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# The Influence of Concurrent Visual Feedback During Treadmill Training in Parkinson's Disease

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# THE INFLUENCE OF CONCURRENT VISUAL FEEDBACK DURING TREADMILL TRAINING IN PARKINSON'S DISEASE

by

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THESIS

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Jake, Molly & James, Megan & Frank, Jesse & Jill, Claire & Ian, Liz & Mike & Craig

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## Dedication

There are two individuals that I would like to dedicate this thesis to:

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You have been my personal inspiration to complete this project. While I have observed your personal struggle with Parkinson's, I have learned so much. Thank you for sharing your story with me. You have motivated me to complete this degree. I love you so much!

&

My cousin, Terrence Patrick McCann, a.k.a. Terr

Your short life has inspired so many. I think of you often and I will miss you always!!!

# Table of Contents

# List of Figures

# List of Tables

**Chapter 2:**



**Chapter 3:**

# Chapter 1: Abstract

Walking is an exercise that has been thought to benefit Parkinson's disease (PD). In a laboratory setting treadmills have been employed to successfully improve certain aspects of gait in PD (Cakit et al., 2007, Fisher et al., 2008, Herman et al., 2007, Miyai et al., 2000, Miyai et al., 2002, Pohl et al., 2003). Research has also indicated that walking with visual cues can improve aspects of gait that are impaired in PD (Azulay et al., 1999, Bagely et al., 1997, Nieuwboer et al., 2007), however , the integration of visual cues and treadmill training has yet to be studied. Thus, the purpose of this thesis was to determine the effect of treadmill training in PD, with and without the availability of concurrent visual feedback.

The first chapter was focused on identifying previous exercise strategies that have been utilized in PD. Since a multitude of exercise interventions have been investigated, an evaluation of previous literature included analysis of a number of critical factors including: frequency, intensity and duration of training, the participant sample size, and outcome measures employed. Further, a review of recent PD aerobic testing and training studies guided the development of the current treadmill testing and training protocols.

The second chapter examines the influence of 12 weeks of treadmill training with and without concurrent visual feedback on PD motor symptom severity, physiological efficiency and gait responses at baseline, immediately after training and again six weeks later. Findings showed that the motor symptom severity scores worsened immediately after training and remained unchanged six weeks later. However, improvements in aerobic efficiency were found immediately after treadmill training that remained improved at six weeks post training. Similarly, the spatio-temporal characteristics of gait improved immediately after treadmill

training and were also maintained at six weeks post training. Overall, immediately after treadmill training with concurrent visual feedback greater gait and aerobic improvements were found that did not wear off when compared to training without this feedback. The results of this study suggest that treadmill training does not improve motor symptom severity. However, treadmill training as a rehabilitative strategy can offer aerobic and gait improvements in PD.

The third chapter examines the influence of 12 weeks of treadmill training in PD with and without concurrent visual feedback on the rate of perceived exertion, mean arterial pressure, timed up-and-go and Layfayette pegboard times at baseline, immediately after training and at follow up six weeks later. Across the assessments findings showed not only did the mean arterial pressure lower for both groups but also faster pegboard insertion and removal times were found. Further, trends indicated that with each successive assessment period all participants subjectively reported lower levels of required exertion for each workload and were also faster at the timed up-and-go test. Overall, regardless of group no detectable differences in the functional and clinical outcomes were found. However, after the treadmill training, decreased blood pressure along with faster fine motor control speeds indicated the range of potential benefits that can be attained from this form of training.

The last chapter summarizes the principle findings of this thesis that include the physiological efficiency responses, the spatio-temporal gait changes, the motor symptom severity evaluations and the clinical and functional outcomes assessed. This chapter reviews the significant findings and intriguing trends found across the three evaluation periods that included pre-test, post-test and at follow up six weeks after training was completed. These findings are interpreted to provide a platform for the continued investigation of the effects of treadmill training in PD. Similarly, the limitations that occurred were also reviewed to emphasize the necessary considerations for future work in this area. Finally to appropriately conclude and ensure the findings are easily understood, take-home messages were provided to simplify the complex nature of this study. Treadmill training has benefits to offer the PD population that include greater aerobic efficiency and corresponding improvements in gait, however this form of exercise was not successful in motor symptom severity improvement.

# Chapter 2: Prologue

Recognition for Exercises' Potential as a Rehabilitative Strategy in Parkinson's dise Parkinson's disease is known for its' debilitating and progressive effects on individuals fine and gross control of movement. The manifestations of motor symptoms include, but are not limited to tremor, bradykinesia or slowness of movement, rigidity, postural instability and difficulty with movement initiation. Further, severities of symptoms are individually variable and thus increase the complexity in understanding disease progression. Most rehabilitative strategies have focused on improving strength, flexibility or aerobic change. Interestingly, only some exercise-based rehabilitative strategies have additionally focused on and included any corresponding motor symptom severity change that occurs. The incorporation of motor symptom severity evaluation alongside goals of exercise rehabilitation is necessary to provide evidence for the positive effect of exercise on motor symptom severity remains inconclusive. Thus, the continued investigation of exercises' effect is required to provide indisputable scientific evidence to demonstrate this relationship. To assist in the determination of whether exercise can actually help in PD, it is imperative to consider what exercise training studies have documented to date.

Previously reported exercise studies have included a multitude of strategies. For appropriate conclusions to be drawn, studies are categorized according to five major types of training programs that include home based exercise training, resistance training, multidisciplinary rehabilitation training, goal-specific training and aerobic training programs. Multidisciplinary rehabilitation has incorporated a variety of exercise combinations into their training. An alternative approach is goal-specific training, where the emphasis is on a particular movement strategy during training. Of the exercise training programs reported in literature, it is of interest to determine the strengths and weaknesses of each to provide a comprehensive approach to the current aerobic study. Therefore the merit of the exercise categories will be assessed by comparing and contrasting explicit aspects of these studies. The conclusions will then be applied to our current aerobic study that will be presented in two articles that follow this review of literature.

## 2.1 Recognition for Exercise's Potential as a Rehabilitative Strategy in Parkinson's disease

### 2.1.1 Essential Considerations from Previous Exercise Studies

The components deemed necessary to consider from previous exercise studies include the evaluation of the training principles that include the frequency, intensity and duration of training, the sample size utilized, the measurement of motor symptom severity and the measurement of gait. These components are considered the focal aspects of PD exercise studies to provide a meaningful synopsis of the effectiveness of training, thus they will be utilized to distinguish differences in previous studies. Prior to drawing conclusions from previous research findings, a concise review that details the importance of each identified component will be summarized.

To adequately differentiate between exercise studies the training undertaken must be understood. Therefore, descriptions of the training principles that include the frequency, intensity and duration of exercise are necessary to establish. Exercise frequency denotes the number of training sessions completed per unit time. This is important to consider since differences will exist if participants exercise daily versus weekly. Exercise intensity describes the physical exertion or stress individuals undertook while training, thus essentially how hard an individual is working. This is important to consider because the workloads achieved by participants provide information on the difficulty of exercise testing or training completed. The exercise duration refers to both the length of exercise sessions or episodes and the total time or length of the program. These are important to consider since they denote the actual time allotted for each exercise segment and the length until program completion. The evaluation of the specific exercise training components will permit the most appropriate comparisons are made.

A further component that must be considered during evaluations of PD exercise studies includes the participant sample size. The optimal scenario involves the recruitment of larger sample sizes, this procedure is time and energy consuming, even with a readily available participant database. However, to ensure reasonable comparisons are made it is necessary that future studies attempt to recruit a minimum of 20 participants in any assessed groups. This sample size was determined via a power calculation that incorporated an effect size ($\delta$) = 0.8 at an alpha level ($\alpha$) = 0.05. This calculation determined a minimum of 19.5 participants would be required in each exercising group to attain a study power of 80%. Thus, fewer then 20 participants would inevitably lower the study power. In the exercise studies that include a smaller number of participants, it is necessary that the obtained results are considered in the context of the sample size to avoid broad generalizations, for example clearly indicating they are pilot projects. Thus to avoid such assumptions, it is therefore imperative to consider the size of samples when exercise research studies are being compared.

