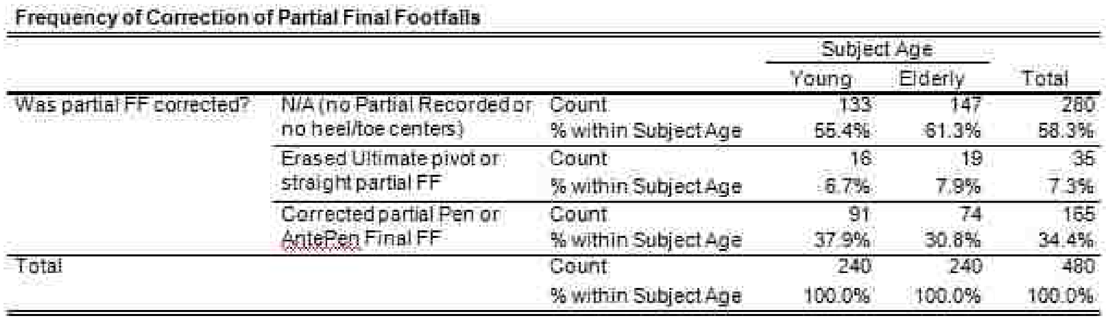
			Subject Age		
			Young	Elderly	Total
Stride Sequence Recorded on Gaitrite	Right-Stride 1st	Count	120	126	246
		% within Subject Age	50.0%	52.5%	51.2%
	Left-Stride 1st	Count	120	114	234
		% within Subject Age	50.0%	47.5%	48.8%
Total		Count	240	240	480
		% within Subject Age	100.0%	100.0%	100.0%

Stride Sequence Recorded on Gaitrite

Direction				Subject Age		
				Young	Elderly	Total
Straight Walk	Stride Sequence Recorded on Gaitrite	Right-Stride 1st	Count	60	56	116
			% within Subject Age	50.0%	46.7%	48.3%
		Left-Stride 1st	Count	60	64	124
			% within Subject Age	50.0%	53.3%	51.7%
	Total		Count	120	120	240
			% within Subject Age	100.0%	100.0%	100.0%
Right Turn	Stride Sequence Recorded on Gaitrite	Right-Stride 1st	Count	60	70	130
			% within Subject Age	50.0%	58.3%	54.2%
		Left-Stride 1st	Count	60	50	110
			% within Subject Age	50.0%	41.7%	45.8%
	Total		Count	120	120	240
			% within Subject Age	100.0%	100.0%	100.0%

Appendix E

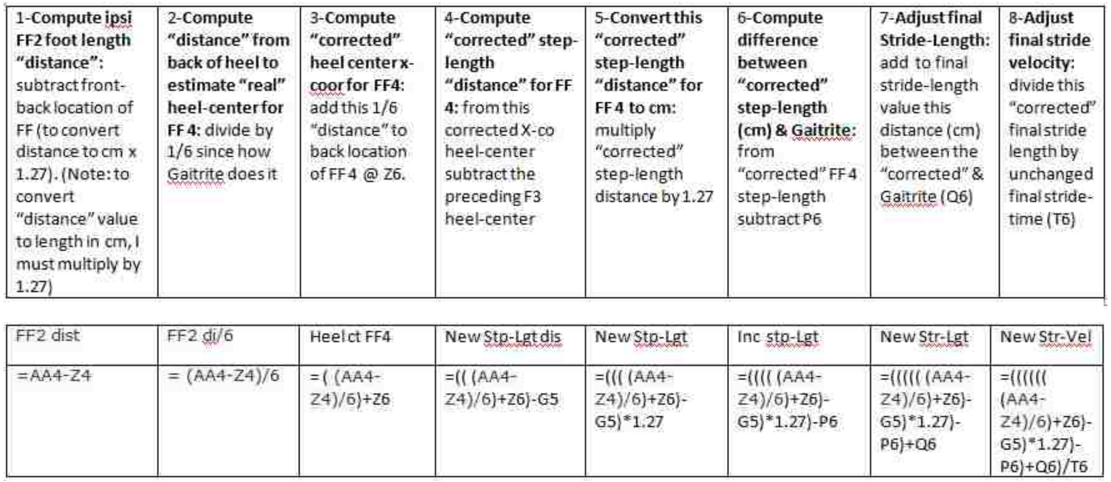
Correction of Partial Final Footfalls



Frequency of Correction of Partial Final Footfalls

			Subject Age		
			Young	Elderly	Total
Was partial FF corrected?	N/A (no Partial Recorded or no heel/toe centers)	Count	133	147	280
		% within Subject Age	55.4%	61.3%	58.3%
	Erased Ultimate pivot or straight partial FF	Count	16	19	35
		% within Subject Age	6.7%	7.9%	7.3%
	Corrected partial Pen or AntePen Final FF	Count	91	74	165
		% within Subject Age	37.9%	30.8%	34.4%
Total		Count	240	240	480
		% within Subject Age	100.0%	100.0%	100.0%

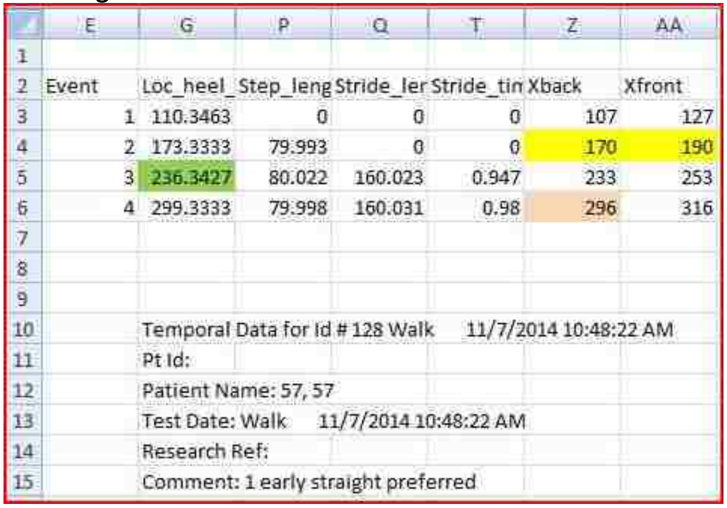
Formula to Correct for partial final footfalls (FF4)



1-Compute ipsi FF2 foot length "distance": subtract front-back location of FF (to convert distance to cm x 1.27). (Note: to convert "distance" value to length in cm, I must multiply by 1.27)	**2-Compute "distance" from back of heel to estimate "real" heel-center for FF 4:** divide by 1/6 since how Gaitrite does it	**3-Compute "corrected" heel center x-coor for FF4:** add this 1/6 "distance" to back location of FF 4 @ Z6.	**4-Compute "corrected" step-length "distance" for FF 4:** from this corrected X-co heel-center subtract the preceding F3 heel-center	**5-Convert this "corrected" step-length "distance" for FF 4 to cm:** multiply "corrected" step-length distance by 1.27	**6-Compute difference between "corrected" step-length (cm) & Gaitrite:** from "corrected" FF4 step-length subtract P6	**7-Adjust final Stride-Length:** add to final stride-length value this distance (cm) between the "corrected" & Gaitrite (Q6)	**8-Adjust final stride velocity:** divide this "corrected" final stride length by unchanged final stride-time (T6)

FF2 dist	FF2 di/6	Heel ct FF4	New Stp-Lgt dis	New Stp-Lgt	Inc stp-Lgt	New Str-Lgt	New Str-Vel
=AA4-Z4	= (AA4-Z4)/6	=((AA4-Z4)/6)+Z6	=(((AA4-Z4)/6)+Z6)-G5	=((((AA4-Z4)/6)+Z6)-G5)*1.27	=(((((AA4-Z4)/6)+Z6)-G5)*1.27)-P6	=((((((AA4-Z4)/6)+Z6)-G5)*1.27)-P6)+Q6	=(((((((AA4-Z4)/6)+Z6)-G5)*1.27)-P6)+Q6)/T6

Viewing the Gaitrite data in Excel:



	E	G	P	Q	T	Z	AA
1							
2	Event	Loc_heel_	Step_leng	Stride_ler	Stride_tin	Xback	Xfront
3	1	110.3463	0	0	0	107	127
4	2	173.3333	79.993	0	0	170	190
5	3	236.3427	80.022	160.023	0.947	233	253
6	4	299.3333	79.998	160.031	0.98	296	316
7							
8							
9							
10		Temporal Data for Id # 128 Walk		11/7/2014 10:48:22 AM			
11		Pt Id:					
12		Patient Name: 57, 57					
13		Test Date: Walk	11/7/2014 10:48:22 AM				
14		Research Ref:					
15		Comment: 1 early straight preferred					

Steps 1 to 3: Compute a new “corrected” x-coordinate A-P heel center location for the partial final footfall FF4 (G6 cell in Excel) based upon the foot-length of the previous ipsilateral FF2: the foot length distance in # of sensors for FF2 is computed by subtracting the x-coordinate (anterior-posterior) location marking the back of footfall 2-FF2 (Z4 cell in Excel) from the x-coordinate location marking the front of footfall 2-FF2 (AA4 cell in Excel). A new “corrected” x coordinate A-P heel center for FF4 is then computed by dividing this distance (i.e. the number of sensors separating the back of the heel to the front of the toes of FF2) by 1/6, and then adding this to the x-coordinate location marking the back of the heel of FF4 (Z6 cell in Excel). Thus, this computed value represents the new “corrected” G6 (cell in Excel) which equals the “real” location of the heel center for FF4, and replaces the “errant” value as measured by the Gaitrite based upon a partial FF4 and displayed in Excel Gaitrite footfall detail output. [The reason a 1/6 foot length distance is being used as an estimate for the AP heel center of a footfall is that according to the Gaitrite technical reference manual (CIR Systems, Inc., 2013, p 33), the Gaitrite calculates foot length by multiplying the distance from the heel center to the toe center by a factor of 1.5 or 6/4 as a fraction. Gaitrite refers to the line connecting the heel-center and toe-center as the “midline of the footprint”. Thus, moving from posterior to anterior, it is reasonable to assume a 1/6 foot length distance separates the back of the heel from an estimate of the heel center (and a 1/6 foot length distance would also separate an estimate of the toe center from the front of the toes)].

Step 4: compute a new “corrected” step-length distance in # of sensors for FF4 based upon the new “corrected” G6 (cell in Excel) heel center for FF4: the new “corrected” step-length for FF4 is computed by subtracting the x-coordinate heel center location for the previous footfall FF3 (G5 cell in Excel) from the new “corrected” x-coordinate heel center location for FF4 as just computed above (CIR Systems, Inc., 2013, p 32)

Step 5: convert this step-length distance from the units of # of sensors to the units of cm: in this process, the new “corrected” step-length distance in # of sensor units for FF4 must be converted to cm using a conversion factor of 1 sensor = 1.27 cm, since the Gaitrite sensor pads are placed on .5 inch (1.27 cm) centers (CIR Systems, Inc., 2013, pp. 11, 28, 41)

Step 6: compute the increase in the new “corrected” step-length for FF4 in cm: The increase in step-length for FF4 in cm (which represents the correction distance for the errant step-length based upon a partial FF4) is also

computed by subtracting the errant FF4 step-length (P6 cell in Excel) from the new "corrected" step-length for FF4
Step 7: compute a new "corrected" ipsilateral stride-length in cm: this increase in step-length for FF4 is then added to the previous errant stride-length for the ipsilateral side (Q6 cell in Excel) based upon the partial foot length of FF4
Step 8: compute a new "corrected" ipsilateral stride-velocity in cm/s: this new "corrected" ipsilateral stride-length is then divided by the same ipsilateral stride-time (T6 cell in Excel) to compute a new "corrected" ipsilateral stride-velocity (cm/s).

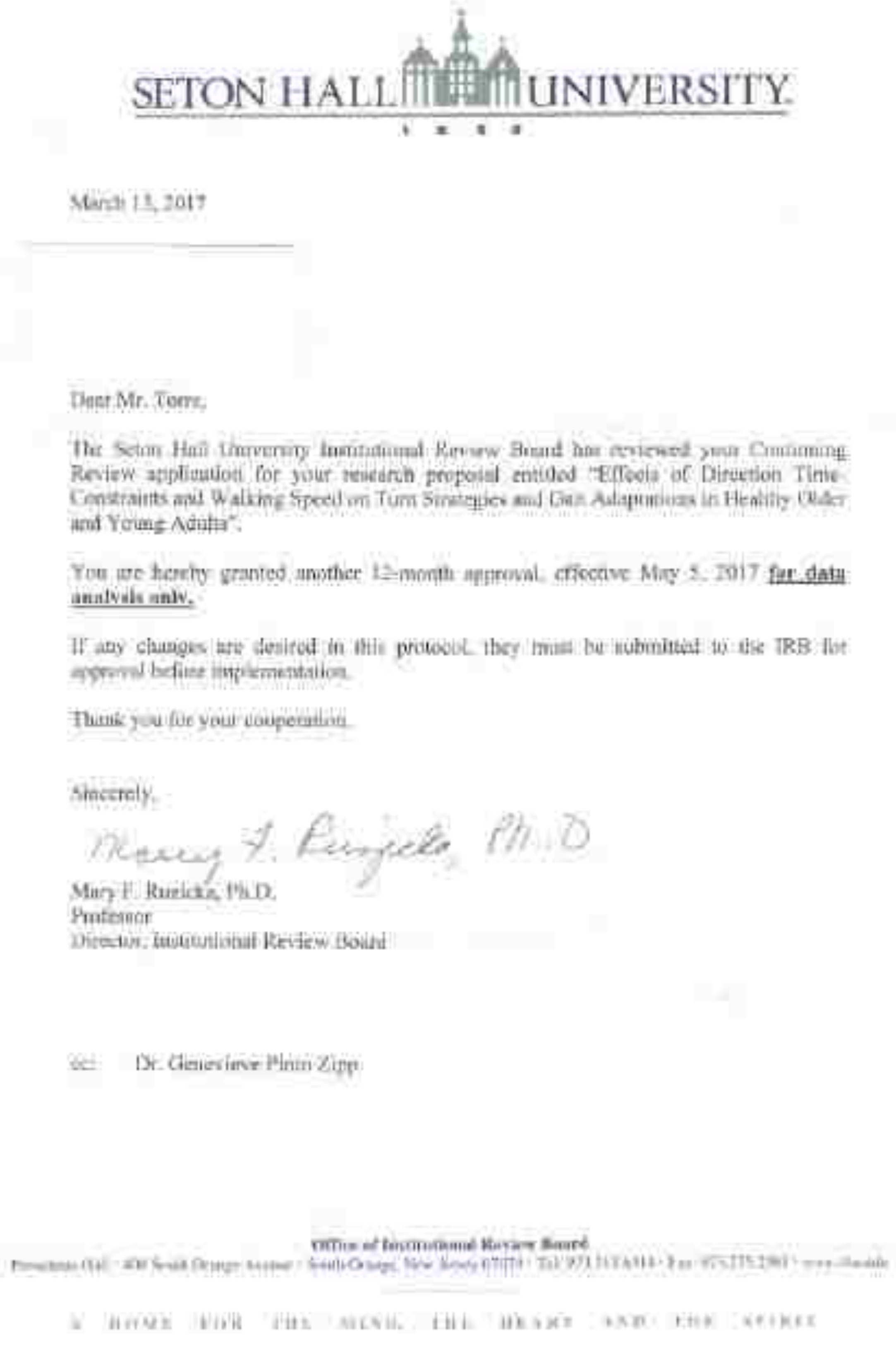
Partial final footfalls (FF4) also had the capacity to distort H-H BOS measures. To this end, the Gaitrite calculates H-H BOS using both the right & left heel-centers, and determines each heel center by computing the pivot point of the two-dimensional activated sensor pattern within the heel quadrilateral (CIR Systems, Inc., 2013, p. 30). An indication that H-H BOS may have been distorted was when visual inspection of the midline of a partial final footfall i.e. footprint (FF4) appeared in an usually exaggerated position of toe-out/in, especially when the toe in/out as seen on the Gaitrite screen did not agree with the amount of toe in/out as seen on video. [Note, as the Gaitrite computes toe-out/in based upon the orientation of a footprint's midline (comprised of the line connecting the heel-center to the toe-center) relative to the line of progression of the contra-lateral stride (CIR Systems, Inc., 2013, pp. 31-33) the Gaitrite only provides measures of toe-out/in for FF2 & FF3, but not FF1 nor FF4, regardless of whether or not the final footfall is partial]. A visual yet "practical" technique to address the potential for a partial final footfall distorting an H-H BOS measure was also developed for the purposes of this study. Hence, after using the formula to correct spatial parameters related to step-length, when a distorted H-H BOS measure was suspected, the Gaitrite trial was re-suspended so the footfall editor's erasing tool could be used to "trim" the partial final footfall (FF4) towards its midline. This was done in an attempt to estimate the correct location of the ML y-coordinate of the heel center since as said above, proper location of the heel center is needed to compute H-H BOS, and the Gaitrite calculates the heel center as a centroid of the heel sensor area. Obviously, in reality when a partial final footfall FF4 does exist, the "true" H-H BOS value is unknown; nonetheless, the "trimming" technique was helpful in estimating a more realistic measure when H-H BOS appeared distorted.

Finally, unlike spatial parameters, it did not appear necessary to make corrections for temporal parameters as a consequence of a partial final footfall, given that in healthy adults the posterior aspect of the heel makes initial ground contact. When the x-coordinate location marking the back of the heel of FF4 is intact, temporal parameters are essentially unchanged. The reason for this is that Gaitrite temporal parameters (step-time, stride-time, SLS, DLS, stance time, swing time) are defined within the context of the time elapsed beginning with sensor activation upon first contact, which in healthy adults coincides with posterior-lateral heel strike (CIR Systems, Inc., 2013, pp. 35-36, 37). Moreover, as the Gaitrite divides the footprint into three quadrilaterals [a toe, mid-foot, and heel quadrilateral which are all of equal length along the footprint's medial aspect (CIR Systems, Inc., 2013, pp. 29)], and a final partial footfall often lacks an observable mid-foot and or toe quadrilateral, the posterior aspect of the heel quadrilateral can often be the only part of the foot to activate sensors when the foot lands at the transition between the active/inactive region of the Gaitrite mat (54.5 cm before its edge).

Appendix F

Seton Hall University Institutional Review Board

Current & Original Approval Letters, Approved Informed Consent Form, and Approved Advertisement Flyer



SETON HALL UNIVERSITY
1 8 5 6

March 13, 2017

Dear Mr. Torre,

The Seton Hall University Institutional Review Board has reviewed your Continuing Review application for your research proposal entitled "Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults".

You are hereby granted another 12-month approval, effective May 5, 2017 **for data analysis only.**

If any changes are desired in this protocol, they must be submitted to the IRB for approval before implementation.

Thank you for your cooperation.

Sincerely,

Mary F. Ruzicka, Ph.D

Mary F. Ruzicka, Ph.D.
Professor
Director, Institutional Review Board

cc: Dr. Genevieve Pinto Zipp

Office of Institutional Review Board

A HOME FOR THE MIND, THE HEART AND THE SPIRIT

SETON HALL UNIVERSITY
1856

May 5, 2014

Dear Mr. Torre,

The Seton Hall University Institutional Review Board has reviewed the information you have submitted addressing the concerns for your proposal entitled "Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults". Your research protocol is hereby approved as revised under full review.

Enclosed for your records are the signed Request for Approval form, the stamped original Consent Form and recruitment flyer. Make copies only of these stamped forms.

The Institutional Review Board approval of your research is valid for a one-year period from the date of this letter. During this time, any changes to the research protocol must be reviewed and approved by the IRB prior to their implementation.