The evaluation of motor symptom severity measurement is necessary when comparing and contrasting PD exercise studies given that these assessments determine whether exercise training may change, maintain or worsen the participants' symptoms. The value obtained from exercise training studies in the PD population are diminished without the measurement of motor symptom severity. Further, the differences in the evaluations that have been utilized for disease classification and symptom severity measurement in pervious literature indicates that standardization is required. Therefore, the measurement of motor symptom severity and the assessment tools utilized are important considerations when concluding the effectiveness of exercise training programs.

Disturbances of gait are common in the PD population, therefore improvements that are attained could help to delineate what exercises or tests are most successful. Thus, the measurement of gait is important to consider providing precise change can be quantitatively represented. In PD, disease progression is unilaterally at onset then proceeds to progress bilaterally where after this, individuals begin to suffer with the debilitating decrease in step size, control of step speed and eventually step initiation. The measurement of gait before and after exercise training would therefore provide specific information on the effect or outcome achieved from an exercise program or intervention.

To best describe the effect of each exercise category in PD, the use of each previously described component will be documented. These comparisons will therefore provide a framework for a greater understanding of the effect of this rehabilitative strategy in PD.

## 2.2 Overview of Home Based Training in Parkinson's disease

Home based training programs permit people with PD to exercise in the comfort of their own home. Two methods of application are most common to this type of intervention. A qualified trainer or physiotherapist (PT) may physically go to an individuals' home to teach most, if not all exercise sessions. Alternatively, an individual may be taught the exercises in a group setting outside the home so that they can perform exercise on their own at home. In the latter, the individuals are held accountable for his or her exercise training and adherence for the allotted period of training. Since the individual is responsible for the completion and documentation of their progress, evidently problems of study control arise. Therefore, the overall quality of training accomplished from a trainer versus an individually taught exercise must be considered in home based studies.

### 2.2.1 Home Based Training Principles: Frequency, Intensity and Duration

For increased strength of study results, an exercise training study requires that a sufficient amount of training is achieved. Exercise training studies must therefore incorporate and effectively utilize training principles of frequency, duration and intensity. Previous home based training studies have employed various frequencies of exercise training. In the studies by Ashburn et al., (2006) and Hurwitz et al., (1989) the expected frequency of training was set to once a week. However, Ashburn et al., (2006) studied participants for a total of 24 weeks that exercised for an hour each week at a chosen intensity that was deemed appropriate for the individual. In the study by Hurwitz et al., (1989) participants exercised daily for a total of 32 weeks, with weekly supervision provided for a single 30 minute session. Quantitative description of the intensity of exercise was not provided making it difficult to provide recommendations for future studies. Nonetheless, both studies had indicated that exercise training once a week is only sufficient for immediate or short term benefits to this population. For example, the hourly sessions by Ashburn et al., (2006) demonstrated decreased fall rates after training for all participants ($p=0.004$) that were only maintained in the less severe individuals at 6 months ($p=0.007$) (Ashburn et al., 2006). Alternatively, in the study by Hurwitz et al., (1989) significantly decreased rigidity was found only for the right arm at four months ($p<0.05$) that did not persist at the 8 month follow up assessment (Hurwitz et al., 1989). These findings indicated that for long term benefits to be attained, specifically targeted intensity and frequency goals are necessary. Thus, the current study will attempt to individually tailor the exercise intensity and incorporate established guidelines for aerobic exercise.

Interestingly, in a study by Calgar et al., (2005) there was no documentation of exercise intensity expected or achieved by participants. Personally taught, daily training episodes for eight weeks in total was required from the participants. For each training episode, participants were instructed to carry out the exercises ten times each, three times a day for total duration of one hour. Given that each exercise episode was lengthy in duration may have been the reasoning for the lack of intensity provided. In this study, the personal accountability for training adherence from this intensive exercise schedule proved to be beneficial. Results demonstrated significantly decreased 10 & 20 m walk times and the time it took to walk around a chair. Also, an increased first pace length was observed and improved motor performance was reported for both hands ($p<0.01$) (Calgar et al., 2005). Overall this study concluded that a professionally run exercise program may not be required since individuals demonstrated positive effects of training when self-supervised. Similarly, in the training approach by Lun et al., (2005) training twice a week for a total of eight weeks for hourly episodes was required. The training for a total of 16 sessions demonstrated to be sufficient because both the self-supervised and PT supervised groups showed improvements in motor symptom severity after training ($p < 0.022$ and $p < 0.009$, respectively) (Lun et al., 2005). These findings had indicated that provided participants adhered to the training program, improvements can be obtained with personalized training. The current study aims to include individualized training for all sessions dependent upon each participant's capabilities, although consistent rather then intermittent exercise episodes will be our training focus.

Overall, the training principle of frequency was the critical factor for the effectiveness for home based exercise training studies. Studies that required training more than once a week demonstrated the greatest improvements. Also, these studies demonstrated that the required duration of exercise sessions worked in combination with the intensity of the exercise accomplished. It was observed that the programs with greater exercise intensities did not require the same length of exercise durations. It can be asserted that participants that are unable to meet the exercise intensity goal may attain similar benefits with lengthened durations of the training sessions. However, future research may benefit from a greater emphasis placed on the monitoring of participant's intensity levels. Further, the total durations of home based programs reported a minimum of 8 weeks of training incorporated was deemed necessary. The current study aims to incorporate a greater frequency of training, specifically 3 sessions per week, for 30 minutes allotted for each session. This supervised training will provide individualized intensity aims for each training session over the total program duration of 12 weeks.

### 2.2.2 Home Based Training and Sample Sizes Utilized

The sample sizes utilized in home based training exercise research included a total of 19 (Lun et al., 2005), 30 (Calgar et al., 2005) , 142 (Ashburn et al., 2006) and 153 (Nieuwboer et al, 2006) participants. Each study that was examined incorporated an exercising group and a control group. The studies by Ashburn et al., (2006), Hurwtiz et al., (1989) and Calgar et al., (2005) all incorporated non-exercising control groups. However, in the study by Lun et al., (2005) the control group was provided with the opportunity to exercise since prior to study initiation each participant was asked their preference to either be taught or to self teach exercises. Similarly, in the crossover study by Nieuwboer et al., (2007) both groups participated in an exercise and a rest or non exercise period over the study design. Since the strength of the study is increased when a control group exists this will be included in our design, given that it enables the comparison to the intervention group. The current study will therefore include an exercising control group in addition to our intervention group to increase the strength of comparisons made in our study.

### 2.2.3 Home Based Training and Motor Symptom Severity Measurement

The inclusion criteria from home based training studies incorporated a variety of validated classification batteries including Hohen and Yahr staging classifications (H&Y) (Calgar et al., 2005; Hurwitz et al., 1989; Lun et al., 2005; Nieuwboer et al., 2006) and the Unified Parkinson's Disease Rating motor scale (UPDRS) (Ashburn et al., 2006; Lun et al., 2005) to document disease classification or stage at baseline. Surprisingly, the specific measurement of motor symptom severity was only considered an outcome measure of interest in two studies out of five in total. The motor subscale of the UPDRS was used to evaluate motor symptom severity change (Lun et al., 2005) where another study included only a composite score of gait and posture sub-score items to evaluate the effectiveness of training (Nieuwboer et al., 2006). In one other study the use of fall rates was utilized to evaluate the program effectiveness (Ashburn et al., 2006), but no overall symptom measurement.