According to federal regulations, continuing review of already approved research is mandated to take place at least 12 months after this initial approval. You will receive communication from the IRB Office for this several months before the anniversary date of your initial approval.

Thank you for your cooperation.

In harmony with federal regulations, none of the investigators or research staff involved in the study took part in the final discussion and the vote.

Sincerely,

Mary F. Ruzicka, Ph.D.

Mary F. Ruzicka, Ph.D.
Professor
Director, Institutional Review Board

cc: Dr. Genevieve Pinto Zipp

Office of Institutional Review Board

REQUEST FOR APPROVAL OF RESEARCH, DEMONSTRATION OR RELATED ACTIVITIES INVOLVING HUMAN SUBJECTS

All material must be typed.

PROJECT TITLE: Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults

CERTIFICATION STATEMENT:

In making **this application,** I(we) certify that I(we) have read and understand the University's policies and procedures governing research, development, and related activities involving human subjects. I (we) shall comply with the letter and spirit of those policies. I(we) further acknowledge my(our) obligation to (1) obtain written approval of significant deviations from the originally-approved protocol BEFORE making those deviations, and (2) report immediately all adverse effects of the study on the subjects to the Director of the Institutional Review Board, Seton Hall University, South Orange, NJ 07079.

Dennis Torre 2/17/2014

RESEARCHER(S) OR PROJECT DIRECTOR(S) DATE

Dennis Torre

Please print or type out names of **all researchers below signature.
Use separate sheet of paper, if necessary.**

My signature indicates that I have reviewed the attached materials and consider them to meet IRB standards.

Genev Zipp PT, EdD 2/17/14

RESEARCHER'S ADVISOR OR DEPARTMENTAL SUPERVISOR DATE

Genevieve Pinto Zipp PT, EdD 2-17-14

Please print or type out name below signature

The request for approval submitted by the above researcher(s) was considered by the IRB for Research Involving Human Subjects Research at the April 2014 meeting.

The application was approved ✓ not approved ___ by the Committee. Special conditions were _____ were not ✓ set by the IRB. (Any special conditions are described on the reverse side.)

Mary F. Ruzicka, Ph.D. 5/5/14

DIRECTOR, DATE
SETON HALL UNIVERSITY INSTITUTIONAL
REVIEW BOARD FOR HUMAN SUBJECTS RESEARCH

SETON HALL UNIVERSITY
1856

Seton Hall University
Institutional Review Board

MAY 05 2014

Approval Date

Expiration Date
MAY 05 2015

Informed Consent Form

Project Title:

Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults.

Researcher's Affiliation with Seton Hall University:

Dennis Torre is a PhD student in the Graduate Programs in Health Sciences, Seton Hall University.

Purpose of the Study:

The purpose of this study is to determine: a) whether there is a relationship between age, walking speed, time limitations to respond to a cue to change direction, and turn strategy preference; and b) whether age-related differences exists in walking based upon speed and time limitations to respond to a cue to change direction.

Duration of Participation:

Participants will be asked to attend one test session which will last no more than 2½ hours.

Procedures:

Participants will be asked to come to the test center wearing comfortable clothes and walking shoes or sneakers. Upon arrival at the testing site on the SHU campus which will be in either the Chancellor Suite (Student Center) or the Corrigan Hall Room 67 (Functional Performance Lab), the participant will be required to read and sign the consent forms, provide their contact information and complete a demographic form which will inquire about date of birth, age, gender, medical history including medications, fall history, use of walking aides, and level of education. In order to determine eligibility, participants will then be tested for their cognitive ability, functional balance adaptability when walking is challenged, and self-rated balance confidence with standardized tests commonly used by physical therapists. Only those who meet the eligibility criteria of these tests will be able to participate further in the study.

Prior to performing the turning tests, participants will be weighed, and a tape measure will be used to record height and leg length. These measurements will allow the researcher to compare participants of different stature. Measurements for leg length will require the primary researcher, who is a male, to locate bony landmarks in the hip region by touching over clothing.

In order to analyze the choice of turn strategy and walking adjustments, participants will be videotaped as they walk along a 14' carpet (which measures stepping changes) and perform either a right/left 90^0 turn or no turn once stepping off the carpet. Turn direction cues (right, left or no turn) will be provided at eye level using directional signal arrows placed on a black board located about 12 feet directly in front of the walkway. These directional cues will be delivered at different times.

Participants will be randomly tested for the three directions (right, left, no turn) with turn direction cued at different times while walking along the carpet at both their preferred natural speed and fastest comfortable walking speed. A total of 18 trails will be performed at each walking speed. A one minute rest period will be given between walking trials with a 5 minute rest period provided between the two walking speed blocks. However, additional rest periods will be given upon request.

All participants will wear a Velcro adjustable gait safety waist belt and be closely guarded by the primary researcher, or Mr. Anthony Porcelli or Mr. Kweku Agyerman both of whom are trained research assistants, when screened for functional balance and during each walking trial.

Instruments:

Participants will be screened for study eligibility with the following instruments: cognitive function using the Mini-Mental State Examination which consist of 11 items which test an individual for orientation, attention, calculation, recall, and language; functional balance using the Dynamic Gait Index which assesses eight different walking tasks including at different speeds, with head movements, over and around objects, quickly stopping after turning around, and walking up/down steps; and the psychological aspect of balance using the Activities-specific Balance Confidence Scale in which participants rate their confidence when contemplating 16 hypothetical tasks of varying balance difficulty. Changes in walking will be measured using a 14-foot electronic walkway carpet called a GaitRite which is embedded with pressure sensors connected to a computer.

Voluntary Nature of Participation:

Participation in this study is completely voluntary and participants may withdraw from the study at any time by informing the researcher, with no penalty, prejudice or questions asked.

Statement on Anonymity:

Each participant will be assigned a random code number following the signing of informed consent. A master key will be created containing each participant's name, code number and contact information should any follow up be necessary. The participant's demographic information, screening tests scores, walking data and video will be identified using the code number, and video images of the participant's face will be masked to prevent identification, thus maintaining participant anonymity.

Statement on Confidentiality:

The completed consent form and master key will be stored in a separate locked file cabinet from the locked cabinet in which files containing each participant's demographic information and standardized tests will be stored. Both cabinets will be located within the principal investigator's home office. Additionally, walking data will be saved on USB memory keys and Windows Media Video files and will be saved on DVD with both also stored in a separate locked cabinet from the locked cabinet in which the consent forms and master key will be located in the principal investigator's home office.

Extent of Record Confidentiality:

Only the researcher of this study will have access to the documents and data related to the participants.

Potential Risks or Discomforts:

There is a chance of falling during the screening test for functional balance with the Dynamic Gait Index and during the turning tests, but participants will wear a safety belt around their waist and a research assistant will walk along side of each participant. Additionally, although it is not anticipated that any of the testing procedures used will result in any pain or discomfort, should participants experience discomfort of any kind, the testing will be terminated. Participants may feel fatigued after completing the session but this should subside after a period of rest.

Expiration Date
MAY 05 2015

Seton Hall University
Institutional Review Board

MAY 05 2014

Approval Date

Potential for Direct Benefits:

There are no anticipated direct health benefits to the participants. Participants will not receive any monetary benefits for their participation in this study.

Compensation:

There is no compensation.

Contact Information for Any Questions:

If participants have any questions or concerns related to the study, they are encouraged to contact the researchers, Dennis Torre, through the Graduate Program in Health Sciences, (973) 275-2076, dennis.torre@student.shu.edu, or Dr. Genevieve Pinto Zipp, (973) 275-2457, Genevieve.zipp@shu.edu PI advisor. Additional questions or concern about your rights as a human participant in this research study should be addressed to the Institutional Review Board at Seton Hall University, (973) 313-6314, irb@shu.edu.

Participant Copy of Consent Form:

All participants will be provided with a copy of the signed and dated Informed Consent Form prior to the initiation of data collection and testing.

Copies of all completed Consent Forms will be retained by the principal investigator for a minimum duration of 3 years following the termination of the study.

Signature: ______________________________ Date: ______________

Name: ________________________________

Seton Hall University
Institutional Review Board

MAY 05 2014

Approval Date

Expiration Date
MAY 05 2015

Seton Hall University
Institutional Review Board

MAY 05 2014

Approval Date

Expiration Date
MAY 05 2015

Take a Turn... ...for the Better!

Healthy Senior (ages of 65-75) & Young Adult (ages of 21-40) Volunteers needed for a Research Study on Turning

Purpose of the Study: To determine: a) whether there is a relationship between age, walking speed, time limitations to respond to a cue to change direction, and turn strategy preference; and b) whether age-related differences exists in walking based upon speed and time limitations to respond to a cue to change direction.

Expected Duration of Participation: One test session lasting less than 2½ hrs.

Description of Procedures: Participants will complete a demographic form inquiring about date of birth, age, gender, medical history including medications, fall history, use of walking aides, and level of education. Potential subjects will be screened for study eligibility: cognitive function by responding to questions of orientation, attention, calculation, recall, and language; functional balance when walking is challenged; and self-rated balance confidence when considering tasks of varying difficulty. Body weight will be measured, and height and leg length will be recorded in those subjects eligible for the turning tests. The choice of turn strategy and walking adjustments will then be analyzed by videotaping participants as they walk several times along a 14-foot long carpet at both a natural and fast comfortable speed while turning 90^0 left or right in response to a visual signal given at different points along the walkway.

Voluntary Nature of the Study: Participation is completely voluntary and subjects can withdraw at any time with no penalty, prejudice or questions asked.

Anonymity and Confidentiality: All information will be kept strictly confidential and anonymous by encoding names with random numbers and separately securing the name/number key from subject data.

For More Details Please Contact: Dennis Torre, PhD student in the Graduate Programs in Health Sciences, Seton Hall University, (973) 275-2076, dennis.torre@student.shu.edu

Appendix G

Video Consent Form

Video Consent Release Form for Research Purposes

Project Title: Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults

Principal Investigator: Dennis Torre

By signing this consent form below, the participant gives the principal investigator the right, privilege and consent to videotape his/her testing session. The video files will be identified using the code number assigned to the participant, and video images of the participant's face will be masked to prevent identification. The Windows Media Video files will be saved on DVD and stored in a separate locked cabinet from the locked cabinet containing the consent forms and master key. Only the principal investigator will have access to the video files for use in data analysis. Neither the principal investigator nor faculty of the Graduate Program in Health Sciences will have permission to use the video when presenting or lecturing. The video files will be destroyed at the completion of the study.

Participant Copy of Video Consent Form:

All participants will be provided with a copy of the signed and dated Video Consent Form prior to the initiation of data collection and testing.

Copies of all completed Video Consent Forms will be retained by the principal investigator for a minimum duration of 3 years following the termination of the study.

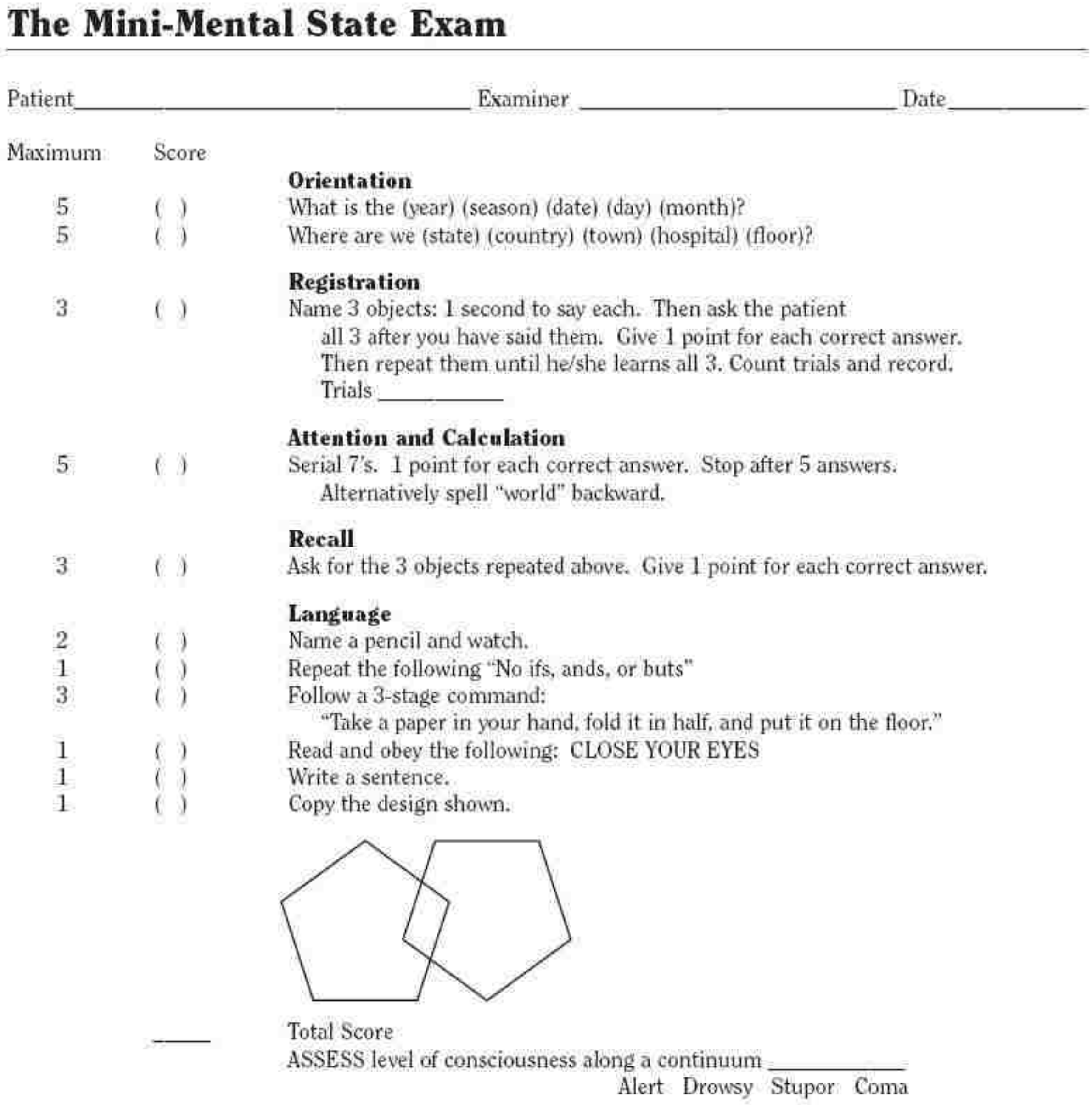
Signature: ____ Date: _________________

Name: ____

Appendix H

The Mini-Mental State Examination

The Mini-Mental State Examination is accessible free for download and copying.



The Mini-Mental State Exam

Patient________________________ Examiner ____________________ Date__________

Maximum	Score	
		Orientation
5	( )	What is the (year) (season) (date) (day) (month)?
5	( )	Where are we (state) (country) (town) (hospital) (floor)?
		Registration
3	( )	Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record. Trials __________
		Attention and Calculation
5	( )	Serial 7's. 1 point for each correct answer. Stop after 5 answers. Alternatively spell "world" backward.
		Recall
3	( )	Ask for the 3 objects repeated above. Give 1 point for each correct answer.
		Language
2	( )	Name a pencil and watch.
1	( )	Repeat the following "No ifs, ands, or buts"
3	( )	Follow a 3-stage command: "Take a paper in your hand, fold it in half, and put it on the floor."
1	( )	Read and obey the following: CLOSE YOUR EYES
1	( )	Write a sentence.
1	( )	Copy the design shown.
	_____	Total Score

ASSESS level of consciousness along a continuum __________

Alert Drowsy Stupor Coma

The Mini-Mental State Examination is accessible free for download and copying.

Appendix I

Dynamic Gait Index

The Dynamic Gait Index is accessible free for download and copying.

Dynamic Gait Index

Subject Code #:______________________

Description: Developed to assess the likelihood of falling in older adults. Designed to test eight facets of gait.

Equipment needed: Box (Shoebox), Cones (2), Stairs, 20’ walkway, 15” wide

Completion:

Time: 15 minutes

Scoring: A four-point ordinal scale, ranging from 0-3. “0” indicates the lowest level of function and “3” the highest level of function.

Total Score = 24

Interpretation: ≤ 19/24 = predictive of falls in the elderly

> 22/24 = safe ambulators

1. Gait level surface _____

Instructions: Walk at your normal speed from here to the next mark (20’)

Grading: Mark the lowest category that applies.

(3) Normal: Walks 20’, no assistive devices, good sped, no evidence for imbalance, normal gait pattern

(2) Mild Impairment: Walks 20’, uses assistive devices, slower speed, mild gait deviations.

(1) Moderate Impairment: Walks 20’, slow speed, abnormal gait pattern, evidence for imbalance.

(0) Severe Impairment: Cannot walk 20’ without assistance, severe gait deviations or imbalance.

2. Change in gait speed _____

Instructions: Begin walking at your normal pace (for 5’), when I tell you “go,” walk as fast as you can (for 5’). When I tell you “slow,” walk as slowly as you can (for 5’).

Grading: Mark the lowest category that applies.

(3) Normal: Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast and slow speeds.

(2) Mild Impairment: Is able to change speed but demonstrates mild gait deviations, or not gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.

(1) Moderate Impairment: Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, or changes speed but has significant gait deviations, or changes speed but loses balance but is able to recover and continue walking.

(0) Severe Impairment: Cannot change speeds, or loses balance and has to reach for wall or be caught.

3. Gait with horizontal head turns _____

Instructions: Begin walking at your normal pace. When I tell you to “look right,” keep walking straight, but turn your head to the right. Keep looking to the right until I tell you, “look left,” then keep walking straight and turn your head to the left. Keep your head to the left until I tell you “look straight,“ then keep walking straight, but return your head to the center.

Grading: Mark the lowest category that applies.

(3) Normal: Performs head turns smoothly with no change in gait.

(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e., minor disruption to smooth gait path or uses walking aid.

(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.

(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers outside 15” path, loses balance, stops, reaches for wall.

4. Gait with vertical head turns _____

Instructions: Begin walking at your normal pace. When I tell you to “look up,” keep walking straight, but tip your head up. Keep looking up until I tell you, “look down,” then keep walking straight and tip your head down. Keep your head down until I tell you “look straight,“ then keep walking straight, but return your head to the center.

Grading: Mark the lowest category that applies.

(3) Normal: Performs head turns smoothly with no change in gait.

(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e., minor disruption to smooth gait path or uses walking aid.

(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.

(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers

outside 15” path, loses balance, stops, reaches for wall.

5. Gait and pivot turn _____

Instructions: Begin walking at your normal pace. When I tell you, “turn and stop,” turn as quickly as you can to face the opposite direction and stop.

Grading: Mark the lowest category that applies.

(3) Normal: Pivot turns safely within 3 seconds and stops quickly with no loss of balance.

(2) Mild Impairment: Pivot turns safely in > 3 seconds and stops with no loss of balance.

(1) Moderate Impairment: Turns slowly, requires verbal cueing, requires several small steps to catch balance following turn and stop.

(0) Severe Impairment: Cannot turn safely, requires assistance to turn and stop.

6. Step over obstacle ____

Instructions: Begin walking at your normal speed. When you come to the shoebox, step over it, not around it, and keep walking.

Grading: Mark the lowest category that applies.

(3) Normal: Is able to step over the box without changing gait speed, no evidence of imbalance.

(2) Mild Impairment: Is able to step over box, but must slow down and adjust steps to clear box safely.

(1) Moderate Impairment: Is able to step over box but must stop, then step over. May require verbal cueing.

(0) Severe Impairment: Cannot perform without assistance.

7. Step around obstacles _____

Instructions: Begin walking at normal speed. When you come to the first cone (about 6' away), walk around the right side of it. When you come to the second cone (6' past first cone), walk around it to the left.

Grading: Mark the lowest category that applies.

(3) Normal: Is able to walk around cones safely without changing gait speed; no evidence of imbalance.

(2) Mild Impairment: Is able to step around both cones, but must slow down and adjust steps to clear cones.

(1) Moderate Impairment: Is able to clear cones but must significantly slow, speed to accomplish task, or requires verbal cueing.

(0) Severe Impairment: Unable to clear cones, walks into one or both cones, or requires physical assistance.

8. Steps _____

Instructions: Walk up these stairs as you would at home, i.e., using the railing if necessary. At the top, turn around and walk down.

Grading: Mark the lowest category that applies.

(3) Normal: Alternating feet, no rail.

(2) Mild Impairment: Alternating feet, must use rail.

(1) Moderate Impairment: Two feet to a stair, must use rail.

(0) Severe Impairment: Cannot do safely.

TOTAL SCORE: ___ / 24

The Dynamic Gait Index is accessible free for download and copying.

Appendix J

Activities-specific Balance Confidence (ABC) Scale

The Activities-specific Balance Confidence (ABC) Scale is accessible free for download and copying.

The Activities-specific Balance Confidence (ABC) Scale

Subject Code #:______________________

<u>Instructions:</u> For <u>each</u> of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale form 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as it you were using these supports.

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

"How confident are you that you will <u>not</u> lose your balance or become unsteady when you...

0% 10 20 30 40 50 60 70 80 90 100%

No Confidence **Completely Confident**

1. …walk around the house? ____%

2. …walk up or down stairs? ____%

3. …bend over and pick up a slipper from the front of a closet floor ____%

4. …reach for a small can off a shelf at eye level? ____%

5. …stand on your tiptoes and reach for something above your head? ____%

6. …stand on a chair and reach for something? ____%

7. …sweep the floor? ____%

8. …walk outside the house to a car parked in the driveway? ____%

9. …get into or out of a car? ____%

10. …walk across a parking lot to the mall? ____%

11. …walk up or down a ramp? ____%

12. …walk in a crowded mall where people rapidly walk past you? ____%

13. …are bumped into by people as you walk through the mall?____%

14. … step onto or off an escalator while you are holding onto a railing?____%

15. … step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%

16. …walk outside on icy sidewalks? ____%

Total Score = ___________________

Total Score in % = Total Score/16 = ___________%

The Activities-specific Balance Confidence (ABC) Scale is accessible free for download and copying.

Appendix K

Demographic Sheet

Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults

Demographic Sheet

1) Date of Birth:_________________________ Age: _________
2) Gender: Male Female
3) Medical History:
   ____
   a. Muscle, Bone, Joint problems: Yes No If yes describe___________________________
   b. Neurological problems: Yes No If yes describe________________________________
   c. Respiratory insufficiency or shortness of breath: Yes No If yes describe____ ________
   d. Uncontrolled diabetes: Yes No If yes describe________________________________
   e. Uncontrolled high blood pressure: Yes No If yes describe________________________
   f. Vestibular involvement or dizziness with head movements: Yes No If yes describe____ _________
   g. Uncorrected visual problems: Yes No If yes describe_____________________________
   h. Medications:____ ____ __________________
4) Have you fallen in the past year? Yes No If yes 1x 2x >2x
   Briefly describe falling event____
5) Do you use any walking aides outdoors (i.e. cane, walker)? Yes No
6) Level of education? Middle School High School College/Graduate School
7) Foot Dominance (right or left)
   a. Which foot would you use to write your name in the sand? R or L

b. Which foot would you use to roll a golf ball around a 10" diameter circle as fast as possible?   R or L
c. Which leg would you use to kick up as high as possible to place your foot up on a wall height chart? R of L
d. Are you right or left handed? R or L

For Researcher to Complete:

Subject Code #:______________________

Standardized Tests Scores:

a. Score on Mini Mental State:___/30
b. Score on Dynamic Gait Index:___/24
c. Score on Activities-specific Balance Confidence Scale: ___________%

Height (cm): ________   Leg Length (cm): _______   Weight: _______ (lb.) = _______ (kg)

2.2 (lb.)

Appendix L

Effects of Direction Time Constraints and Walking Speed on Turn Strategies and Gait Adaptations in Healthy Older and Young Adults

Pre-Screening Questionnaire Form

Age:

Medical History:

Medication:

Prescription

Over-the-counter

History of muscular-skeletal injury or fracture in past 6 months? yes no

If yes briefly describe:

____

History of neuromuscular disease? yes no

History of cardio-respiratory insufficiency? yes no

History of uncontrolled diabetes? yes no

History of uncontrolled high blood pressure? yes no

History of shortness of breath? yes no

History of debilitating arthritis? yes no

History of vestibular involvement or dizziness when turning head or looking up/down? yes no

History of uncorrected visual impairment? yes no

History of falling while ambulating over past year: yes no

(Note: a fall here is defined as an unexpected event where a person stumbles and either strikes an object or comes to rest at a lower level such as the ground)

Do you use a walking aid (i.e. cane, walker)? yes no

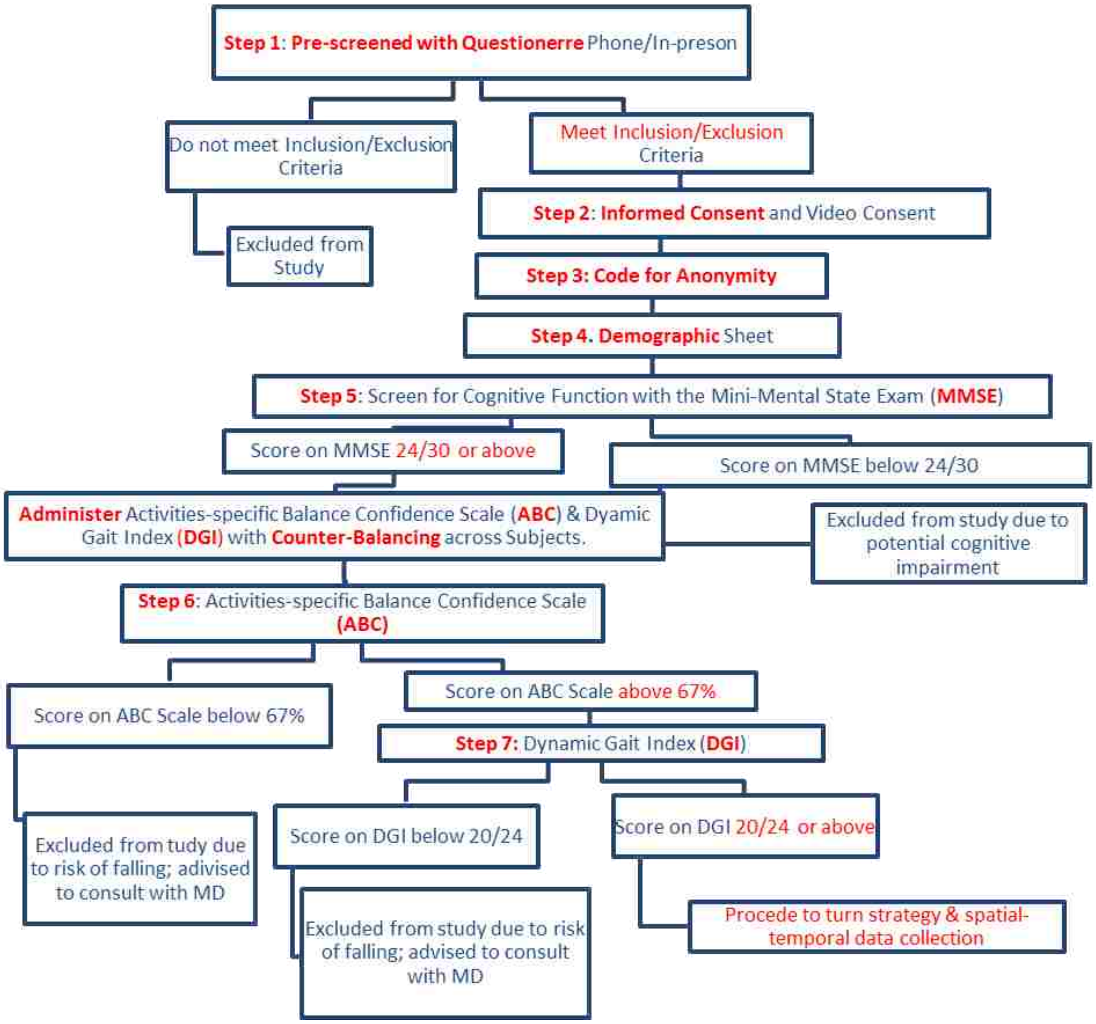
Do you presently have lower extremity weakness, limited motion or pain? yes no

Do you have at minimum a middle school level of education? yes no

(For females) are you pregnant? yes no

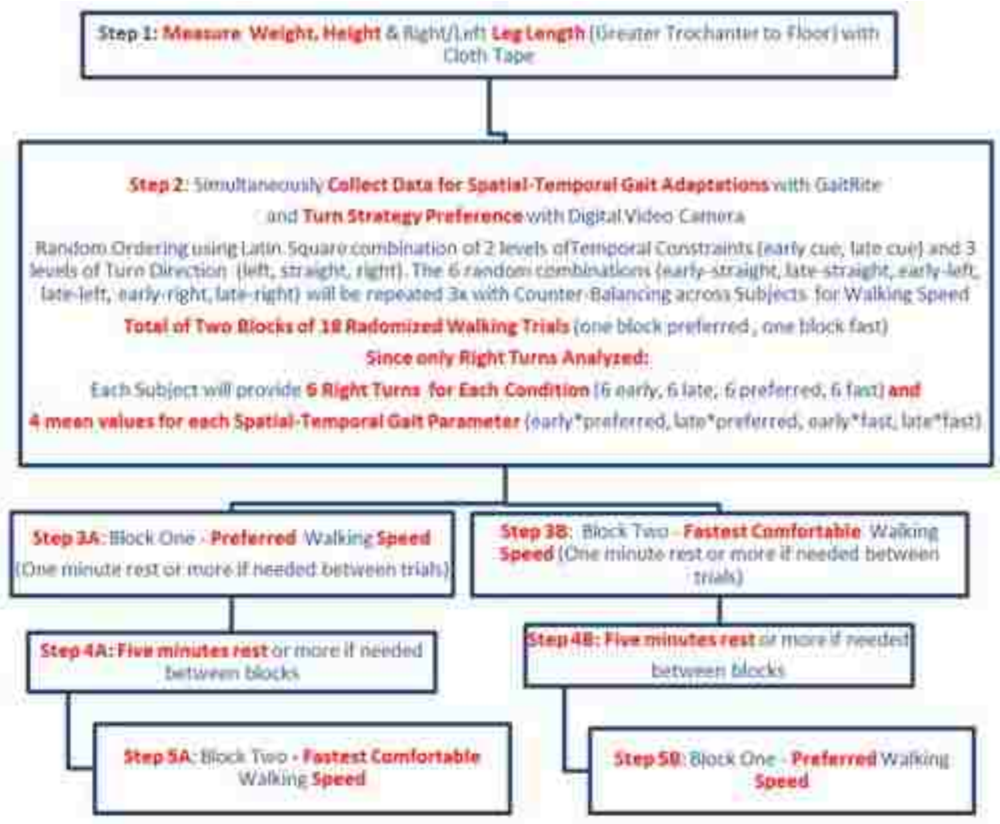
Appendix M

Flow chart of procedures for screening using standardized clinical measures



Appendix N

Flow chart of procedures for collecting spatial-temporal gait data and turn strategy preferences



Step 1: Measure Weight, Height & Right/Left **Leg Length** (Greater Trochanter to Floor) with Cloth Tape

Step 2: Simultaneously **Collect Data for Spatial-Temporal Gait Adaptations** with GaitRite and **Turn Strategy Preference** with Digital Video Camera

Random Ordering using Latin Square combination of 2 levels ofTemporal Constraints (early cue, late cue) and 3 levels of Turn Direction (left, straight, right). The 6 random combinations (early-straight, late-straight, early-left, late-left, early-right, late-right) will be repeated 3x with Counter-Balancing across Subjects for Walking Speed

Total of Two Blocks of 18 Radomized Walking Trials (one block preferred , one block fast)

Since only Right Turns Analyzed:

Each Subject will provide **6 Right Turns for Each Condition** (6 early, 6 late, 6 preferred, 6 fast) **and 4 mean values for each Spatial-Temporal Gait Parameter** (early*preferred, late*preferred, early*fast, late*fast)

Step 3A: Block One - **Preferred** Walking **Speed** (One minute rest or more if needed between trials)

Step 3B: Block Two - **Fastest Comfortable** Walking **Speed** (One minute rest or more if needed between trials)

Step 4A: Five minutes rest or more if needed between blocks

Step 4B: Five minutes rest or more if needed between blocks

Step 5A: Block Two - **Fastest Comfortable** Walking **Speed**

Step 5B: Block One - **Preferred** Walking **Speed**

Appendix O

Procedure for manual computation of odds ratios & 95% Confidence Intervals

Odds Ratio = a/c ÷ b/d =ad/bc (Fields, 2009; Portney & Watkins, 2009; Szumilas, 2010)

Upper 95% CI = EXP[LN(OR)+1.96 √(1/a +1/b+ 1/c +1/d)]
Lower 95% CI = EXP[LN(OR)-1.96 √(1/a +1/b+ 1/c +1/d)] (Szumilas, 2010)

Manual computation of odds ratios and 95% confidence intervals for the significant Speed*Turn Strategy interaction, [X^2 (2) = 7.92, p = 0.02] using a mixed-turn as the reference.

Turn Strategy * Speed Crosstabulation (Right-Direction Turns only)

			Speed		
			Preferred	Fast	Total
Turn Strategy	Step-Turn	Count	50	51	101
		Expected Count	50.5	50.5	101.0
		% within Turn Strategy	49.5%	50.5%	100.0%
		% within Speed	41.7%	42.5%	42.1%
		% of Total	20.8%	21.3%	42.1%
		Std. Residual	-.1	.1	
	Spin-Turn	Count	60	45	105
		Expected Count	52.5	52.5	105.0
		% within Turn Strategy	57.1%	42.9%	100.0%
		% within Speed	50.0%	37.5%	43.8%
		% of Total	25.0%	18.8%	43.8%
		Std. Residual	1.0	-1.0	
	Mixed -Turn	Count	10	24	34
		Expected Count	17.0	17.0	34.0
		% within Turn Strategy	29.4%	70.6%	100.0%
		% within Speed	8.3%	20.0%	14.2%
		% of Total	4.2%	10.0%	14.2%
		Std. Residual	-1.7	1.7	
Total		Count	120	120	240
		Expected Count	120.0	120.0	240.0
		% within Turn Strategy	50.0%	50.0%	100.0%
		% within Speed	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

Comparison 1) Odds of a step-turn (using a mixed-turn as the reference) when walking-fast as opposed to at preferred-speed:

	Step-turn	Mixed-Turn
Preferred	50 a	10 c
Fast	51 b	24 d

Odds of step-turn (with mixed-turn as the reference) when walking fast # StT when fast/ # Mxd when fast =51/24 = 2.13

Odds of step-turn (with mixed-turn as the reference) when walking at preferred # StT when preferred/ # Mxd when preferred = 50/10 = 5.00

Odds ratio = Odds of a step-turn (with mixed-turn as the reference) when walking fast / Odds of a step-turn (with mixed-turn as the reference) when walking at preferred

= 2.13/5.00 = 0.43. This tells us that when walking fast, the odds of a step-turn is 0.43 times the odds when walking at preferred speed (using mixed-turn as the reference).

Another way to interpret this is using: 1/0.43 = 2.33 (Fields, 2009), whereby the odds of a step-turn is 2.33 times lower when walking fast as opposed to when walking at preferred speed (when mixed-turn is the reference) .

To compute 95% CI off odds ratio:

1) Convert odds ratio to natural log: LN(OR): LN 2.33 = 0.846 or rounding off to 0.85…this is point estimate for CI

2) 95% CI +/- 1.96 Standard Error of LN(OR)

$\text{SEln(OR)} = \sqrt{(1/50+1/10+1/51+1/24)} = \sqrt{(.02+.1+..02+.042)} = \sqrt{0.182} = 0.43$

3) find upper & lower limits of LN from point estimate: 0.85+/- 1.96(.43) lower estimate 0.85 – 0.843 = 0.007, upper estimate 0.85 + 0.843= 1.69

4) Convert lower & upper out of LN using EXP function to get lower/upper CI: lower limit: EXP(.007) = 1.01, upper limit: EXP(1.69) = 5.42

5) Convert odds ratio out of LN using EXP function: EXP(0.846) = 2.33

Odds ratio with 95% CI: is 2.33 (1.01, 5.42). Given the confidence interval contains a 1.0, the relationship between less step-turns relative to mixed-turns when walking fast is likely not significant at $p \leq 0.05$. Since odds ratio contains 1.0, we cannot be confident that the direction of the relationship of the odds of a step-turn decreasing (relative to a mixed-turn) when walking fast is true in the population (Fields, 2009 p. 289).

Comparison 2) Odds of a spin-turn (using mixed-turn as the reference) when walking-fast as opposed to at preferred-speed:

	Spin-turn	Mixed-Turn
Preferred	60	10
Fast	45	24

Odds of spin -turn (with mixed-turn as the reference) when walking fast

\# SpT when fast/ # Mxd when fast =45/24 = 1.88

Odds of spin -turn (with mixed-turn as the reference) when walking at preferred

\# SpT when preferred/ # Mxd when preferred= 60/10 = 6.00

Odds ratio = Odds of a spin-turn (with mixed-turn as the reference) when walking fast / Odds of a spin -turn (with mixed-turn as the reference) when walking at preferred

= 1.88/6.00 = 0.31 .This tells us that when walking fast, the odds of a spin -turn (with mixed-turn as the reference) is 0.31 times the odds when walking at preferred speed.

Another way to interpret this is using: 1/0.31 = 3.23, whereby the odds of a spin -turn (when a mixed-turn is the reference) is 3.23 times lower when walking fast as opposed to when walking at preferred speed.

To compute 95% CI off odds ratio:

1) Convert odds ratio to natural log: LN(OR): LN 3.23 = 1.17 …this is point estimate for CI

2) 95% CI +/- 1.96 Standard Error of LN(OR)

SEln(OR) =$\sqrt{(1/60+1/10+1/45+1/24)}$ = $\sqrt{(.017+.1+.022+.042)}$ =$\sqrt{0.181}$ = 0.43

3) find upper & lower limits of LN from point estimate: 1.17+/-1.96(.43) lower estimate 1.17 – 0.843 = 0.327, upper estimate 1.17 + 0.843= 2.01

4) Convert lower & upper out of LN using EXP function to get lower/upper CI: lower limit: EXP(.327) = 1.39, upper limit: EXP(2.01) = 7.46

5) Convert odds ratio out of LN using EXP function: EXP(1.17) = 3.23

Odds ratio with 95% CI: is 3.23 (1.39, 7.46). Given the confidence interval does not contain a 1.0, the relationship between less spin-turns relative to mixed-turns when walking fast is significant at $p \leq 0.05$. Since odds ratio does not contain 1.0, we can be confident that the direction of the relationship of the odds of a spin-turn (relative to a mixed-turn) decreasing when walking fast is true in the population (Fields, 2009 p. 289).