In the study by Ashburn et al., (2006) inferences of symptom severity change were made by the differences in fall rates of participants. This study divided participants into less severe (H&Y stages I-III) and severe (H&Y stage IV) disease severity subgroups to undergo training where they were visited weekly for hourly sessions over six weeks by a PT. Continued daily training expected for participants included muscle strengthening for the knee and hip extensors and hip abductors, range of movement exercises for the ankle, pelvis, trunk and head in addition to balance training aimed to improve movement initiation and to provide fall compensation strategies. Results from the evaluated subgroups reported that falling rates were similar in both groups at the eight week assessment where at six months after baseline the less severe subgroup decreased their fall rate, where the more severe subgroup increased their fall rate (Ashburn et al., 2006). These results indicated that longer term improvements in more severely affected individuals are achieved with simultaneous help from a qualified trainer.

Interestingly, an earlier study by Lun et al., (2005) found similar effects in self taught versus PT taught exercises. These authors reported significant motor symptom severity score improvements for both self-taught and PT taught groups after 8 weeks of training ($p < 0.021$ and $p < 0.009$, respectively) (Lun et al., 2005). The self taught group, participants were familiarized with the same exercises to those in the PT supervised group that included stretching, strength-training, balance and core stability exercises. The self taught participants were also provided with a booklet that included written instructions and diagrams for supplementary instruction. Since no differences in motor symptom severity improvements were found, it can be concluded that supplementary instruction was beneficial regardless of whether a PT or the individual was responsible for the training adherence.

Alternatively, in the home based RESCUE trial study by Nieuwboer et al., (2007) motor symptom severity improvements were recorded by the composite posture and gait scores of the UPDRS after training. This home based cueing program was designed to correct the temporal aspects of gait, prevent freezing of gait and improve overall balance that was achieved with the addition of the participants' preferred cueing modality, either auditory, visual or somatosensory. Training specifically consisted of initiation and termination of gait, heel strike and push off practice, sideways and backwards stepping, dual tasking while walking and walking over different surfaces for different distances. Participants were assigned to one of two groups in this crossover design where three week training periods occurred. When both groups completed the crossover training a significant treatment effect was observed in the posture and gait score. An improvement of 4.2% was found after the intervention ($p=0.005$) and at follow up six weeks later, the significant improvements were maintained ($p=0.03$) (Nieuwboer et al., 2007). These findings indicated that the gait-focused exercises with the addition of a preferred cueing modality benefited participants posture and gait scores. These results suggest that cueing during gait training was effective for improved motor symptom severity score components in the short and long term thus has advocated the continued investigation of the separate modalities.

#### 2.2.4 Home Based Training and Gait: Measurement and Exercises

Home based training programs incorporated a spectrum of both direct and indirect outcome measures of gait. Direct outcome measures of gait consisted of explicit aspects of the gait cycle that were quantitatively measured, where indirect outcomes included non-specific measurements of gait characteristics or assessments that were qualitatively based. Evidently, after each home based training program, the responses for the attained gait measures differed. In the study by Calgar et al., (2005) significant differences were found between the exercising and non exercising control groups from baseline to the end of their 8 week training period. The exercise groups' time for both the 10 m and 20 m walk significantly decreased ($p<0.01$ and $p<0.009$ respectively) where a trend was shown for the observed lengthened first pace ($p<0.056$) (Calgar et al., 2005). The repetitive frequency of training over two months was deemed responsible for the gait benefits achieved since there were no descriptions of what the 'walking exercises' completed had entailed. Thus, the significant gait improvements attained were speculated to be produced from the allotted time that these participants had practiced training.

The studies by Ashburn et al., (2006) and Lun et al., (2005) differed because they utilized the indirect however validated TUG test to measure gait. Interestingly, neither study found statistically improved times after the training programs provided. These results suggested that the six levels of progression for the exercise that included muscle strengthening, range of movement, balance training and walking had not provided enough specificity or intensity of training for an effect to be observed in the exercised group (Ashburn et al., 2006). Similarly, in the study by Lun et al., (2005) the 40 exercises undertaken that consisted of stretching, strength training, balance and core stability for both self and PT groups did not transfer to improved times attained in the TUG test (Lun et al., 2005). It can be asserted that the exercises completed in these two studies were simply not sufficient to improve gait. It is therefore of interest to determine whether similar responses in this timed, functional performance measurement are attained after our gait training program. The current study will therefore incorporate the measurement of TUG to determine whether gait training specifically improves the times achieved.

Lastly, in the study by Hurwitz et al., (1989) a quantitative gait measurement was not included. No gait disturbances were reported in the gait measurement subcategory termed 'Self Care' in the Home Assessment Tool utilized (Hurwitz et al., 1989). These results are expected since rating gait disturbance on a Likert scale would only capture the subjective impression of the nurse responsible. Any quantitative change that may have been demonstrated after the training program could have been easily looked over since intricate gait or ambulation change may have been overlooked. Overall, for reliable gait analysis, quantitative measurement of gait should be considered with additional objective/subjective report when deemed necessary. The current study will incorporate gait outcomes through quantitative measurements to capture precise change that is reliable and easily comparable to future studies.

Across all home based exercise studies, the ability to compare amongst studies was diminished because most programs lacked descriptions of exercise and some omitted the exercises completely altogether. Extremely general guidelines were a major limiting factor, for example the 'Exercise Menu' reported in the study by Ashburn et al., (2006). Further, the self-help manual, the additional teaching tool utilized did not describe the exercises in the detail necessary. For example, the only gait related descriptions promoted the use of body movements through the 'walking exercises' that were provided (Calgar et al., 2005). Similarly, the study by Hurwitz et al., (1989) utilized the National Parkinson's Foundation's manual called 'Living with Parkinson's' that reported both images and descriptions for the gait exercises were provided, although the details were not specified in this study (Hurwitz et al., 1989). Further the study by Lun et al., (2005) a similar approach was adopted where both PT and home based groups were provided with booklets with written instructions for the required exercises, along with supplementary illustrations. Similarly, vague descriptions for the 40 exercises that were utilized were reported and additionally no mention of any gait exercises was included, other then the speculated walking that occurred during the arm up and cool down (Lun et al., 2005). The detailed descriptions of both our testing and training components will therefore be included in our study so that future studies can understand, replicate and benefit from our findings.

### 2.3 Overview of Resistance Training in Parkinson's disease

Many individuals with PD report issues with weakness and so rehabilitation via strength training is completed to improve force generation. Aging itself deteriorates the ability for muscle to build however with PD, greater levels of fatigue that may be experienced provide ample requirements to continue the development of muscle strength gains. Strength changes for both the upper and lower extremity muscle groups are documented in PD resistance training literature. The primary muscle groups reported on included the quadriceps femoris (Dibble et al., 2006; Hass et al., 2007), hamstrings (Hirsch et al., 2003) and gastrocneimus (Hass et al., 2007; Hirsch et al., 2003) in the lower extremity and the biceps and triceps (Hass et al., 2007) in the upper extremity. All resistance training studies measured the response of muscle contractions to the predetermined workloads at baseline and immediately after each training program where only one study included a post training, follow up assessment 4 weeks after the program ended (Hirsch et al., 2003). Primary outcome measures reported on maximum isometric (Dibble et al., 2006), high force eccentric (Dibble et al., 2006), dynamic concentric (Hass et al., 2007) and progressive concentric and eccentric (Hirsch et al., 2003) muscle contractions. One study incorporated additional outcome measures focused on balance (Hirsch et al., 2003) and another that included functional outcome measurements (Dibble et al., 2006).

### 2.3.1 Resistance Training Principles: Frequency, Intensity and Duration

The resistance training studies evaluated had similar expectations for exercise frequency, although the durations of the studies differed. The training frequency and duration component administered was the same in both studies by the authors Dibble et al., (2006), where participants trained three times a week for a total of 12 weeks. Similarly, in the study by Hirsch et al., (2003) participants trained three times a week for a total of 10 weeks. The least amount training occurred in the study by Haas et al., (2007) where the requisite to train was only twice a week for six weeks total. Overall, to provide adequate time for training effects to be observed the average of 10 weeks length, three times weekly was deemed adequate.

The differences in training effects observed from resistance training studies may have also occurred due to the intensity requirements or lack thereof for each exercise. The first study on high intensity resistance training by Dibble et al., (2006) trained their participants for 45-60 minutes in duration per session. This duration of training provided increased mobility and muscle volume in both the more and less affected limbs that was reported from the eccentric group when compared to the standard care group (Dibble et al., 2006). In this study, all participants' intensity of exercise training was recorded by the original Borg's 20-point rating of perceived exertion (RPE) scale®. This RPE measure is considered an indirect, yet reliable method of determining the intensity level of exercise (Borg, 1982). Thus, the RPE ratings helped quantify the perceived intensity from the participants of various disease severities that partook in the same training protocol. The current study has considered this measurement instrumental to be included to document the perceived difficulty of our exercise testing.

The second study by Dibble et al., (2006) analyzed the contraction intensities of the quadriceps while the participant pedalled in reverse. Participants were required to provide three-5 second long maximal contractions with three minutes of rest to determine their maximal isometric strength. This maximal strength was calculated through the averaged force that was produced at four different time points over 12 weeks. These authors reported that maximal isometric quadriceps strength increased overtime ($p=0.006$) and that overall, eccentric exercise induced muscle mass gain, strength and mobility for the PD population

(Dibble et al., 2006). These findings suggested that the PD population is capable of near maximal exercise training when the lower extremities are considered. In the current study, it is of interest to determine the responses of near maximal exercise intensity attained from the utilization of both the upper and lower extremities from our treadmill protocol.

In the study by Hirsch et al., (2003) 15 minute durations incorporated had encouraged participants reach their maximum effort. Participants' were required to lift for 12 repetitions (4 maximal) for each muscle group at their personal best intensities. The intensity increased progressively where the first two weeks individuals trained at 60% of their repetition maximum and the second two weeks 80% of their repetition maximum. The additional balance component of this training had individuals work for 30 minutes three times a week under two conditions. The first balance condition had participants stand on foam, where the second condition occurred without foam. Each participant was asked to partake in six different sensory conditions for 5 trials of 20 seconds in length for each (Hirsch et al., 2003). Participants were then asked to complete a second set of balance trials, under the same sensory conditions, but with additional perturbations provided manually by the researcher. The results provided were the collapsed balance scores over the pre-test, post-test and follow up assessments. These authors reported that the combination of resistance and balance training significantly improved the balance scores more than when balance training was considered alone (Hirsch et al., 2003). These findings support the utilization of exercise intensity requirements that are dependent on the participants' personal best achievement. Future rehabilitation programs would benefit from personalized training since this may target the particular deficiencies experienced. The current study will therefore incorporate individualized training goals that are both specific and achievable for each participant.

In the study by Hass et al., (2007) the intensity aim was not to push participants to their maximum, but instead to evaluate the muscular endurance of both a chest press and leg extension. The achievable intensity for each participant was determined from their 1-repetition maximum for both exercises at baseline. Muscle endurance was determined through the number of repetitions that was reached until failure, where the intensity began at 60% of their baseline 1-repetition maximum. Participants' trained with 9 exercises, with 1 set of 8-12 repetitions required for each leg flexion and extension, chest press and lat pull down, overhead press, triceps curl and extension, back extensions and seated calf raises (Hass et al., 2007). The findings reported a group by time interaction, where both groups demonstrated relative increased strength for the leg extension exercise ($p<0.05$). Muscle endurance was also reported to have significantly increased in both the creatine supplemented and placebo supplemented groups ($p<0.05$). Specifically, after training the placebo-supplemented group improved by 59% and the creatine supplemented group improved by 95% (Hass et al., 2007). These findings supported that strength gains can be achieved in the PD population. The current study targeted to train the large muscle groups of the legs in order to determine the gait efficiency changes exhibited after the current gait training program. However, our study findings will provide a greater representation of the overall efficiency in PD because the upper extremity would also contribute and be accounted for in our measurement of efficiency.

The duration of exercise sessions required differed in the resistance training studies reviewed. The individual variability that would exist for the time to completion for the required exercise repetitions is a valid explanation for the lack of descriptions for the session durations. However, the resistance training programs that did provide specific details for duration included training for 3 times a week for 45-60 minutes (Dibble et al., 2006) and training for 3 times a week for 15 minute sessions (Hirsch et al., 2003). The current study has deemed that training that incorporates 3 sessions weekly for 30 minutes over 12 weeks will provide sufficient time to capture training effects that may occur.

### 2.3.2 Resistance Training and Sample Sizes Utilized

A spectrum of sample sizes was incorporated into resistance training studies, although all included fewer then 30 participants. The sample sizes ranged from 29 (Dibble et al., 2006), 20 (Hass et al., 2007), 15 (Hirsch et al., 2003) and 10 (Dibble et al., 2006) participants. Most of these studies included control participants, although the extent of training for these groups varied. Two studies utilized the control group to receive only part of the exercise training program. In the study by Dibble et al., (2006) 10 controls were considered the standard care group and were provided with standard exercises created for the management of PD. The additional 9 participants had extra resistance training exercises provided (Dibble et al., 2006). In the second study completed by Dibble et al., (2006) differences from the original study prompted another investigation that coincidently involved a smaller sample size without the inclusion of a control group (Dibble et al., 2006). In the study by Hirsch et al., (2003) 9 participants were considered controls and they were provided with only one aspect of the program, the component that focused on balance (Hirsch et al., 2003). Lastly, in the study by

Haas et al., (2007) participants were divided into either a creatine supplemented group or a placebo supplemented group to distinguish differences that occurred after training (Hass et al., 2007). After training, findings reported that positive muscle gains were achieved and future research should consider even greater sample sizes to detect further meaningful differences amongst the groups. The value of training is highlighted when comparisons to an exercising control group are included. However, non-exercising controls should be discouraged in this population since benefits will not be attained unless training is involved. Given that difficulty with recruitment and training adherence occur in any sample, it is deemed appropriate that future studies aim to recruit more individuals then less. The current study has determined the importance of exercising controls and will therefore incorporate this form of comparison.

### 2.3.3 Resistance Training and Motor Symptom Severity Measurement

The primary goal of resistance training research was to establish the muscles' response to workloads through either increased muscle mass or muscle damage that occurred. The measurement of possible motor symptom severity change that could have also occurred was omitted by the majority of the studies reviewed (Dibble et al., 2006; Hirsch et al., 2003). These studies instead only reported the disease severity of the participants at baseline using the Hohen and Yahr (H&Y) staging classification. Across these studies, all participants were categorized into H&Y stages III or less, which indicated study results were based only on individuals mildly or moderately affected by the disease.

Only in the study by Haas et al., (2007) included the outcome measure of motor symptom severity at both the baseline and the post training assessments. The goal of this study was to assess any therapeutic effects attained from resistance training with and without the use of creatine supplementation. The resistance training workload was increased by 5 or 10% for each exercise only once participants could perform 12 repetitions or more for any particular exercise. After the completion of training, results demonstrated there was no change in motor symptom severity found for either the creatine supplemented group (p=0.73) or for the placebo group (p=0.43) (Hass et al., 2007). These results suggested that resistance training alone cannot provide improvements in symptom severity, although the majority of studies reviewed failed to evaluate this outcome, this inference cannot be confirmed. Resistance training offers the ability to build strength through increased muscle mass and these strength gains may benefit the PD population through overall increased stability, postural improvements, the ease to ambulate and enhanced balance. Given such strength improvements could be attained, the motor symptom severity responses may also positively benefit. Future training studies that promote increased muscle mass either directly or indirectly would therefore benefit from the inclusion of motor symptom severity measurements.