Manual computation of odds ratios and 95% confidence intervals for the significant Cue*Turn Strategy interaction, [X^2 (2) = 15.35, p = 0.00] using a mixed-turn as the reference.

Turn Strategy * Cue Crosstabulation (Right-Direction Turns only)

			Cue		
			Early	Late	Total
Turn Strategy	Step-Turn	Count	60	41	101
		Expected Count	50.5	50.5	101.0
		% within Turn Strategy	59.4%	40.6%	100.0%
		% within Cue	50.0%	34.2%	42.1%
		% of Total	25.0%	17.1%	42.1%
		Std. Residual	1.3	-1.3	
	Spin-Turn	Count	53	52	105
		Expected Count	52.5	52.5	105.0
		% within Turn Strategy	50.5%	49.5%	100.0%
		% within Cue	44.2%	43.3%	43.8%
		% of Total	22.1%	21.7%	43.8%
		Std. Residual	.1	-.1	
	Mixed -Turn	Count	7	27	34
		Expected Count	17.0	17.0	34.0
		% within Turn Strategy	20.6%	79.4%	100.0%
		% within Cue	5.8%	22.5%	14.2%
		% of Total	2.9%	11.3%	14.2%
		Std. Residual	-2.4	2.4	
Total		Count	120	120	240
		Expected Count	120.0	120.0	240.0
		% within Turn Strategy	50.0%	50.0%	100.0%
		% within Cue	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

Comparison 1) Odds of a step-turn (using a mixed-turn as the control) when cued-late as opposed to early:

	Step-turn	Mixed-Turn
Early	60	7
Late	41	27

Odds of step-turn (with mixed-turn as the reference) after being cued-late
StT when late/ # Mxd when late =41/27 = 1.52
Odds of step-turn (with mixed-turn as the reference) after being cued-early
StT when early/ # Mxd when early = 60/7 = 8.57

Odds ratio = Odds of a step-turn (with mixed-turn as the reference) after being cued-late / Odds of a step-turn (with mixed-turn as the reference) after being cued-early

= 1.52/8.57 = 0.18. This tells us that when cued-late, the odds of a step-turn (with mixed-turn as the reference) is 0.18 times the odds when cued-early.

Another way to interpret this is using: 1/.18 = 5.56, whereby the odds of a step-turn (when a mixed-turn is the reference) is 5.56 times lower when cued-late as opposed to when cued- early.

To compute 95% CI off odds ratio:

1) Convert odds ratio to natural log: LN(OR): LN 5.56 = 1.7156 or rounding off to 1.72…this is point estimate for CI

2) 95% CI +/- 1.96 Standard Error of LN(OR)

SEln(OR) =√(1/60+1/7+1/41+1/27) = √(.017+.143+.024+.037) =√0.221 = 0.47

3) find upper & lower limits of LN from point estimate: 1.72+/-1.96(.47)
lower estimate 1.72 - .92 = 0.8, upper estimate 1.72 + .92 =2.64

4) Convert lower & upper out of LN using EXP function to get lower/upper CI: lower limit: EXP(.8) = 2.23, upper limit: EXP(2.64) = 14.01

5) Convert odds ratio out of LN using EXP function: EXP(1.72) = 5.56

Odds ratio with 95% CI: is 5.56 (2.23, 14.01). Given the confidence interval does not contain a 1.0, the relationship between less step-turns relative to mixed-turns when cued-late is significant at *p*≤ 0.05. Since odds ratio does not contain 1.0 we can be confident that the direction of the relationship of the odds of a step-turn (relative to a mixed-turn) decreasing when cued-late is true in the population

Comparison 2) Odds of a spin-turn (using mixed-turn as the reference) when cued-late as opposed to early:

	Spin-turn	Mixed-Turn
Early	53	7
Late	52	27

Odds of spin -turn (with mixed-turn as the reference) after being cued-late
SpT when late/ # Mxd when late =52/27 = 1.93
Odds of spin -turn (with mixed-turn as the reference) after being cued-early
SpT when early/ # Mxd when early = 53/7 = 7.57

Odds ratio = Odds of a spin-turn (with mixed-turn as the reference) after being cued-late / Odds of a spin -turn (with mixed-turn as the reference) after being cued-early

= 1.93/7.57 = 0.25 .This tells us that when cued-late, the odds of a spin -turn (with mixed-turn as the reference) is 0.25 times the odds when cued-early.

Another way to interpret this is using: 1/.25 = 4.00, whereby the odds of a spin -turn (when a mixed-turn is the reference) is 4.00 times lower when cued-late as opposed to when cued-early.

To compute 95% CI off odds ratio:

1) Convert odds ratio to natural log: LN(OR): LN 4.00 = 1.386 or rounding off to 1.39…this is point estimate for CI

2) 95% CI +/- 1.96 Standard Error of LN(OR)

SEln(OR) =√(1/53+1/7+1/52+1/27) = √(.019+.143+.019+.037) =√0.218 = 0.47

3) find upper & lower limits of LN from point estimate: 1.39+/-1.96(.47)

lower estimate 1.39- 0.92 =0.47, upper estimate 1.39+0.92=2.31

4) Convert lower & upper out of LN using EXP function to get lower/upper CI: lower limit: EXP(.47) = 1.60, upper limit: EXP(2.31) = 10.07

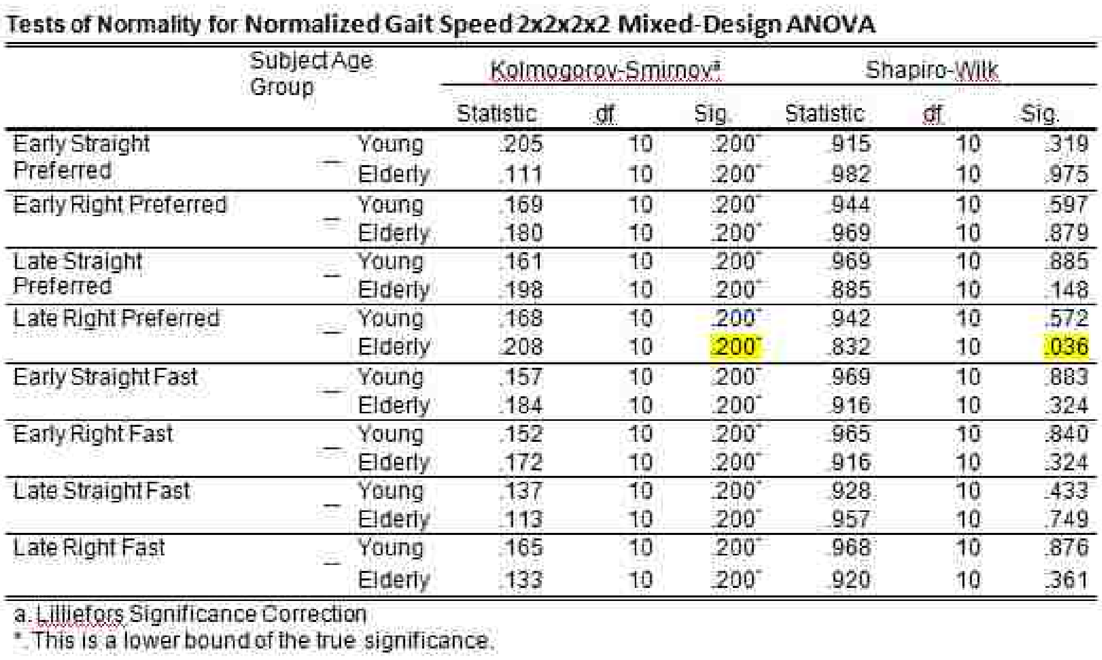
5) Convert odds ratio out of LN using EXP function: EXP(1.39) = 4.00

Odds ratio with 95% CI: is 4.00 (1.60, 10.07). Given the confidence interval does not contain a 1.0, the relationship between less spin-turns relative to mixed-turns when cued-late is significant $p \leq 0.05$.

Appendix P

Exploring Assumptions for Normalized Gait Speed

2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

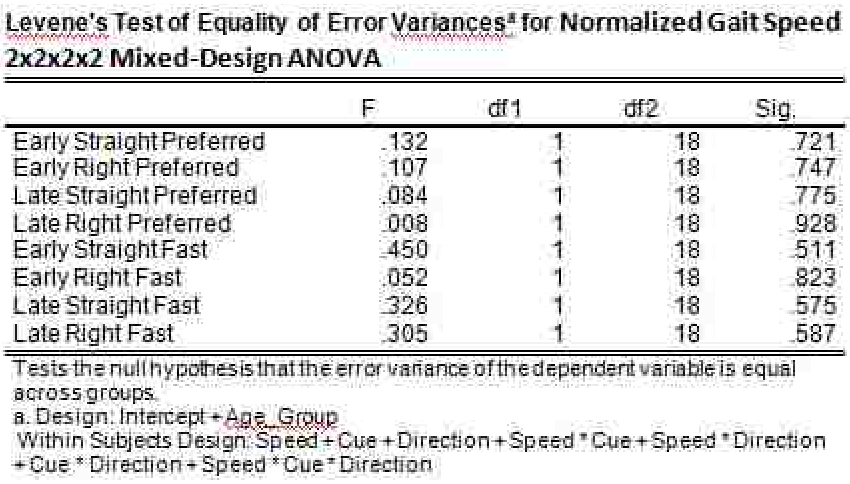


Tests of Normality for Normalized Gait Speed 2x2x2x2 Mixed-Design ANOVA

	Subject Age Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Early Straight Preferred	Young	.205	10	.200*	.915	10	.319
	Elderly	.111	10	.200*	.982	10	.975
Early Right Preferred	Young	.169	10	.200*	.944	10	.597
	Elderly	.180	10	.200*	.969	10	.879
Late Straight Preferred	Young	.161	10	.200*	.969	10	.885
	Elderly	.198	10	.200*	.885	10	.148
Late Right Preferred	Young	.168	10	.200*	.942	10	.572
	Elderly	.208	10	.200*	.832	10	.036
Early Straight Fast	Young	.157	10	.200*	.969	10	.883
	Elderly	.184	10	.200*	.916	10	.324
Early Right Fast	Young	.152	10	.200*	.965	10	.840
	Elderly	.172	10	.200*	.916	10	.324
Late Straight Fast	Young	.137	10	.200*	.928	10	.433
	Elderly	.113	10	.200*	.957	10	.749
Late Right Fast	Young	.165	10	.200*	.968	10	.876
	Elderly	.133	10	.200*	.920	10	.361

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



Levene's Test of Equality of Error Variances[a] for Normalized Gait Speed 2x2x2x2 Mixed-Design ANOVA

	F	df1	df2	Sig.
Early Straight Preferred	.132	1	18	.721
Early Right Preferred	.107	1	18	.747
Late Straight Preferred	.084	1	18	.775
Late Right Preferred	.008	1	18	.928
Early Straight Fast	.450	1	18	.511
Early Right Fast	.052	1	18	.823
Late Straight Fast	.326	1	18	.575
Late Right Fast	.305	1	18	.587

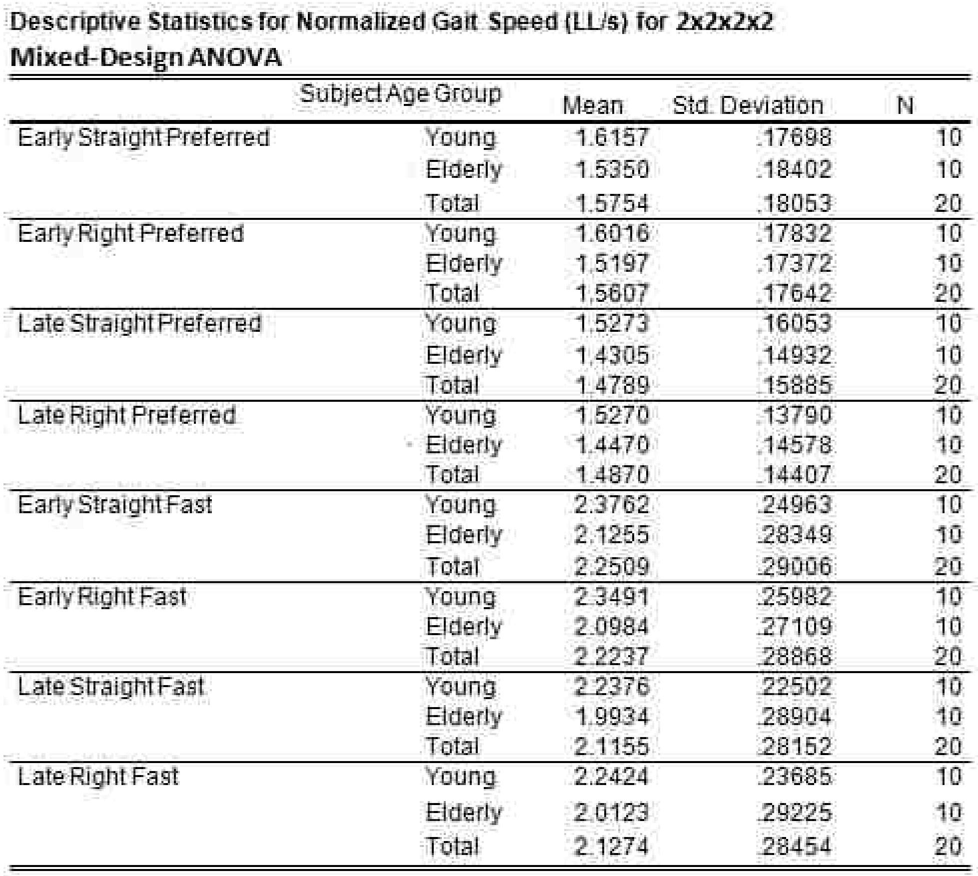
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Age_Group

Within Subjects Design: Speed + Cue + Direction + Speed * Cue + Speed * Direction + Cue * Direction + Speed * Cue * Direction

Appendix Q

Descriptive Statistics, Tests of Between Subjects Effects, Tests of Within-Subjects Effects for Normalized Gait Speed (LL/s) 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only), & Disagreement of Tukey with Significant Interactions



Descriptive Statistics for Normalized Gait Speed (LL/s) for 2x2x2x2 Mixed-Design ANOVA

	Subject Age Group	Mean	Std. Deviation	N
Early Straight Preferred	Young	1.6157	.17698	10
	Elderly	1.5350	.18402	10
	Total	1.5754	.18053	20
Early Right Preferred	Young	1.6016	.17832	10
	Elderly	1.5197	.17372	10
	Total	1.5607	.17642	20
Late Straight Preferred	Young	1.5273	.16053	10
	Elderly	1.4305	.14932	10
	Total	1.4789	.15885	20
Late Right Preferred	Young	1.5270	.13790	10
	Elderly	1.4470	.14578	10
	Total	1.4870	.14407	20
Early Straight Fast	Young	2.3762	.24963	10
	Elderly	2.1255	.28349	10
	Total	2.2509	.29006	20
Early Right Fast	Young	2.3491	.25982	10
	Elderly	2.0984	.27109	10
	Total	2.2237	.28868	20
Late Straight Fast	Young	2.2376	.22502	10
	Elderly	1.9934	.28904	10
	Total	2.1155	.28152	20
Late Right Fast	Young	2.2424	.23685	10
	Elderly	2.0123	.29225	10
	Total	2.1274	.28454	20

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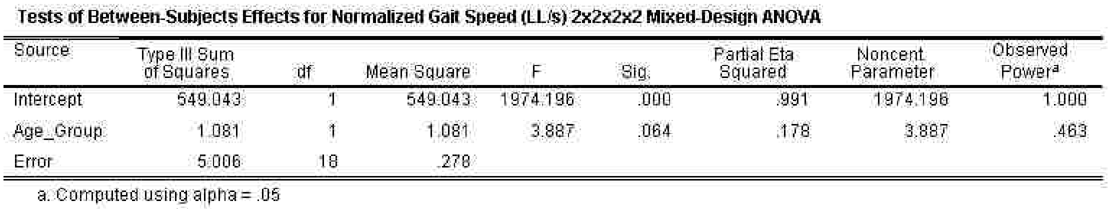
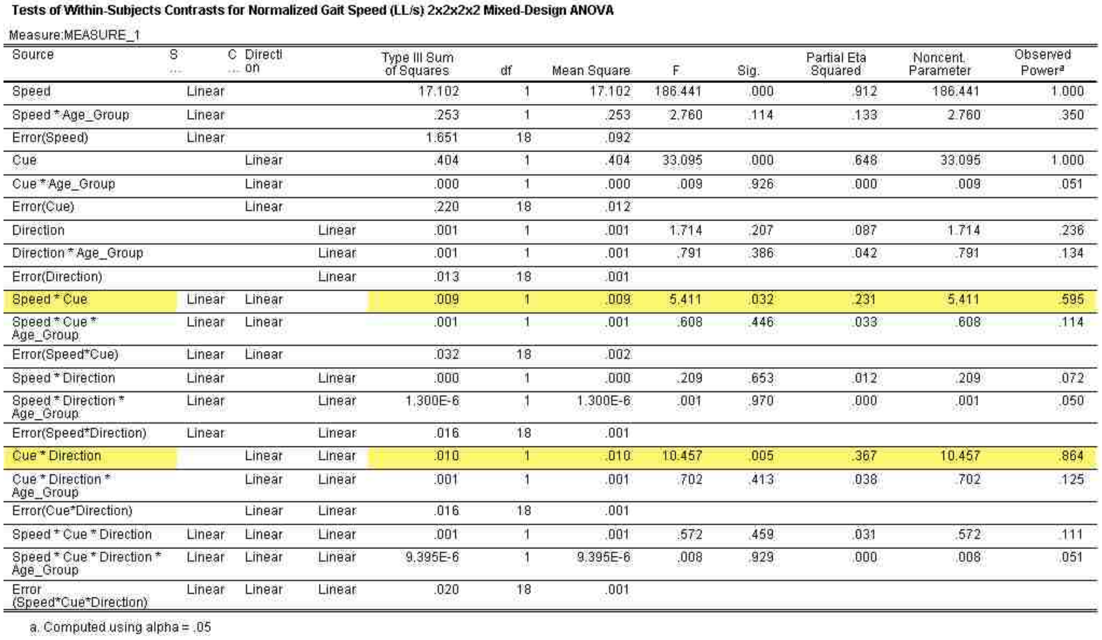


Tests of Between-Subjects Effects for Normalized Gait Speed (LL/s) 2x2x2x2 Mixed-Design ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	549.043	1	549.043	1974.196	.000	.991	1974.196	1.000
Age_Group	1.081	1	1.081	3.887	.064	.178	3.887	.463
Error	5.006	18	.278					

a. Computed using alpha = .05

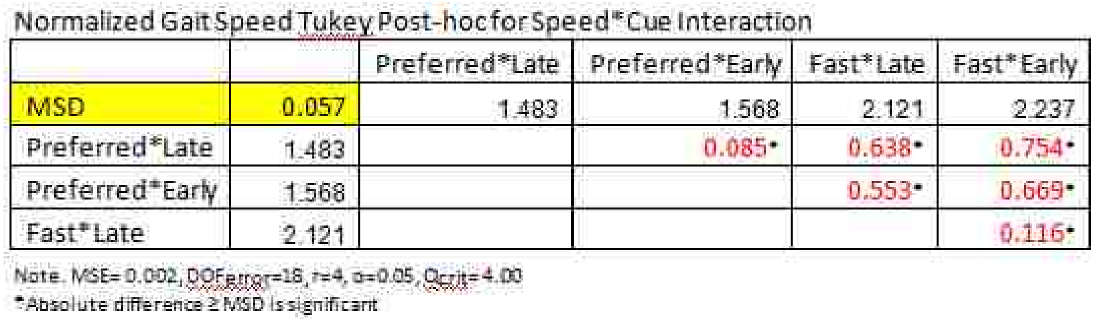


Tests of Within-Subjects Contrasts for Normalized Gait Speed (LL/s) 2x2x2x2 Mixed-Design ANOVA