### 2.3.4 Resistance Training and Measurement of Gait

The majority of resistance training studies reviewed utilized the muscle groups that are responsible for gait. These studies reported on the muscle gains that were found after the training periods allotted that included increased muscle strength of the legs after leg extensions (p<0.05) (Hass et al., 2007) where another study reported that the strength of the quadriceps was greater than the hamstrings and gastrocnemis (p<0.001) (Hirsch et al., 2003). Additionally, greater quadriceps force was shown after training (p=0.02) (Dibble et al., 2006) and also increased muscle volume was also demonstrated for both the affected and non affected sides of the participants after training (p=0.0014 and p=0.03, respectively) (Dibble et al., 2006).

The usefulness of resistance training studies was diminished with the limited gait analysis that was included. Only a single study by Dibble et al., (2006) assessed outcome measures that involved gait. The measurements of gait included the distance achieved in a six minute walk and the stair ascent and descent times. In this study, the eccentric group was compared to a standard care exercising control group. After training had finished, these authors reported the eccentric group had significantly increased the distance achieved in the six minute walk test (p=0.013) and showed faster stair ascend and descend times (p=0.06 and p=0.007, respectively) (Dibble et al., 2006). These documented measurements are related to functional rather then quantitative change in gait mechanics, the overall value attained from these study findings is greater with some evaluation of gait included. Overall, it is surprising that these studies measured for strength changes in the leg musculature and did not measure accompanying change in gait, particularly since muscular atrophy occurs in the natural aging process. Future studies would benefit from the evaluation of specific gait change, such that both the functional and quantitative aspects of gait are recorded. The current study therefore aims to incorporate quantitative gait measurements obtained from the GaitRITE® carpet alongside functional measurements to demonstrate possible improvements from increased muscle strength gains of the legs.

## 2.4 Overview of Multidisciplinary Training in Parkinson's disease

The purpose of multidisciplinary training is to involve a combination of exercises and exercise strategies that enhance the participants' movement. Multidisciplinary training is unique since it specifically aims to include a variety of exercise training techniques that benefit participants through lowered severity of their motor symptoms.

### 2.4.1 Multidisciplinary Training Principles: Frequency, Intensity and Duration

Multidisciplinary training was limited in terms of the detail provided for the descriptions of the frequency, intensity and durations of the programs utilized. In the study by Carne et al., (2005) overall the training duration ranged from one to three years, whereby exercise intensity descriptions involved the referral of participants to various treatment strategies that incorporated physical, occupational and speech-language therapies. The durations and intensities of each exercise session provided by the PADRECC healthcare delivery model specifically were not described (Carne et al., 2005). This model was created by the Veterans Health Administration (VHA) and it was apparent that greater interest existed to develop a privatized program for veterans with PD then to provide detail for the PD population. Clearly, without the descriptions of which repetitive exercises were completed, the development of future exercises and protocols was greatly limited.

All the training principles were only described in the study by Comella et al., (1994) whereby participants exercised three times a week for 4 weeks with 60 minute durations per training session. This crossover design included a phase of no exercise for 6 months, followed by another physical therapy session of 4 weeks. The intensity of the 69 repetitive exercises was increased by the addition of repetitions, which was dependent upon participant ability (Comella et al., 1994). Future studies could benefit from the concept of individualized exercise intensity progressions in order to help motivate the achievement of higher workloads. It is therefore of interest to determine how a longer length program with less duration per session would compare to this time-intensive type of intervention layout utilized. The current study developed our program to suit daily life, to increase exercise adherence and to provide lasting gains for our participants. Since some participants may be unfamiliar with treadmill training exercise, it was also deemed necessary that our protocol is feasible and adaptable, thus individualized to be inclusive for all disease severities.

The physical rehabilitation program by Patti et al., (1996) had considered the individuality of their participants, who exercised for four weeks. The detail on the frequency of individual training sessions however was not provided. These authors did provide detail that the physical therapy incorporated rhythmic symmetrical movements that increased in amplitude with particular emphasis placed on the change of speed, mobility and motion of the extremities. Participants were trained according to ability, such that the delivery of the exercises differed amongst the groups that were categorized by disease severity stages (H&Y stages II-V) (Patti et al., 1996). Specifically, the intensity of trained exercises varied, where some exercises occurred in a supine position, while others were completed while standing or walking. The training was adapted according to the participants' ability and this individually tailored exercise therapy was beneficial. It is deemed important for exercise studies to create programs with the variable nature of disease progression in mind. Personal involvement in the decision process for exercise intensity may also increase the benefit attained. The current study aims to involve participants in their own training process such that intensity levels will only be raised when the participant is comfortable.

**2.4.2 Multidisciplinary Training and Sample Sizes Utilized**

Participant sample sizes included for multidisciplinary training interventions in PD incorporated 49 (Carne et al., 2005), 28 (Patti et al., 1996) and 19 (Comella et al., 1994) individuals. Of the three reviewed studies two included the use of control participants. In the crossover design study by Comella et al., (1994) participants both exercised in their rehabilitation program and were also considered controls with authorization to exercise on their own. The inclusive nature of this study design is commendable because it promoted increased physical activity for all involved. This concept of increased activity levels for all participants is one that should be more seriously considered in future exercise study designs for PD. Alternatively, in the study by Patti et al., (1996) the control group was not provided the opportunity to exercise throughout the study duration. Participants' group allocation to either exercise or control groups was determined by computer generated randomization. These authors reported that the non exercising control groups' UPDRS scores significantly worsened and similarly, so did the mean amplitude and speed of step (Patti et al., 1996). These findings suggested that the inclusion of some form of physical or rehabilitative therapy should be considered for all individuals with PD in research related exercise programs. Since PD will progress and therefore continue to deteriorate an individuals' ability to move, research should aim to benefit this population through support for the participants' involvement in a program whereby improvements could be expected.

### 2.4.3 Multidisciplinary Training and Motor Symptom Severity Measurement

Multidisciplinary training had intended to benefit motor symptom severity and therefore it is not surprising that the multidisciplinary studies reviewed incorporated an evaluation of disease severity. Of the reviewed studies, improved UPDRS motor scores were found (Carne et al., 2005; Comella et al., 1994; Patti et al., 1996). However, the significant improvements that were found occurred at different time points after the training programs. In the study by Patti et al., (1996) these authors incorporated two separate study groups in their study design. The first group received physical rehabilitation for 4 weeks and also the exercisers in the second group. The second group however also included a control group that did not receive rehabilitation. The first group showed reduced (improved) UPDRS motor scores after 4 weeks of training (UPDRS mean motor subsection score ± SD: Baseline 32.3 (± 22.7); 4 weeks: 21.5 (±11.5), $p<0.05$) but showed increased scores when measured two months after the rehabilitation ended (Patti et al., 1996). The second exercising group also demonstrated significantly reduced (improved) motor symptom severity scores after 4 weeks of training ($p<0.000$) that remained improved six months later when compared to the baseline scores (Patti et al., 1996). The difference between these groups was that only the second group was evaluated again at the six month mark. Both groups reduced their motor symptom severity after the program ended suggests that the program effectively reduced motor symptoms. However, the second group also showed reduced motor symptom severity scores at the six month mark when compared to baseline, these findings were indicative that a continuation of exercise may have been responsible for these sustained improvements. Since the participants in first group experienced improvements in their scores after training that were lost, where the second group maintained the improvements at six months had suggested that a continuation of increased activity would reasonably explain these maintained benefits.

Alternatively, the crossover study by Comella et al., (1994) incorporated two physical therapy sessions of four weeks duration separated by a period of 6 months. Participants were randomized to either normal physical activity (no rehabilitation) or intensive rehabilitation groups. Each participant was tested after four weeks of either training, then again after six months of no specific exercise. Then participants began the alternative session for four weeks and were tested again six months later. During the six month phases participants were asked to maintain their normal level of physical activity. Interestingly, significant improvements in motor symptom severity were found only immediately after the four weeks of the intensive rehabilitation intervention ($p=0.007$), with no long term gains found at six months post intervention (Comella et al., 1994). Further, a slight decline was observed in the motor symptom severity scores of the normal physical activity group, although these scores were not significantly different from baseline and also did not change at the six month assessment. The 69 exercises that were completed had provided motor symptom severity benefit, although only with the intensive delivery. The current study has aimed to provide a comfortable gait training exercise experience however, our participants may also benefit from an intensive delivery. Our study will therefore individually tailor our protocols with guidelines to promote increased exercise intensity through increasing the treadmill training speeds. Our commitment to improve each participant's efficiency of gait may therefore benefit from this delivery strategy

Lastly the findings from the three year project from the Parkinson's disease Research, Education and Clinical Centre (PADRECC) by Carne et al., (2005) reported that 75.5% of exercising participants demonstrated significantly improved or stabilized UPDRS motor symptom severity scores after their multi-tiered therapy. Participants were categorized according to those who demonstrated a positive response (reduced/maintained symptom severity) deemed program 'responders' and those who were considered non responders (increased symptom severity) in the assessment of this health care model. Of the 49 participants, 28 were followed up at one year, 15 at two years and 6 participants had three years of follow up. These results highlighted the success of multi-faceted training in PD however were difficult in terms of comparisons given that the various exercises performed were not adequately described. The development of a paramount program for this population will occur only when studies include detailed descriptions that highlight the uniqueness of each program, so that only beneficial exercises are included. The current study aims to provide detailed explanations of the gait training program provided so that our study findings are understood and comparable to future research studies.

### 2.4.4 Multidisciplinary Training and Measurement of Gait

The lack of documented gait measurements throughout the multidisciplinary training studies exemplifies why standardized outcome measures assessed both before and after training are required. In the study by Carne et al., (2005) gait analysis was recorded by computerized posturography where findings indicated that no significant gait differences existed between the responders and non-responders to the program (Carne et al., 2005). However, this study had failed to provide the particular aspects of gait that were analyzed.

The knowledge of such measurements from a longitudinal study could have helped determine the most representative variable(s) of gait for the PD population. Similarly, in the study by Comella et al., (1994) the gait exercises utilized were developed by authors Wroe and Greer in 1973, although the exercise details nor the gait assessments incorporated at baseline or at post test were included (Comella et al., 1994). Instead these authors only utilized the UPDRS subsections since their gait evaluation and although gait related changes are captured in both the motor and activity of daily living scores, the specific components that were included from each scale were not presented. Provided this study was a controlled clinical trial, the aim to evaluate physical disability in advanced PD did not appropriately report on explicit gait changes necessary for the benefit of future studies.

Only the study by Patti et al., (1996) incorporated detailed gait evaluations that included assessments of mean speed of ambulation (m/s) and mean amplitude of step (s). These authors reported that after four weeks of exercise, the first group of eight participants showed a significantly increased walking speeds when compared to baseline (mean ± SD: Baseline: 0.74 (±0.0); 4 weeks: 1.03 (±0.4)) (Patti et al., 1996). Findings also showed that the exercised participants in the second group also significantly increased both the mean amplitude and the speed of steps after four weeks of training ($p=0.0016$ and $p=0.002$, respectively) but also at the 6 month evaluation ($p=0.044$ and $p=0.006$, respectively) (Patti et al., 1996). These findings highlighted that gait assessments are important to include because these outcomes are responsive to training and may also be receptive months later. The current study has considered the responsiveness of gait and will therefore include evaluations after our training program and again at six weeks post training to determine the successfulness of our program.

### 2.5 Overview of Goal Specific Training in Parkinson's disease

Goal specific training emphasizes a single focused purpose for the exercise undertaken. A specific approach or strategy is utilized to tailor specifically to a particular training goal. For example, focused training has occurred for training specific gait patterns, to determine the influence of external cues, specific strength increases or coordination patterns have been utilized during exercise.

#### 2.5.1 Goal Specific Training Principles: Frequency, Intensity and Duration

The goal specific training studies have incorporated a wide scope of training principles into their study designs. The shortest was the balance training study that occurred for only 10 days, twice a day for session durations of 20 minutes each (once in the morning, once in the afternoon) (Jobges et al., 2004). The training intensity of this study was determined by the strength of the pushes and pulls provided by the PT where the intensity was determined by the instability of the participant. The length of training for only 10 days was inadequate and responsible for the lack of longer term benefits achieved. For adequate long term training effects to be achieved, adequate training must occur.

Alternatively, in the large amplitude training study by Farley et al., (2005) participants exercised 4 times a week for hourly sessions over 4 weeks. This study utilized a personalized, one-on-one approach during their training sessions. The intensity of training was established by the individuals' maximal bigness for their exercises. The frequent training sessions of this program and additional personalized approach was deemed responsible for the improvements observed. The current study also aims to personalize our training sessions to ensure quality one-on-one training is provided. Our focus on an individualized training approach will assist participants to raise their personal goals for training intensity.

In a flexibility study, training lasted for 8 weeks, although participants were required to exercise for only 60 minutes weekly (Mitchell et al., 1987). This length of the training program showed promise, although the benefits of longer sessions with less frequency are still uncertain. Interestingly, the training principle of intensity was most disputable in this study. The requirements that participants exercised at a metabolic cost no greater than walking limited the possibility for training effects to be achieved. The current study aims to achieve training effects that are substantial and therefore guidelines have been provided to continually motivate participants to challenge themselves to increase their exercise intensities.

In both the coordination dynamics therapy and spinal flexibility studies the total length of training for 10 weeks was utilized. Participants trained for 4 hours a week on their specialized coordination dynamics machine that appeared similar to that of a semi recumbent cycle ergometer. During the testing period, participants were required to pedal forward for 10 minutes, backwards for 5 minutes and forward again for an additional 5 minutes at their preferred speeds, with the suggestion to maintain the exercise at a low intensity. This study showed variable results whereby the majority (62.5%) of the group improved on forward and backward turning but the remaining (37.5%) improved very little if any at all after training (Schalow et al., 2004). When participants were tested three months later the coordination dynamics changes had reverted back towards baseline whereby all PD participants achieved worse results. The current study is will assess coordination patterns of our PD sample since participants will train to improve their limb coordination while walking. The improved coordination will be assessed via changes in movement efficiency. Alternatively, in the spinal flexibility training study by Schenkman et al., (2007) the frequency of training was set to 3 times a week for 30 to 45 minutes per session. This study integrated an individually based graduated staging for their flexibility training although this unique aspect was unclear because ambiguous levels of progression were provided. The current study will individually tailor our program but will detail our specific guidelines to ensure that requirements are met prior to any increase in intensity.

In the last goal specific study reviewed, 12 weeks of exercise training were utilized where training twice weekly occurred for sixty minutes sessions. These participants were further provided with instructions to complete exercises while at home (Pedersen et al., 1990). Only vague descriptions of the intensity of exercises required were included in an exercise list, although these were not descriptive enough to replicate. The current study has noted the difficulty in determining which exercises improve motor symptom severity when combinations of exercises are utilized. Our focus specifically involved gait training on a treadmill in order to determine the effect achieved with this isolated form of training.