Measure:MEASURE_1

Source	S ...	C ...	Direction	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Speed	Linear			17.102	1	17.102	186.441	.000	.912	186.441	1.000
Speed * Age_Group	Linear			.253	1	.253	2.760	.114	.133	2.760	.350
Error(Speed)	Linear			1.651	18	.092					
Cue		Linear		.404	1	.404	33.095	.000	.648	33.095	1.000
Cue * Age_Group		Linear		.000	1	.000	.009	.926	.000	.009	.051
Error(Cue)		Linear		.220	18	.012					
Direction			Linear	.001	1	.001	1.714	.207	.087	1.714	.236
Direction * Age_Group			Linear	.001	1	.001	.791	.386	.042	.791	.134
Error(Direction)			Linear	.013	18	.001					
Speed * Cue	Linear	Linear		.009	1	.009	5.411	.032	.231	5.411	.595
Speed * Cue * Age_Group	Linear	Linear		.001	1	.001	.608	.446	.033	.608	.114
Error(Speed*Cue)	Linear	Linear		.032	18	.002					
Speed * Direction	Linear		Linear	.000	1	.000	.209	.653	.012	.209	.072
Speed * Direction * Age_Group	Linear		Linear	1.300E-6	1	1.300E-6	.001	.970	.000	.001	.050
Error(Speed*Direction)	Linear		Linear	.016	18	.001					
Cue * Direction		Linear	Linear	.010	1	.010	10.457	.005	.367	10.457	.864
Cue * Direction * Age_Group		Linear	Linear	.001	1	.001	.702	.413	.038	.702	.125
Error(Cue*Direction)		Linear	Linear	.016	18	.001					
Speed * Cue * Direction	Linear	Linear	Linear	.001	1	.001	.572	.459	.031	.572	.111
Speed * Cue * Direction * Age_Group	Linear	Linear	Linear	9.395E-6	1	9.395E-6	.008	.929	.000	.008	.051
Error (Speed*Cue*Direction)	Linear	Linear	Linear	.020	18	.001					

a. Computed using alpha = .05



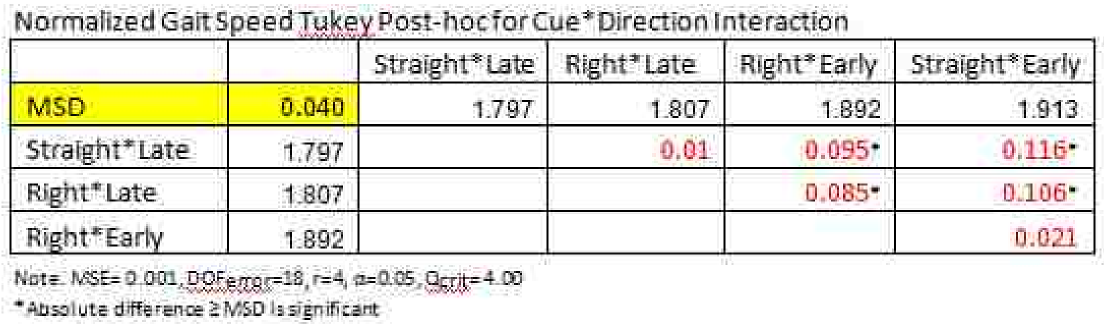
Normalized Gait Speed Tukey Post-hoc for Speed*Cue Interaction

		Preferred*Late	Preferred*Early	Fast*Late	Fast*Early
MSD	0.057	1.483	1.568	2.121	2.237
Preferred*Late	1.483		0.085*	0.638*	0.754*
Preferred*Early	1.568			0.553*	0.669*
Fast*Late	2.121				0.116*

Note. MSE= 0.002, DOF_{error}=18, r=4, α=0.05, Q_{crit}= 4.00

*Absolute difference ≥ MSD is significant

Impression: Tukey does not agree with the Tests of Within-Subjects Effects significant interaction nor the interaction plot. Instead the Tukey shows all comparisons were significantly different.



Normalized Gait Speed Tukey Post-hoc for Cue*Direction Interaction

		Straight*Late	Right*Late	Right*Early	Straight*Early
MSD	0.040	1.797	1.807	1.892	1.913
Straight*Late	1.797		0.01	0.095*	0.116*
Right*Late	1.807			0.085*	0.106*
Right*Early	1.892				0.021

Note. MSE= 0.001, DOF_{error}=18, r=4, α=0.05, Q_{crit}= 4.00

*Absolute difference ≥ MSD is significant

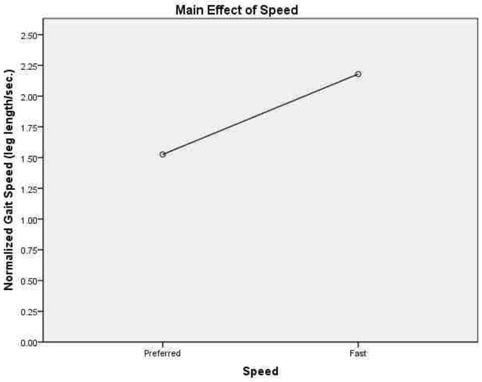
Impression: Tukey does not agree with the Tests of Within-Subjects Effects significant interaction nor the interaction plot. Instead, the Tukey shows no Cue*Direction interaction, and just reveals the main effect for cue (i.e. early > late).

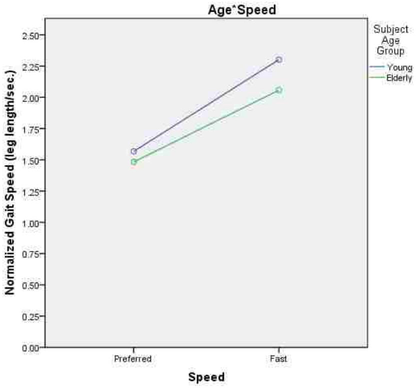
Appendix R

Main Effects for Normalized Gait Speed (LL/s)

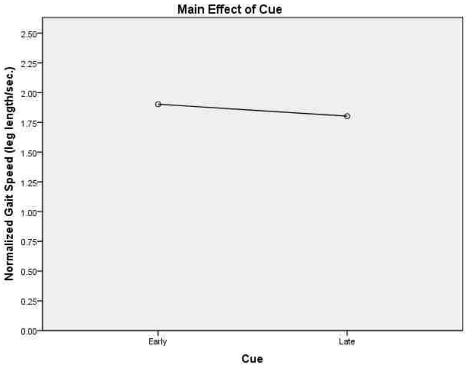
2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

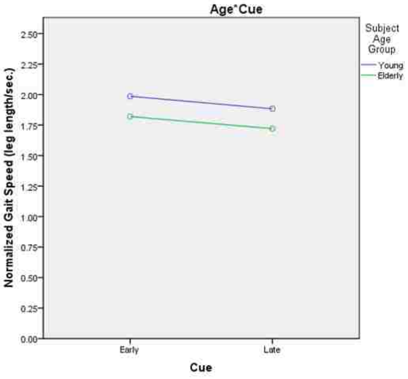
Main effect for the categorical independent variable Speed [F(1,18) = 186.44, *p*=0.00, r=0.95, η^2 =0.91, power =1.00].
Impression: This tells us participants walked faster during the fast-speed block of trials.
The main effect of the categorical independent variable Speed was similar in both age-groups [F(1,18) = 2.76, *p*=0.11].





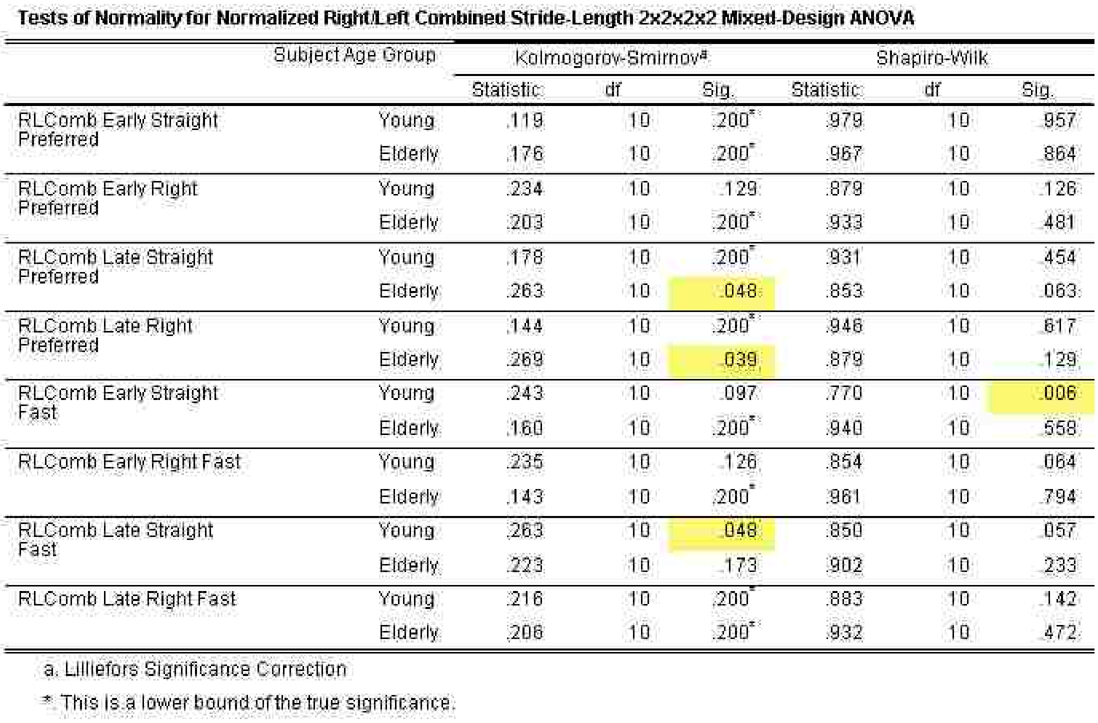
Main effect for Cue [F(1,18) = 33.10, *p*=0.00, r=0.80, η^2 =0.65, power =1.00].
Impression: This tells us participants walked slower when cued-late for direction.
The main effect of Cue was similar in both age-groups [F(1,18) = 0.01, *p*=0.93].





Appendix S

Exploring Assumptions for Normalized Right/Left Combined Stride-Length 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

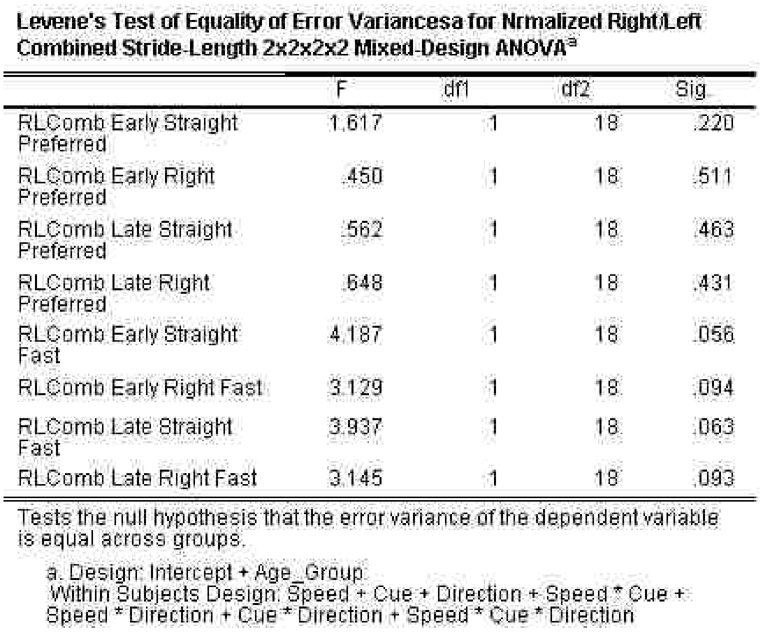


Tests of Normality for Normalized Right/Left Combined Stride-Length 2x2x2x2 Mixed-Design ANOVA

	Subject Age Group	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
RLComb Early Straight Preferred	Young	.119	10	.200*	.979	10	.957
	Elderly	.176	10	.200*	.967	10	.864
RLComb Early Right Preferred	Young	.234	10	.129	.879	10	.126
	Elderly	.203	10	.200*	.933	10	.481
RLComb Late Straight Preferred	Young	.178	10	.200*	.931	10	.454
	Elderly	.263	10	.048	.853	10	.063
RLComb Late Right Preferred	Young	.144	10	.200*	.946	10	.617
	Elderly	.269	10	.039	.879	10	.129
RLComb Early Straight Fast	Young	.243	10	.097	.770	10	.006
	Elderly	.160	10	.200*	.940	10	.558
RLComb Early Right Fast	Young	.235	10	.126	.854	10	.064
	Elderly	.143	10	.200*	.961	10	.794
RLComb Late Straight Fast	Young	.263	10	.048	.850	10	.057
	Elderly	.223	10	.173	.902	10	.233
RLComb Late Right Fast	Young	.216	10	.200*	.883	10	.142
	Elderly	.206	10	.200*	.932	10	.472

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



Levene's Test of Equality of Error Variancesa for Nrmalized Right/Left Combined Stride-Length 2x2x2x2 Mixed-Design ANOVA^{a}

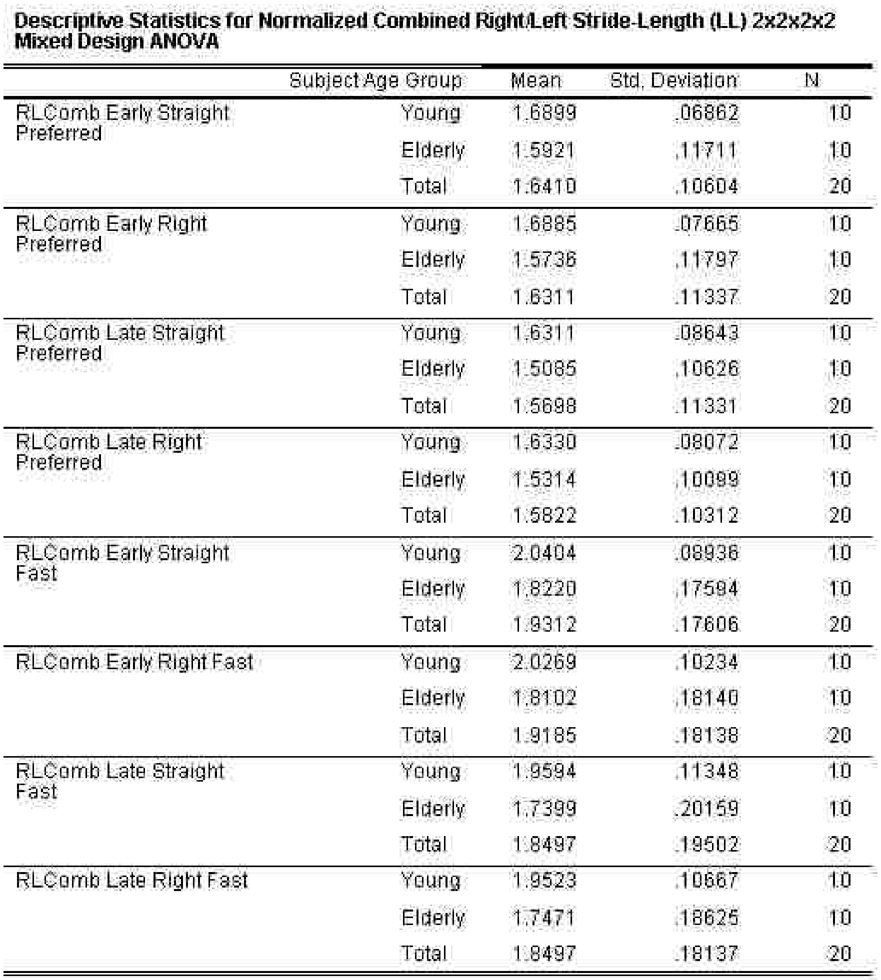
	F	df1	df2	Sig.
RLComb Early Straight Preferred	1.617	1	18	.220
RLComb Early Right Preferred	.450	1	18	.511
RLComb Late Straight Preferred	.562	1	18	.463
RLComb Late Right Preferred	.648	1	18	.431
RLComb Early Straight Fast	4.187	1	18	.056
RLComb Early Right Fast	3.129	1	18	.094
RLComb Late Straight Fast	3.937	1	18	.063
RLComb Late Right Fast	3.145	1	18	.093

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Age_Group
Within Subjects Design: Speed + Cue + Direction + Speed * Cue + Speed * Direction + Cue * Direction + Speed * Cue * Direction

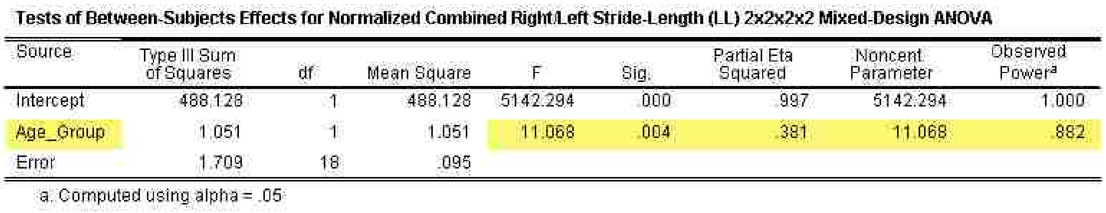
Appendix T

Descriptive Statistics, Tests of Between Subjects Effects, Tests of Within-Subjects Effects for Normalized Combined Right/Left Stride-Length (LL) 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only), & Disagreement of Tukey with Significant Interactions



Descriptive Statistics for Normalized Combined Right/Left Stride-Length (LL) 2x2x2x2 Mixed Design ANOVA

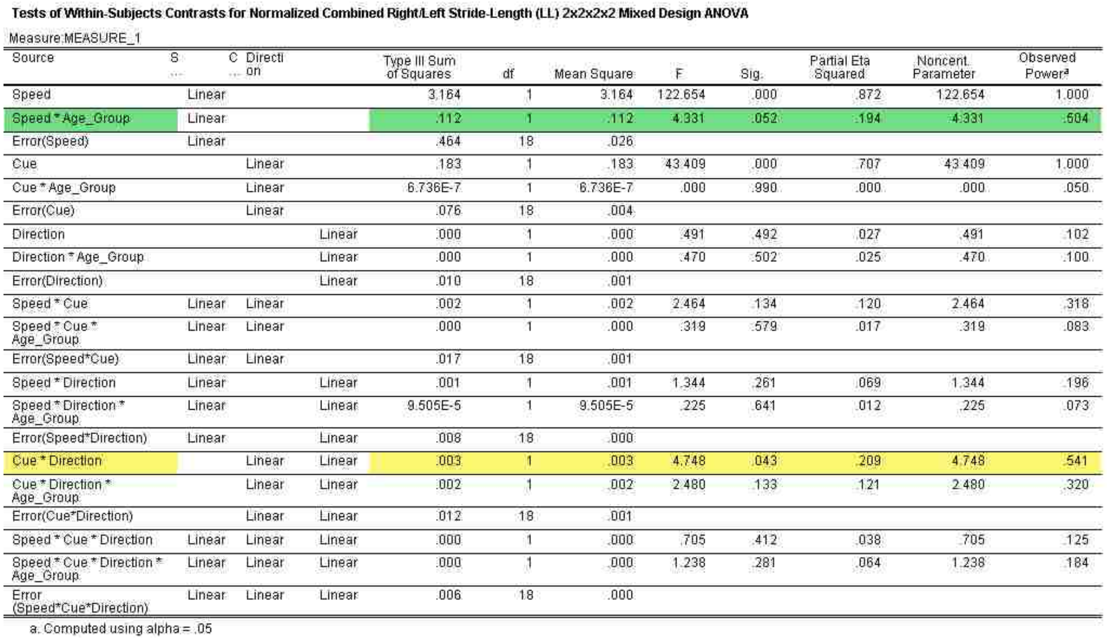
	Subject Age Group	Mean	Std. Deviation	N
RLComb Early Straight Preferred	Young	1.6899	.06862	10
	Elderly	1.5921	.11711	10
	Total	1.6410	.10604	20
RLComb Early Right Preferred	Young	1.6885	.07665	10
	Elderly	1.5736	.11797	10
	Total	1.6311	.11337	20
RLComb Late Straight Preferred	Young	1.6311	.08643	10
	Elderly	1.5085	.10626	10
	Total	1.5698	.11331	20
RLComb Late Right Preferred	Young	1.6330	.08072	10
	Elderly	1.5314	.10099	10
	Total	1.5822	.10312	20
RLComb Early Straight Fast	Young	2.0404	.08936	10
	Elderly	1.8220	.17594	10
	Total	1.9312	.17606	20
RLComb Early Right Fast	Young	2.0269	.10234	10
	Elderly	1.8102	.18140	10
	Total	1.9185	.18138	20
RLComb Late Straight Fast	Young	1.9594	.11348	10
	Elderly	1.7399	.20159	10
	Total	1.8497	.19502	20
RLComb Late Right Fast	Young	1.9523	.10667	10
	Elderly	1.7471	.18625	10
	Total	1.8497	.18137	20



Tests of Between-Subjects Effects for Normalized Combined Right/Left Stride-Length (LL) 2x2x2x2 Mixed-Design ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Intercept	488.128	1	488.128	5142.294	.000	.997	5142.294	1.000
Age_Group	1.051	1	1.051	11.068	.004	.381	11.068	.882
Error	1.709	18	.095					

a. Computed using alpha = .05

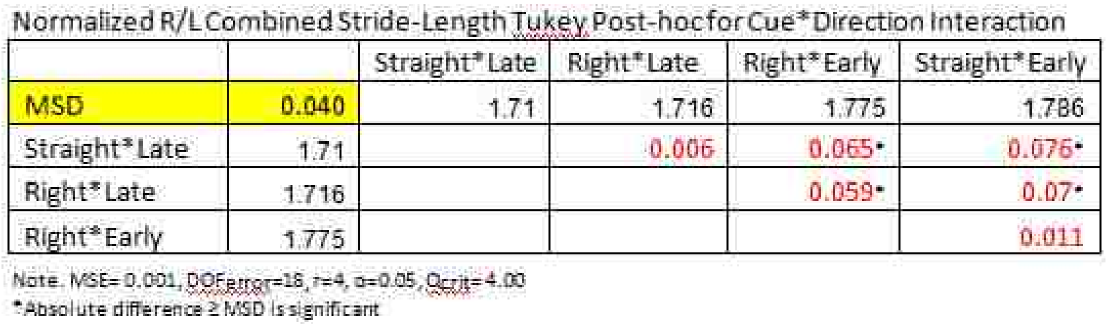


Tests of Within-Subjects Contrasts for Normalized Combined Right/Left Stride-Length (LL) 2x2x2x2 Mixed Design ANOVA

Measure:MEASURE_1

Source	S ...	C ...	Direction	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Speed	Linear			3.164	1	3.164	122.654	.000	.872	122.654	1.000
Speed * Age_Group	Linear			.112	1	.112	4.331	.052	.194	4.331	.504
Error(Speed)	Linear			.464	18	.026					
Cue		Linear		.183	1	.183	43.409	.000	.707	43.409	1.000
Cue * Age_Group		Linear		6.736E-7	1	6.736E-7	.000	.990	.000	.000	.050
Error(Cue)		Linear		.076	18	.004					
Direction			Linear	.000	1	.000	.491	.492	.027	.491	.102
Direction * Age_Group			Linear	.000	1	.000	.470	.502	.025	.470	.100
Error(Direction)			Linear	.010	18	.001					
Speed * Cue	Linear	Linear		.002	1	.002	2.464	.134	.120	2.464	.318
Speed * Cue * Age_Group	Linear	Linear		.000	1	.000	.319	.579	.017	.319	.083
Error(Speed*Cue)	Linear	Linear		.017	18	.001					
Speed * Direction	Linear		Linear	.001	1	.001	1.344	.261	.069	1.344	.196
Speed * Direction * Age_Group	Linear		Linear	9.505E-5	1	9.505E-5	.225	.641	.012	.225	.073
Error(Speed*Direction)	Linear		Linear	.008	18	.000					
Cue * Direction		Linear	Linear	.003	1	.003	4.748	.043	.209	4.748	.541
Cue * Direction * Age_Group		Linear	Linear	.002	1	.002	2.480	.133	.121	2.480	.320
Error(Cue*Direction)		Linear	Linear	.012	18	.001					
Speed * Cue * Direction	Linear	Linear	Linear	.000	1	.000	.705	.412	.038	.705	.125
Speed * Cue * Direction * Age_Group	Linear	Linear	Linear	.000	1	.000	1.238	.281	.064	1.238	.184
Error (Speed*Cue*Direction)	Linear	Linear	Linear	.006	18	.000					

a. Computed using alpha = .05



Normalized R/L Combined Stride-Length Tukey Post-hoc for Cue*Direction Interaction

		Straight*Late	Right*Late	Right*Early	Straight*Early
MSD	0.040	1.71	1.716	1.775	1.786
Straight*Late	1.71		0.006	0.065*	0.076*
Right*Late	1.716			0.059*	0.07*
Right*Early	1.775				0.011

Note. MSE= 0.001, DOFerror=18, r=4, α=0.05, Qcrit= 4.00

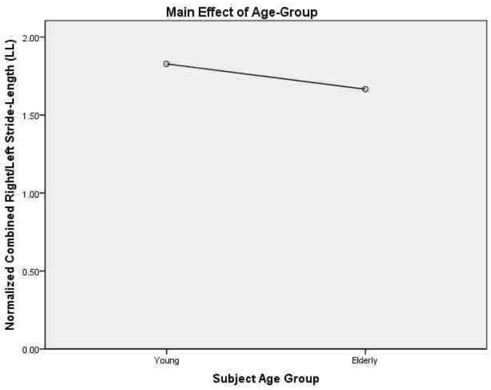
*Absolute difference ≥ MSD is significant

Impression: Tukey does not agree with the Tests of Within-Subjects Effects significant interaction nor the interaction plot. Instead, the Tukey shows no Cue*Direction interaction, and just reveals the main effect for cue (i.e. early > late).

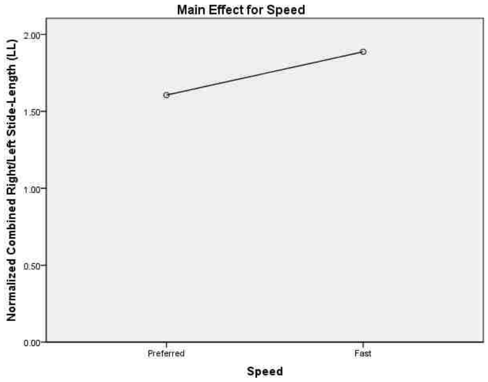
Appendix U

Main Effects for Normalized Combined Right/Left Stride-Length (LL) 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

Main effect for Age-Group [F(1,18) = 11.07, *p*=0.004, r=0.62, η^2 =0.38, power =.88].
Impression: This tells us the elderly took shorter strides



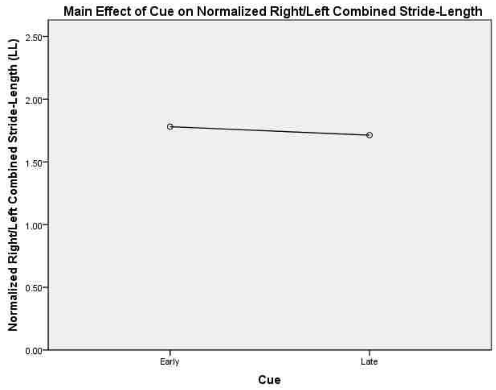
Main effect for Speed [F(1,18) = 122.65, *p*=0.000, r=0.93, η^2 =0.87, power = 1.00].
Impression: This tells us participants took longer strides when walking fast.

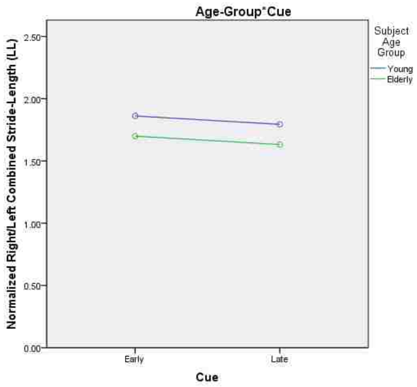


Main effect for Cue [F(1,18) = 43.41, *p*=0.000, r=0.84, η^2 =0.71, power = 1.00].

Impression: This tells us participants took shorter strides when cued-late for direction.

The main effect of Cue was similar in both age-groups [F(1,18) = 0.00, *p*=0.99]. Although no Age*Cue interaction for stride-length was seen, it is interesting to note that young stride length when cued-late appeared longer than elderly stride-length when cued early!

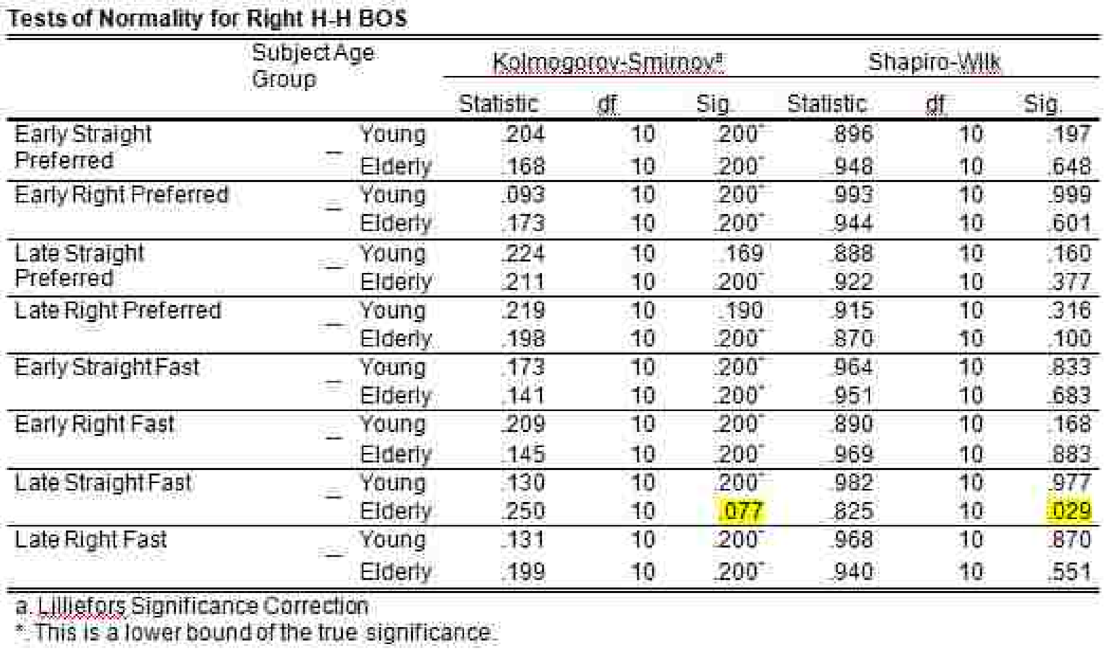




Appendix V

Exploring Assumptions for Normalized Right Heel-to-Heel Base of Support

2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

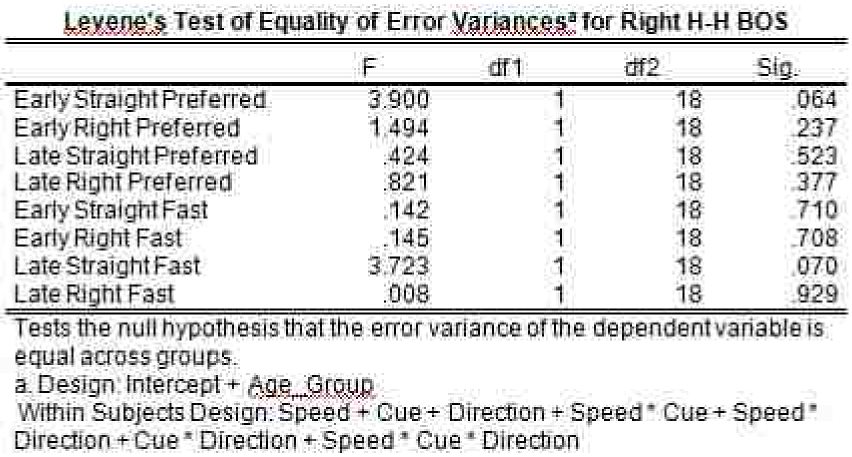


Tests of Normality for Right H-H BOS

	Subject Age Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Early Straight Preferred	Young	.204	10	.200*	.896	10	.197
	Elderly	.168	10	.200*	.948	10	.648
Early Right Preferred	Young	.093	10	.200*	.993	10	.999
	Elderly	.173	10	.200*	.944	10	.601
Late Straight Preferred	Young	.224	10	.169	.888	10	.160
	Elderly	.211	10	.200*	.922	10	.377
Late Right Preferred	Young	.219	10	.190	.915	10	.316
	Elderly	.198	10	.200*	.870	10	.100
Early Straight Fast	Young	.173	10	.200*	.964	10	.833
	Elderly	.141	10	.200*	.951	10	.683
Early Right Fast	Young	.209	10	.200*	.890	10	.168
	Elderly	.145	10	.200*	.969	10	.883
Late Straight Fast	Young	.130	10	.200*	.982	10	.977
	Elderly	.250	10	.077	.825	10	.029
Late Right Fast	Young	.131	10	.200*	.968	10	.870
	Elderly	.199	10	.200*	.940	10	.551

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



Levene's Test of Equality of Error Variances[a] for Right H-H BOS

	F	df1	df2	Sig.
Early Straight Preferred	3.900	1	18	.064
Early Right Preferred	1.494	1	18	.237
Late Straight Preferred	.424	1	18	.523
Late Right Preferred	.821	1	18	.377
Early Straight Fast	.142	1	18	.710
Early Right Fast	.145	1	18	.708
Late Straight Fast	3.723	1	18	.070
Late Right Fast	.008	1	18	.929

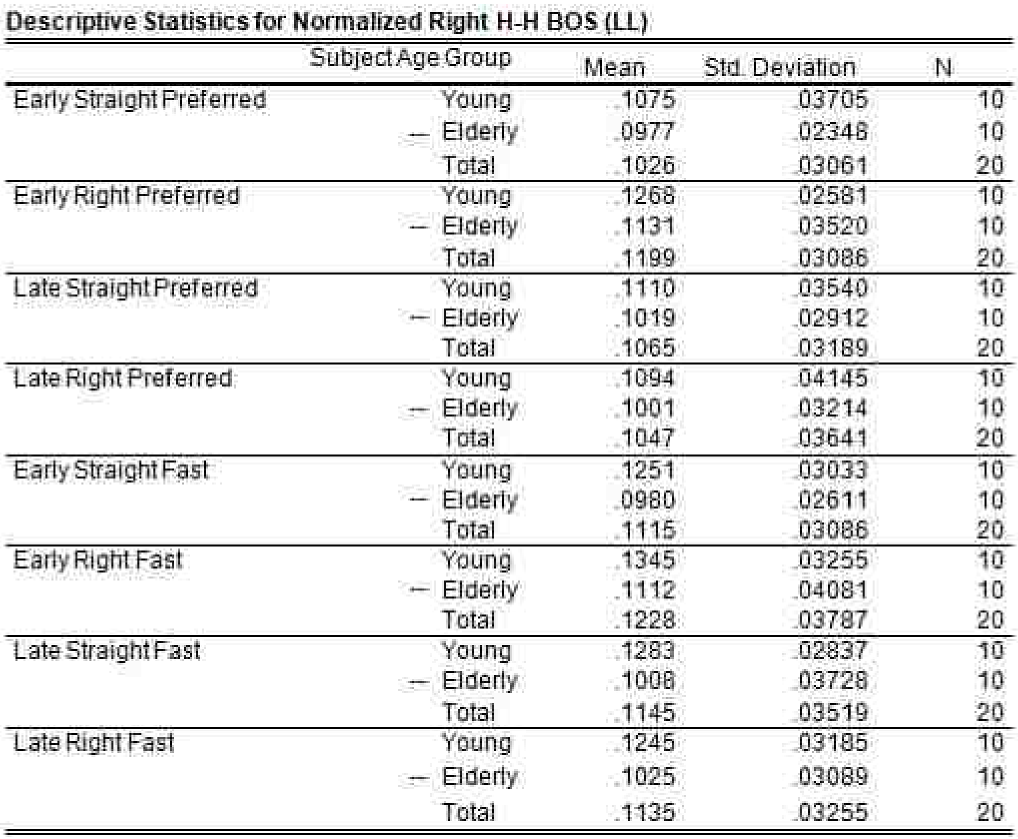
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Age_Group

Within Subjects Design: Speed + Cue + Direction + Speed * Cue + Speed * Direction + Cue * Direction + Speed * Cue * Direction

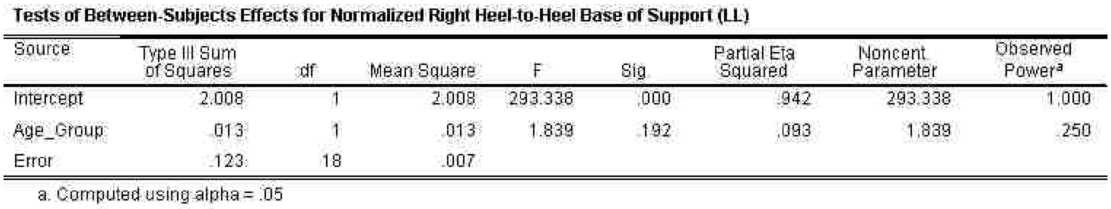
Appendix W

Descriptive Statistics, Tests of Between Subjects Effects, Tests of Within-Subjects Effects for Normalized Right Heel-to-Heel Base of Support (LL) 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only), & Disagreement of Tukey with Significant Interactions



Descriptive Statistics for Normalized Right H-H BOS (LL)