### 2.5.2 Goal Specific Training and Sample Sizes Utilized

The sample size of the goal oriented exercise groups helped identify the strength of the reported changes. Only a single study reviewed had included more than 20 participants, where a total of 51 participants were recruited (Schenkman et al., 2007). Of those studies that incorporated 20 participants or less, none of them included a control group (Farley & Koshland, 2005; Pedersen et al., 1990; Schalow et al., 2004). The recruited participants ranged from 18 in the large amplitude training (Farley & Koshland, 2005), 14 for the balance training (Jobges et al., 2004), 8 for the coordination dynamics therapy (Schalow et al., 2004), 10 in the muscle strength and gait study (Pedersen et al., 1990) and 7 in the flexibility training study (Mitchell et al., 1987).

Given the relatively small sample sizes, it is not surprising that only the study by Schenkman et al., (2007) incorporated a control group that was randomly assigned upon recruitment. The control group was named the usual care arm and consisted of 23 participants. These participants were 'wait-listed' for the exercise program and were requested to maintain their normal level of physical activity but to refrain from starting new exercises. Once the control data was collected these participants were then invited to begin in the exercise intervention that had been extended in order to provide the controls the same exercise experience. The observations from the usual care arm benefited this study since the treatment effects from the intervention group were more clearly represented. The opportunity to exercise that was provided is a good consideration in future studies that require a non exercising control group, because it exemplifies the needs of the participant are met alongside research aims. The current study will only incorporate an exercising control group to clearly establish the additional influence of the concurrent visual feedback that will be incorporated to enhance the of only one group.

### 2.5.3 Goal Specific Training and Motor Symptom Severity Measurement

In the study by Farley and Koshland, (2005) large amplitude training was the focus where the aim was to improve the participants' attention to their whole body awareness while exercising. Specifically, participants' were asked to focus on the largeness of movement alongside the sensations felt during each walking or reaching task required. Participants were categorized separated into H&Y stages I-III groups, although motor symptom severity was not an outcome measure of interest. The assessment of motor symptom severity would have benefited this analysis in order to provide insight for the motor symptoms that are most easily improved. With such information, future studies could have determined exercises that may have targeted more 'stubborn' symptoms that resisted change.

In an alternate goal specific study by Jobges et al., (2004) the primary focus was to improve balance that was targeted through repetitive postural training. Participants were assessed according to the compensatory steps that were taken after repeated pushing and pulling from various angles by the PT. The possible change in motor symptoms from posture, rigidity and balance scores of a motor assessment will unfortunately remain unknown. The symptom severity that was assessed using the UPDRS at baseline, both on and off medication states was not reported at the post training assessment (Jobges et al., 2004). The lack follow up greatly reduced the information derived from this study. A rule of thumb for future studies that makes logical sense is that if the measurement of symptom severity occurs at baseline, these measurements should also be obtained after the intervention to permit comparisons.

Additional goal specific studies examined did not include any standardized assessment of motor symptom severity (Pedersen et al., 1990; Schalow et al., 2004). These studies offered insight regarding their respective goal oriented tasks of muscle strength and gait (Pedersen et al., 1990) and coordination dynamics therapy (Schalow et al., 2004) however, the contribution to PD exercise literature pertains just to these specific tasks measured. Future studies should be motivated to consider the value attained beyond the scope of their immediate research goals.

Two goal oriented studies that focused on spinal flexibility (Schenkman et al., 2007) and flexibility training (Mitchell et al., 1987) included the measurement of motor symptom severity. Interestingly these studies employed less commonly used motor symptom assessment tools. The measurement tools that evaluated symptom severity included the Duke University's Parkinson's disease rating scale (Schenkman et al., 2007) and the Parkinson's Functional Assessment Tool (PFAT), which was derived from the Columbia University's rating scale (Mitchell et al., 1987). Although the inter-rater reliability has been deemed sufficient for the PFAT scale (Yahr, 1969) and the reliability and validity for the Duke University scale was considered comparable to other scales that monitor early to mid stage disease severity (Cutson et al., 1995), the selection and utilization of such symptom severity scales greatly limited the comparability to studies that have included more globally accepted assessment tools. The current study will therefore only incorporate the widely utilized UPDRS scale for our motor symptom severity assessment to facilitate comparisons for future studies.

### 2.5.4 Goal Specific Training and Measurement of Gait

Variables of gait were evaluated in the goal oriented studies reviewed. In the large amplitude study by Farley and Koshland (2005), the measurements of velocity, stride length and cadence were captured using a 14 foot long sensor-filled GaitRITE® carpet under two speed conditions. The first condition was the preferred speed where the second condition required participants to walk their fastest. These authors reported that velocity and stride length significantly increased from pre to post training in the preferred speed condition ($p=0.01$ and $p<0.004$, respectively) where interestingly, the fast condition resulted in only a significantly increased stride length ($p=0.02$) (Farley & Koshland, 2005). Gait velocity instead responded to the fast condition with a non significant increase in speed along with a corresponding non significant decrease in cadence. Essentially, both conditions resulted in different strategies that were employed by the participants, where the fast condition demonstrated a ceiling effect (Farley & Koshland, 2005). These results indicated that PD gait is more responsive to preferred or self selected speed conditions, perhaps because the participant is in greater control of their speed of movement. The current study will therefore implement participants' chosen comfortable walking speed into our testing and training protocols, where increased speed will occur only when the participant is ready. It is of interest to determine whether improved gait efficiency is achieved and further maintained in the longer term evaluations after self selected velocities occurred during training.

In the work by Jobges et al., (2004) the goal to focus on compensatory steps taken also evaluated the participants steps across a distance of 5 meters for a total of three trials. These authors reported that step length and velocity increased only immediately after training (p=0.08 and p=0.007, respectively) (Jobges et al., 2004). Interestingly at the follow up evaluation 2 months later, only the velocity improvements were maintained since they were statistically unchanged at this time. These results provided evidence that velocity of PD gait can be improved and maintained after gait specific training. The current study aims to investigate the response of velocity and step length after our treadmill training that will focus participants to their gait to determine what responses occur both immediately and in the longer-term.

The study by Pedersen et al., (1990) participants' gait was assessed after they trained to focus on dynamic movements of foot and leg exercises with particular the variations in the speed and the adjustments to space. The aim of these exercises was to increase strength, mobility and coordination from both seated and standing positions. In the baseline, post training and 4 month follow up assessments gait was assessed by walking 5 trials of 10 m at five different paces that ranged from the slowest to the fastest they could walk. The gait outcomes that were assessed included stride frequency, stride length and velocity. These authors reported that both the stride length (tested at two constant velocities of 0.5 m/s and 1.1 m/s) and maximum velocity significantly decreased after training. ($p<0.04$, $p< 0.05$ and $p<0.03$ respectively) (Pedersen et al., 1990). Furthermore, the when compared to baseline, only stride length remained significantly lower at the 4 month follow up ($p<0.05$ for both constant velocities) (Pedersen, 1990). This study demonstrated that the maximum velocity did not change at the four month assessment, where stride length did, which indicates the responsiveness of participant controlled strides. Our study aims to evaluate if lengthened steps are found after training and whether they are maintained. Although, participants are affected unilaterally upon diagnosis, therefore the assessment of the most affected side step length would best represent the change in gait, without the possibility for a compensation step of the less affected side that would be included in the measurement of stride length. Thus, the current study aims to evaluate whether training at a comfortable walking pace chosen by the participant will provide significant gait improvements. It was rationalized that the incorporation of the pace chosen by the participant may increase attention to their gait cycle that will encourage increased gait speeds.