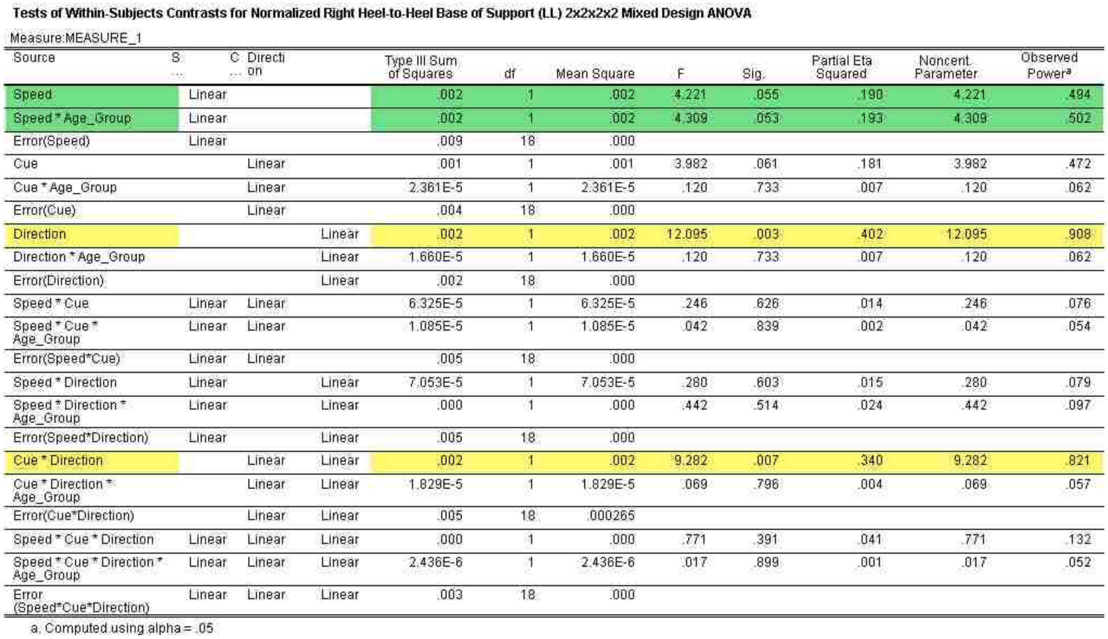
	Subject Age Group	Mean	Std. Deviation	N
Early Straight Preferred	Young	.1075	.03705	10
	Elderly	.0977	.02348	10
	Total	.1026	.03061	20
Early Right Preferred	Young	.1268	.02581	10
	Elderly	.1131	.03520	10
	Total	.1199	.03086	20
Late Straight Preferred	Young	.1110	.03540	10
	Elderly	.1019	.02912	10
	Total	.1065	.03189	20
Late Right Preferred	Young	.1094	.04145	10
	Elderly	.1001	.03214	10
	Total	.1047	.03641	20
Early Straight Fast	Young	.1251	.03033	10
	Elderly	.0980	.02611	10
	Total	.1115	.03086	20
Early Right Fast	Young	.1345	.03255	10
	Elderly	.1112	.04081	10
	Total	.1228	.03787	20
Late Straight Fast	Young	.1283	.02837	10
	Elderly	.1008	.03728	10
	Total	.1145	.03519	20
Late Right Fast	Young	.1245	.03185	10
	Elderly	.1025	.03089	10
	Total	.1135	.03255	20



Tests of Between-Subjects Effects for Normalized Right Heel-to-Heel Base of Support (LL)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2.008	1	2.008	293.338	.000	.942	293.338	1.000
Age_Group	.013	1	.013	1.839	.192	.093	1.839	.250
Error	.123	18	.007					

a. Computed using alpha = .05

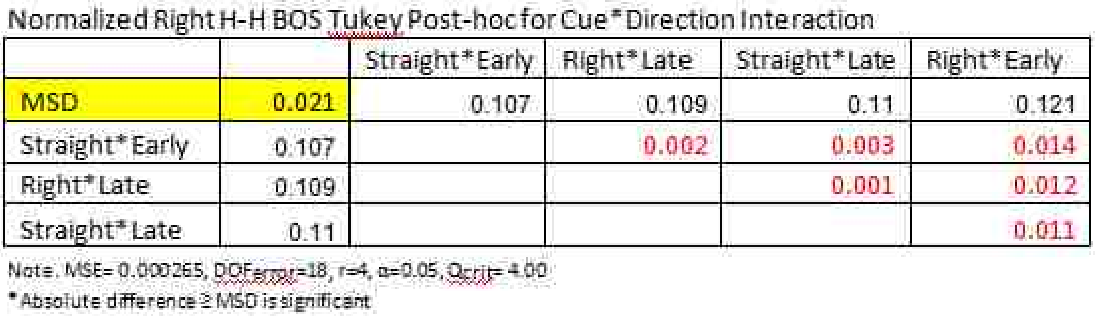


Tests of Within-Subjects Contrasts for Normalized Right Heel-to-Heel Base of Support (LL) 2x2x2x2 Mixed Design ANOVA

Measure:MEASURE_1

Source	S...	C...	Direction	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Speed	Linear			.002	1	.002	4.221	.055	.190	4.221	.494
Speed * Age_Group	Linear			.002	1	.002	4.309	.053	.193	4.309	.502
Error(Speed)	Linear			.009	18	.000					
Cue		Linear		.001	1	.001	3.982	.061	.181	3.982	.472
Cue * Age_Group		Linear		2.361E-5	1	2.361E-5	.120	.733	.007	.120	.062
Error(Cue)		Linear		.004	18	.000					
Direction			Linear	.002	1	.002	12.095	.003	.402	12.095	.908
Direction * Age_Group			Linear	1.660E-5	1	1.660E-5	.120	.733	.007	.120	.062
Error(Direction)			Linear	.002	18	.000					
Speed * Cue	Linear	Linear		6.325E-5	1	6.325E-5	.246	.626	.014	.246	.076
Speed * Cue * Age_Group	Linear	Linear		1.085E-5	1	1.085E-5	.042	.839	.002	.042	.054
Error(Speed*Cue)	Linear	Linear		.005	18	.000					
Speed * Direction	Linear		Linear	7.053E-5	1	7.053E-5	.280	.603	.015	.280	.079
Speed * Direction * Age_Group	Linear		Linear	.000	1	.000	.442	.514	.024	.442	.097
Error(Speed*Direction)	Linear		Linear	.005	18	.000					
Cue * Direction		Linear	Linear	.002	1	.002	9.282	.007	.340	9.282	.821
Cue * Direction * Age_Group		Linear	Linear	1.829E-5	1	1.829E-5	.069	.796	.004	.069	.057
Error(Cue*Direction)		Linear	Linear	.005	18	.000265					
Speed * Cue * Direction	Linear	Linear	Linear	.000	1	.000	.771	.391	.041	.771	.132
Speed * Cue * Direction * Age_Group	Linear	Linear	Linear	2.436E-6	1	2.436E-6	.017	.899	.001	.017	.052
Error (Speed*Cue*Direction)	Linear	Linear	Linear	.003	18	.000					

a. Computed using alpha = .05



Normalized Right H-H BOS Tukey Post-hoc for Cue * Direction Interaction

		Straight*Early	Right*Late	Straight*Late	Right*Early
MSD	0.021	0.107	0.109	0.11	0.121
Straight*Early	0.107		0.002	0.003	0.014
Right*Late	0.109			0.001	0.012
Straight*Late	0.11				0.011

Note. MSE= 0.000265, DDFerror=18, r=4, α=0.05, Qcrit= 4.00

*Absolute difference ≥ MSD is significant

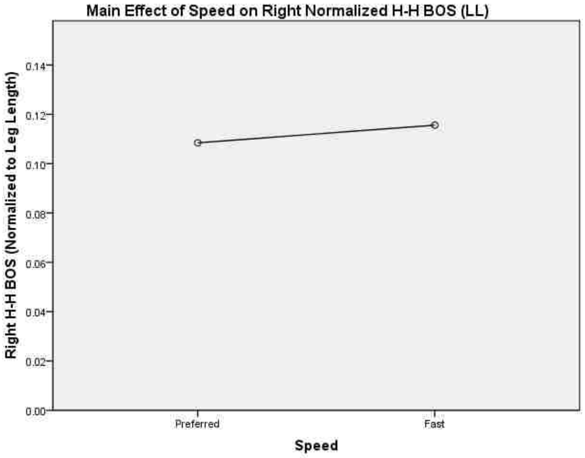
Impression: Tukey does not agree with the Tests of Within-Subjects Effects significant interaction nor the interaction plot. Instead the Tukey shows no differences between comparisons were significant i.e. no interaction or main effect.

Appendix X

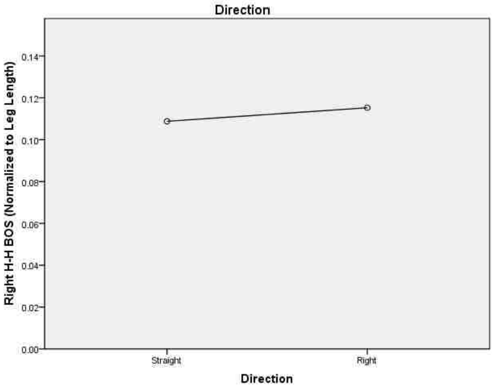
Main Effects for Normalized Right Heel-to-Heel Base of Support (LL)

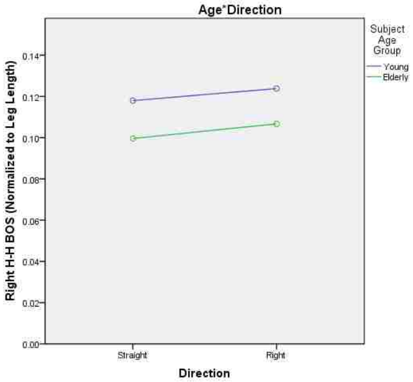
2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

Trend towards significance for Main effect for Speed [F(1,18) = 4.22, *p*=0.055, r=0.44, η^2 =0.19, power = 0.49].
Impression: This tells us participants took longer strides when walking fast.



Main effect for Direction [F(1,18) = 12.10, *p*=0.003, r=0.63, η^2 =0.40, power =0.91].
Impression: This tells us participants used a wider right H-H BOS when approaching to turn right as opposed to continue straight.
The main effect of Cue was similar in both age-groups [F(1,18) = 0.12, *p*=0.73].

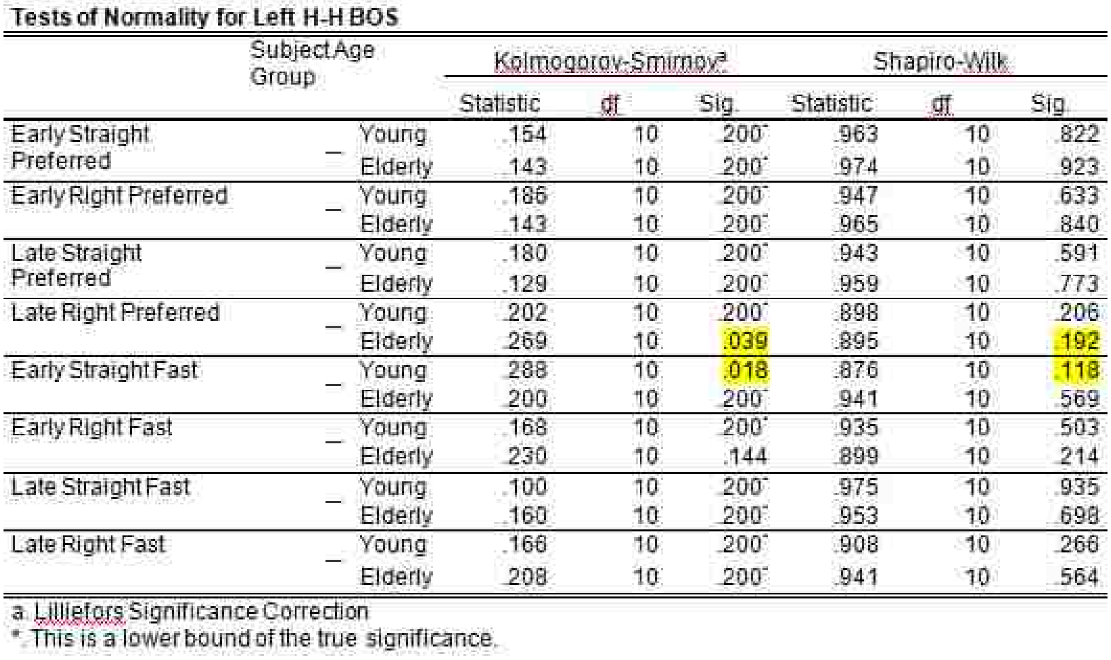




Appendix Y

Exploring Assumptions for Normalized Left Heel-to-Heel Base of Support

2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only)

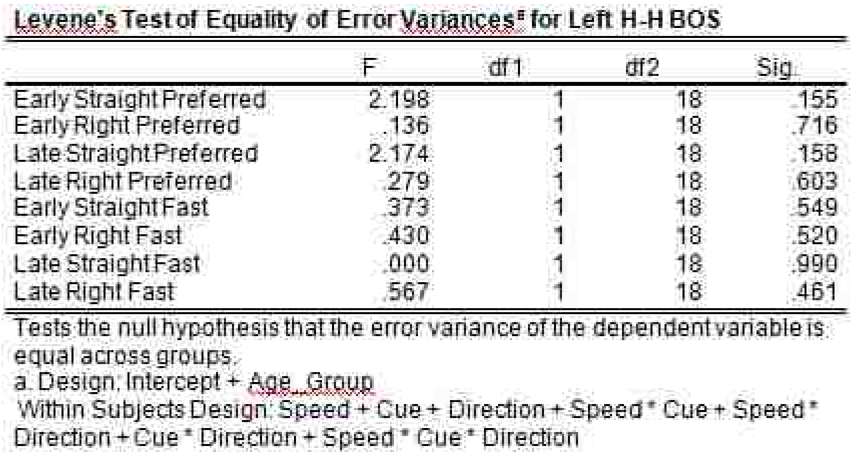


Tests of Normality for Left H-H BOS

	Subject Age Group		Kolmogorov-Smirnov^a			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
Early Straight Preferred	_	Young	.154	10	.200*	.963	10	.822
		Elderly	.143	10	.200*	.974	10	.923
Early Right Preferred	_	Young	.186	10	.200*	.947	10	.633
		Elderly	.143	10	.200*	.965	10	.840
Late Straight Preferred	_	Young	.180	10	.200*	.943	10	.591
		Elderly	.129	10	.200*	.959	10	.773
Late Right Preferred	_	Young	.202	10	.200*	.898	10	.206
		Elderly	.269	10	.039	.895	10	.192
Early Straight Fast	_	Young	.288	10	.018	.876	10	.118
		Elderly	.200	10	.200*	.941	10	.569
Early Right Fast	_	Young	.168	10	.200*	.935	10	.503
		Elderly	.230	10	.144	.899	10	.214
Late Straight Fast	_	Young	.100	10	.200*	.975	10	.935
		Elderly	.160	10	.200*	.953	10	.698
Late Right Fast	_	Young	.166	10	.200*	.908	10	.266
		Elderly	.208	10	.200*	.941	10	.564

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



Levene's Test of Equality of Error Variances^a for Left H-H BOS

	F	df1	df2	Sig.
Early Straight Preferred	2.198	1	18	.155
Early Right Preferred	.136	1	18	.716
Late Straight Preferred	2.174	1	18	.158
Late Right Preferred	.279	1	18	.603
Early Straight Fast	.373	1	18	.549
Early Right Fast	.430	1	18	.520
Late Straight Fast	.000	1	18	.990
Late Right Fast	.567	1	18	.461

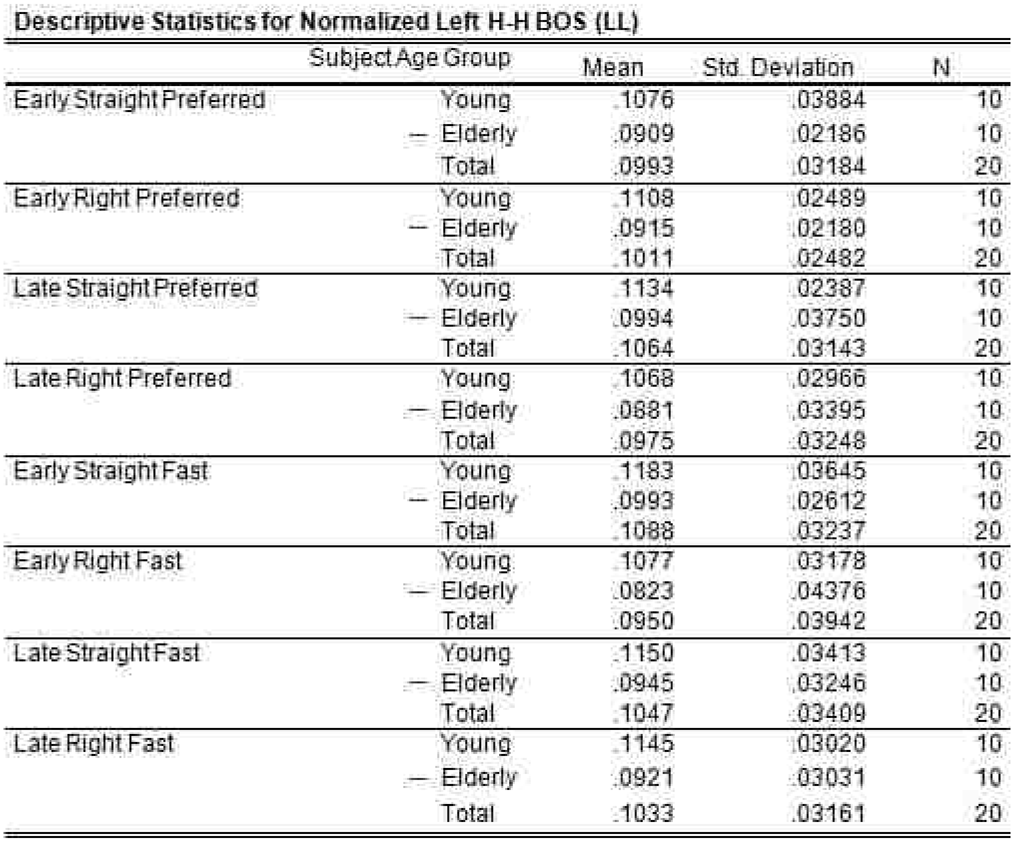
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Age_Group

Within Subjects Design: Speed + Cue + Direction + Speed * Cue + Speed * Direction + Cue * Direction + Speed * Cue * Direction

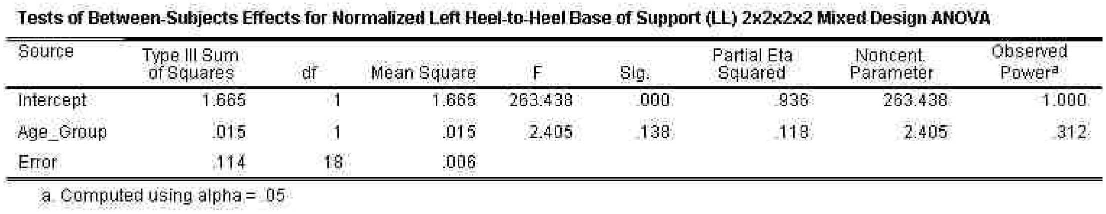
Appendix Z

Descriptive Statistics, Tests of Between Subjects Effects, Tests of Within-Subjects Effects for Normalized Left Heel-to-Heel Base of Support (LL) 2x2x2x2 Mixed-Design ANOVA (Straight & Right Turns Only), & Disagreement of Tukey with Significant Interactions



Descriptive Statistics for Normalized Left H-H BOS (LL)

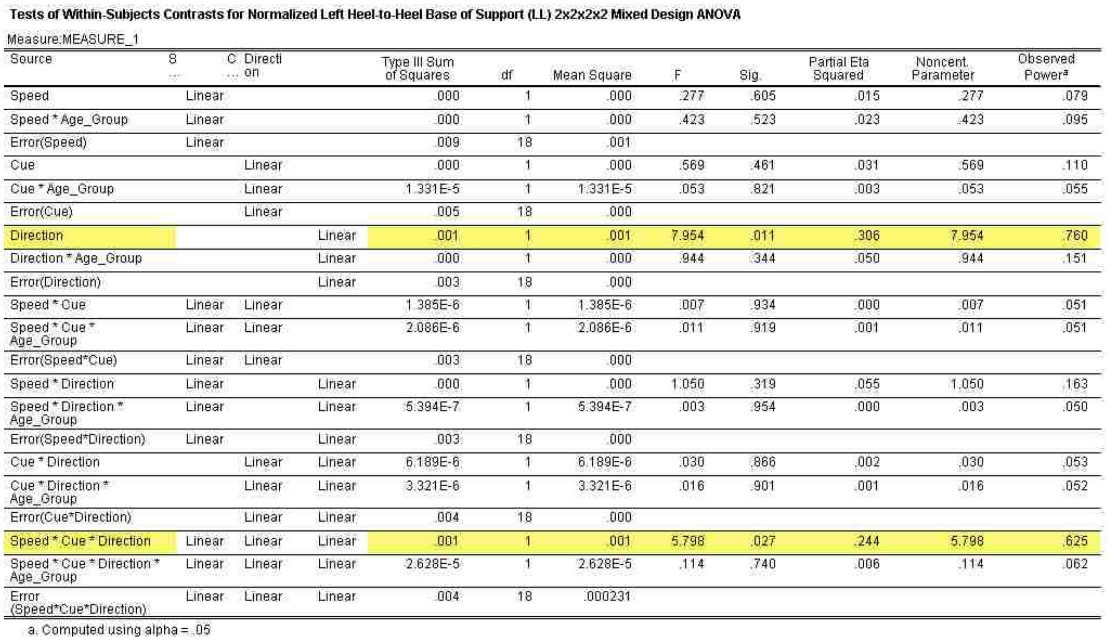
	Subject Age Group	Mean	Std. Deviation	N
Early Straight Preferred	Young	.1076	.03884	10
	Elderly	.0909	.02186	10
	Total	.0993	.03184	20
Early Right Preferred	Young	.1108	.02489	10
	Elderly	.0915	.02180	10
	Total	.1011	.02482	20
Late Straight Preferred	Young	.1134	.02387	10
	Elderly	.0994	.03750	10
	Total	.1064	.03143	20
Late Right Preferred	Young	.1068	.02966	10
	Elderly	.0881	.03395	10
	Total	.0975	.03248	20
Early Straight Fast	Young	.1183	.03645	10
	Elderly	.0993	.02612	10
	Total	.1088	.03237	20
Early Right Fast	Young	.1077	.03178	10
	Elderly	.0823	.04376	10
	Total	.0950	.03942	20
Late Straight Fast	Young	.1150	.03413	10
	Elderly	.0945	.03246	10
	Total	.1047	.03409	20
Late Right Fast	Young	.1145	.03020	10
	Elderly	.0921	.03031	10
	Total	.1033	.03161	20



Tests of Between-Subjects Effects for Normalized Left Heel-to-Heel Base of Support (LL) 2x2x2x2 Mixed Design ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Intercept	1.665	1	1.665	263.438	.000	.936	263.438	1.000
Age_Group	.015	1	.015	2.405	.138	.118	2.405	.312
Error	.114	18	.006					

a. Computed using alpha = .05

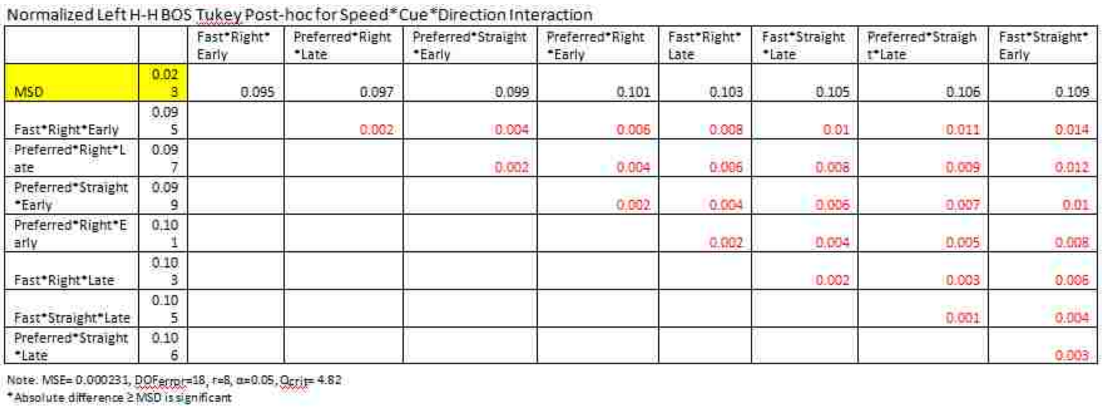


Tests of Within-Subjects Contrasts for Normalized Left Heel-to-Heel Base of Support (LL) 2x2x2x2 Mixed Design ANOVA

Measure:MEASURE_1

Source	S ...	C ...	Direction	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Speed	Linear			.000	1	.000	.277	.605	.015	.277	.079
Speed * Age_Group	Linear			.000	1	.000	.423	.523	.023	.423	.095
Error(Speed)	Linear			.009	18	.001					
Cue		Linear		.000	1	.000	.569	.461	.031	.569	.110
Cue * Age_Group		Linear		1.331E-5	1	1.331E-5	.053	.821	.003	.053	.055
Error(Cue)		Linear		.005	18	.000					
Direction			Linear	.001	1	.001	7.954	.011	.306	7.954	.760
Direction * Age_Group			Linear	.000	1	.000	.944	.344	.050	.944	.151
Error(Direction)			Linear	.003	18	.000					
Speed * Cue	Linear	Linear		1.385E-6	1	1.385E-6	.007	.934	.000	.007	.051
Speed * Cue * Age_Group	Linear	Linear		2.086E-6	1	2.086E-6	.011	.919	.001	.011	.051
Error(Speed*Cue)	Linear	Linear		.003	18	.000					
Speed * Direction	Linear		Linear	.000	1	.000	1.050	.319	.055	1.050	.163
Speed * Direction * Age_Group	Linear		Linear	5.394E-7	1	5.394E-7	.003	.954	.000	.003	.050
Error(Speed*Direction)	Linear		Linear	.003	18	.000					
Cue * Direction		Linear	Linear	6.189E-6	1	6.189E-6	.030	.866	.002	.030	.053
Cue * Direction * Age_Group		Linear	Linear	3.321E-6	1	3.321E-6	.016	.901	.001	.016	.052
Error(Cue*Direction)		Linear	Linear	.004	18	.000					
Speed * Cue * Direction	Linear	Linear	Linear	.001	1	.001	5.798	.027	.244	5.798	.625
Speed * Cue * Direction * Age_Group	Linear	Linear	Linear	2.628E-5	1	2.628E-5	.114	.740	.006	.114	.062
Error (Speed*Cue*Direction)	Linear	Linear	Linear	.004	18	.000231					

a. Computed using alpha = .05



Normalized Left H-H BOS Tukey Post-hoc for Speed*Cue*Direction Interaction

		Fast*Right*Early	Preferred*Right*Late	Preferred*Straight*Early	Preferred*Right*Early	Fast*Right*Late	Fast*Straight*Late	Preferred*Straight*Late	Fast*Straight*Early
MSD	0.023	0.095	0.097	0.099	0.101	0.103	0.105	0.106	0.109
Fast*Right*Early	0.095		0.002	0.004	0.006	0.008	0.01	0.011	0.014
Preferred*Right*Late	0.097			0.002	0.004	0.006	0.008	0.009	0.012
Preferred*Straight*Early	0.099				0.002	0.004	0.006	0.007	0.01
Preferred*Right*Early	0.101					0.002	0.004	0.005	0.008
Fast*Right*Late	0.103						0.002	0.003	0.006
Fast*Straight*Late	0.105							0.001	0.004
Preferred*Straight*Late	0.106								0.003

Note: MSE= 0.000231, DOFerror=18, r=8, α=0.05, Qcrit= 4.82

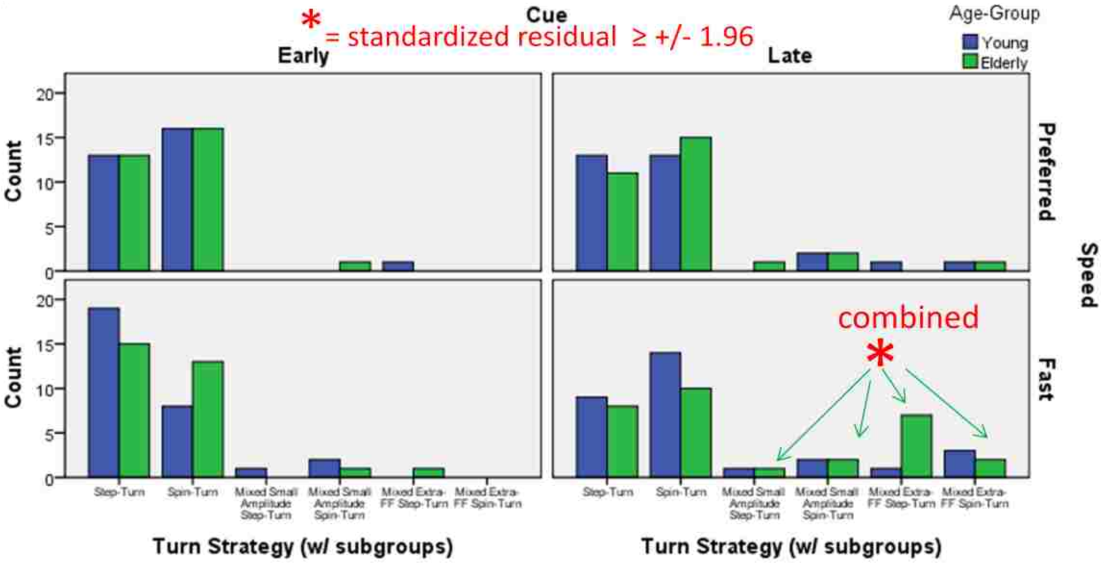
*Absolute difference ≥ MSD is significant

Impression: Tukey does not agree with the Tests of Within-Subjects Effects significant interaction nor the interaction plot. Instead the Tukey shows no differences between comparisons were significant i.e. no interactions or main effects.

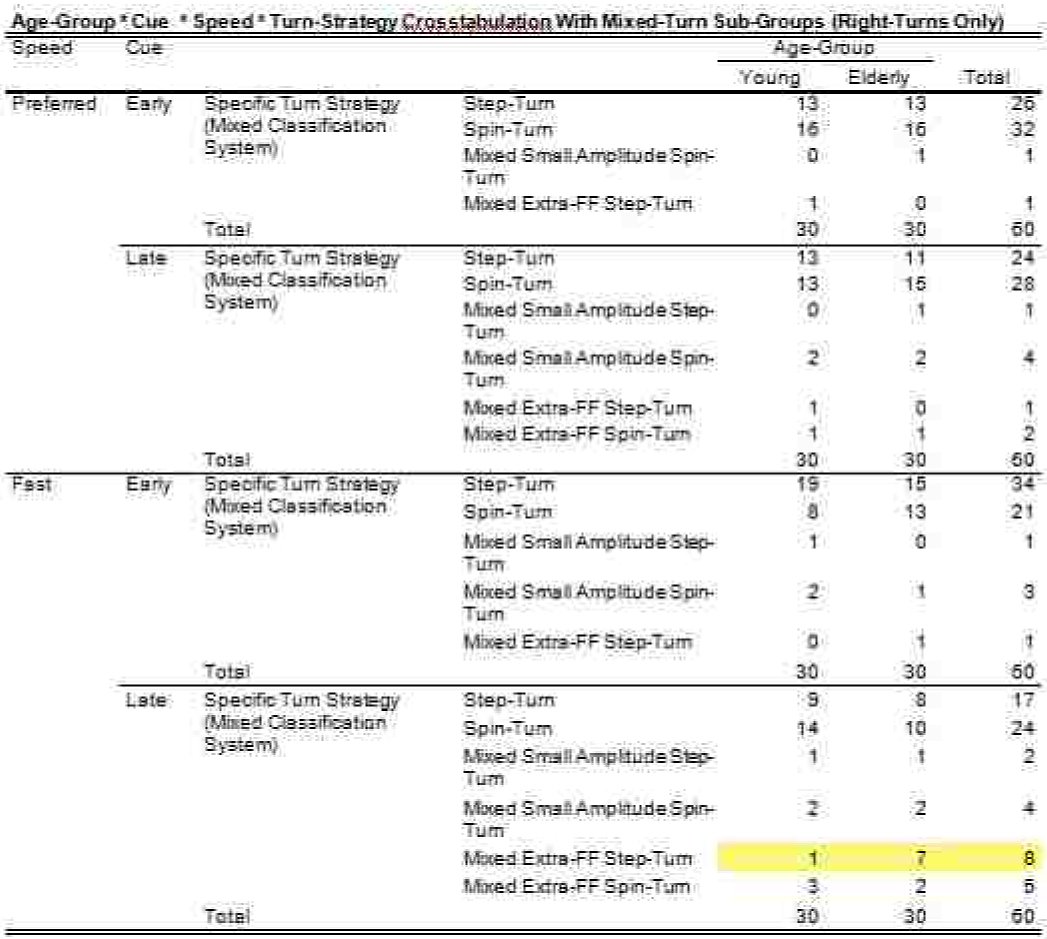
Appendix AA

Age*Speed*Cue*Turn-Strategy with Mixed-Turn Sub-Groups

(Right-Turns Only)



Age*Speed*Cue*Turn-Strategy (Right Direction Turns Only) With Mixed-Turn Sub-Groups. The count for the mixed-extra footfall step-turn at 7 is seen to stand-out for the elderly*fast*late cell. The asterisk * above the elderly*fast*late*mixed-turn cell signifies the absolute value of the standard residual z-score ≥ 1.96 for the four combined mixed-turn sub-groups and thus significant at $p< 0.05$.



Age-Group * Cue * Speed * Turn-Strategy Crosstabulation With Mixed-Turn Sub-Groups (Right-Turns Only)

Speed	Cue			Age-Group		
				Young	Elderly	Total
Preferred	Early	Specific Turn Strategy (Mixed Classification System)	Step-Turn	13	13	26
			Spin-Turn	16	16	32
			Mixed Small Amplitude Spin-Turn	0	1	1
			Mixed Extra-FF Step-Turn	1	0	1
		Total		30	30	60
	Late	Specific Turn Strategy (Mixed Classification System)	Step-Turn	13	11	24
			Spin-Turn	13	15	28
			Mixed Small Amplitude Step-Turn	0	1	1
			Mixed Small Amplitude Spin-Turn	2	2	4
			Mixed Extra-FF Step-Turn	1	0	1
			Mixed Extra-FF Spin-Turn	1	1	2
		Total		30	30	60
Fast	Early	Specific Turn Strategy (Mixed Classification System)	Step-Turn	19	15	34
			Spin-Turn	8	13	21
			Mixed Small Amplitude Step-Turn	1	0	1
			Mixed Small Amplitude Spin-Turn	2	1	3
			Mixed Extra-FF Step-Turn	0	1	1
		Total		30	30	60
	Late	Specific Turn Strategy (Mixed Classification System)	Step-Turn	9	8	17
			Spin-Turn	14	10	24
			Mixed Small Amplitude Step-Turn	1	1	2
			Mixed Small Amplitude Spin-Turn	2	2	4
			Mixed Extra-FF Step-Turn	1	7	8
			Mixed Extra-FF Spin-Turn	3	2	5
		Total		30	30	60

Appendix AB

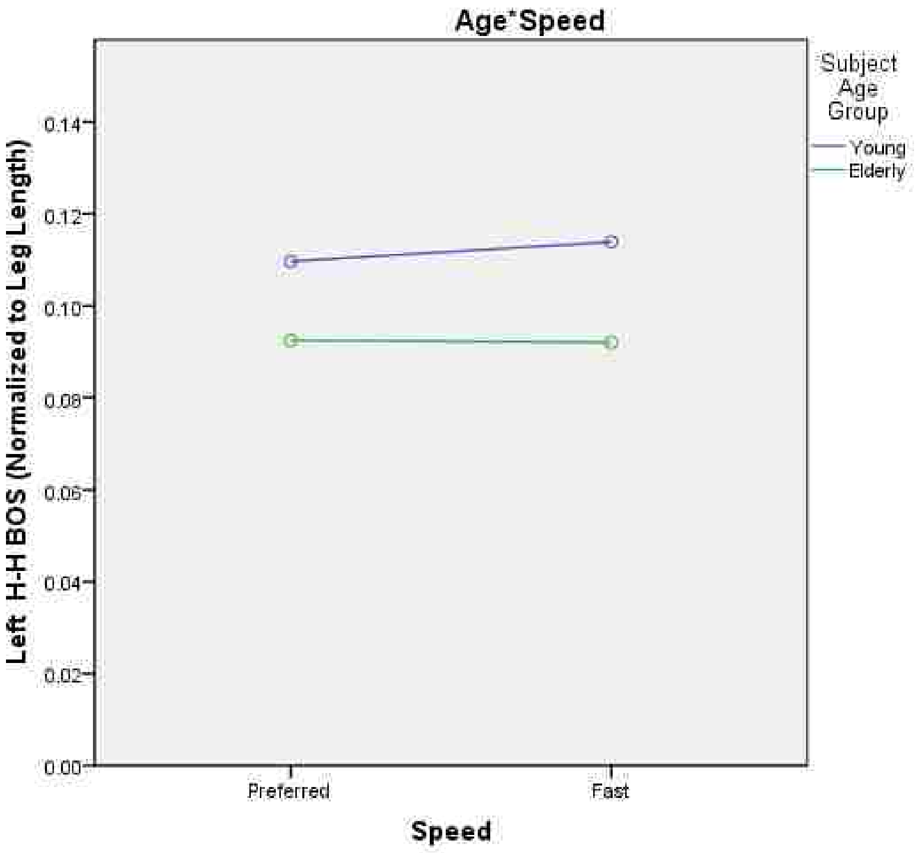
Left Heel-to-Heel Base of Support (Straight & Right-Turns Only)

Age*Speed Estimate Marginal Means and Line Chart

Estimate Marginal Means Age-Group *Speed on Left H-H BOS (Normalized to Leg Length)

Subject Age Group	Speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Young	Preferred	.110	.008	.092	.127
	Fast	.114	.010	.093	.135
Elderly	Preferred	.092	.008	.075	.110
	Fast	.092	.010	.071	.113

Note, there was no significant interaction effect between Age-Group x Speed on Left Normalized H-H BOS, F(1,18) = 0.42, p=0.52



Appendix AC

Instrumentation Manufactures

a. Kinovea, https://www.kinovea.org

b. CIR Systems Inc, 376 Lafayette Ave, Suite 202, Sparta, NJ 07871, USA

c. Sony Electronics Inc, 680 Kinderkamack Rd, Oradell, NJ 07649, USA

d. Microsoft, 1 Microsoft Way, Redmond, WA 98952, USA

e. KapscoMoto, 813 Old Brock Rd #5, Pickering, ON L1W2Y4, Canada

f. Tapeswitch, 100 Schmitt Boulevard, Farmingdale, NY 11735, USA

g. PASW Statistics GradPack 18, SPSS Inc., Chichago, IL 60606, USA

h. G*Power Version 3.1.7, Universitat Kiel, Germany