In the flexibility training study by Mitchell et al., (1987) the participants' sense of control was included in the assessment. After eight weeks of a structured exercise program, both the subjective and objective mobility responses were documented. Objective mobility responses were measured by the mobility subscales of the Parkinson's Functional Assessment Tool (PFAT) where subjective responses were measured by the Parkinson's Perception of Function scale (PPFS). The reported objective responses had significantly increased overall after training (p=0.01) where the subjective responses not reach statistical significance (p=0.06) (Mitchell et al., 1987). These findings demonstrated that the exercises utilized that focused on joint mobility, rhythm and flexibility benefited participants, assessed by the objective mobility score. The lack of subjective improvements after training may be due to the lack of perceived intensity of exercise given that these exercises were derived from recommendations provided by the American Parkinson's Association that suggested exercises should not pose a metabolic cost greater then walking. Although this is an accredited association, these intensity demands are limiting in terms of the challenge posed to the participant. The current study has considered that participants can be challenged beyond an intensity of walking and also that a thorough investigation would incorporate some subjective information from each participant. Therefore the intensity demands will be incorporated according to each participant and also in addition to our primary outcome measures of gait a subjective mobility question will be included to capture the personal responses to our gait program.

In the study by Schenkman et al., (2007) training focused to improve the spinal flexibility and coordinated movement of participants. These authors measured gait at baseline and after the completion of the training program and evaluated both a 6 minute and a 10 meter walk test. Both measurements required participants to walk at a comfortable pace. The 6 minute walk recorded the distance that was achieved in this time, where the time required to complete the 10 meter walk test was analyzed. Findings demonstrated that neither the 6 minute walk nor the 10 m walk tests were significantly changed after training ($p=0.186$ and $p= 0.649$, respectively) (Schenkman et al., 2007). The lack of significant improvement may have occurred because the exercise progression from sitting to standing was utilized. Further, the eight exercise training guidelines incorporated were not aimed to increase strength, but to recruit synergistic muscles. It was speculated that the goal of this program would likely not provide changes in gait. The consideration of whether the training progression provided will produce the expected outcomes is necessary. The current study anticipates that both groups will demonstrate improvements in gait since the participants will train at their own pace on the treadmill and will be encouraged to develop greater efficiency in their gait through increased coordination of the upper and lower limbs.

The last goal specific training program by Schalow et al., (2004) was based on coordination dynamics therapy that aimed to re-teach and structurally repair the required central nervous system networks for coordination (Schalow et al., 2004). The exercise training took place on a unique coordination dynamics therapy device and because gait training specifically was not involved, it was not considered an outcome measure of interest. Although, given that the leg musculature was trained in this program it would have been interesting to observe whether effects of coordination training would have transferred to improvements in gait. It is important for future studies to identify outcome variables that are targeted during training and have them incorporated into assessments to provide meaningful outcomes.

## 2.6 Overview of Aerobic Cycle Ergometry Exercise in Parkinson's disease

Previous aerobic exercise studies have utilized cycle ergometry for a testing and training tool to assess the physiological responses in PD. Since the central aims of these studies have included aerobic efficiency responses, the characteristic outcome variables discussed throughout this review of literature are largely absent. If detail was provided on the outcomes measures of interest they will be discussed however, the primary focus of cycle ergometry studies has been on the physiological responses, thus primarily these responses that are also relevant to the current exercise study will be discussed.

### 2.6.1 Parkinson's disease Responses to Cycle Ergometry

In the metabolic study by Landin et al., (1974) six male PD participants were recruited with moderate to severe PD presented with the dominant symptoms of bradykinesia and rigidity. This study examined the most clinically affected side of these participants during an exercise tolerance test that increased the workloads in a stepwise fashion from 33, 67 to 98 watts to determine the length of time participants' could withstand the highest workload. Participants were then assessed over a forty minute exercise period where workloads were set between 49-65 watts. The exercise responses of the PD participants were compared to five healthy controls that exercised at 65 watts for the same 40 minute period. The assessment of HR was measured at rest and at 5, 10, 15, 20, 30 and 40 minutes in both groups. These authors reported that the PD participants' HR's were significantly higher both at rest and during exercise ($p<0.01$ and $p<0.001$, respectively) at the equivalent or less workloads when compared to controls (Landin et al., 1974). The oxygen consumption ($Vo_2$) uptake and respiratory exchange ratio (RER) were collected both at rest and during exercise at 10 and 40 minutes. The mechanical efficiency, determined by the absolute $Vo_2$ uptake of PD participants was significantly lower by the end of exercise when compared to controls ($p<0.01$) (Landin et al., 1974). Additionally although the RER was higher at rest for the PD participants, statistically higher responses when compared to controls were only determined during exercise ($p<0.01$) (Landin et al., 1974). An obvious limitation found in this study was that they failed to provide measurement of motor symptom severity. Additionally, the sample size was limited in terms comparison, given that only six male participants were included and therefore limited the generalizations that could be made. Also, the absolute $Vo_2$ data minimized the comparability for differences amongst participants and lacked consideration for different body compositions. The current study will therefore include the differences in oxygen consumption that are relative to body weight at each workload in a much larger mix-gendered sample so to provide findings that can be generalized.

In the study by Protas et al., (1996) eight men diagnosed with PD that were classified by H&Y stages II-III were compared to seven healthy age matched men in an incremental exercise test. After a short warm up, the workload resistance was increased every two minutes by 20 watt increments beginning at 40 watts until the established peak exercise requirements were attained. Values were considered peak when two of three requirements were reached: if the participant reached volitional fatigue, ±10 beats of their age-predicted maximum heart rate or if an RER value of greater then one was attained. Age predicted maximal heart rate was estimated by the 220-age equation and all measurements were recorded in the last 20 seconds of each 2 minute stage. These authors reported that no significant differences existed between the groups for the peak $Vo_2$, RER or HR (Protas et al., 1996). Also a trend was reported that indicated the sub maximal HR and $Vo_2$ values appeared to be higher for the PD group then for the control group (Protas et al., 1996). The limitations found in this study included the only-male participants recruited and also that no perceived exertion ratings were obtained from this sample. Such information from an incremental exercise test would provide valuable subjective feedback. Along with a mix-gendered sample, the current study will also include subjective intensity ratings throughout both our treadmill assessments and training.

In the study by Canning et al., (1997) 16 PD participants classified by H&Y stages I-III were recruited and were categorized by their exercise history and allocated to either the 'exercising' or the 'sedentary' group. Participants were required to perform two 10 m walk tests and a maximal test on a cycle ergometer. The walk tests required that one condition occurred at the participants' regular pace and the other that was a fast paced walk. Pens were attached to the participants' heels that marked their steps and that were then used to determine both step length and cadence. Gait velocity was determined by use of a stopwatch. The cycle ergometry test was an incremental test to peak capacity. Participants began at a resistance of 20 watts, pedalling between 50-60 RPM where then the workload was increased by increments of 10, 20 or 30 watts every minute to allow for maximum exercise capacity to be reached between 6 and 12 minutes. The measurements of peak $Vo_2$, peak HR and peak RER were obtained within the final 30 seconds of the test. The dependent variables were compared to the predicted normal age-height and gender matched ranges that were based on published data at the time. This study considered the 'normal ranges' for peak $Vo_2$ and peak RER between ±20 of the previously predicted normal values where peak HR was considered 'normal' within ±1.65 standard deviations from the previously predicted normal mean. Findings reported that no significant differences existed for peak $Vo_2$ between the groups (Canning et al., 1997). Further findings from the 10m walk tests indicated that the mean preferred gait velocity was not significantly different from the mean predicted velocity, although the mean fast condition velocity was significantly different ($p<0.05$) (Canning et al., 1997). Also the mean stride length was significantly less then the predicted stride length values at both the preferred and fast velocities ($p<0.01$ for both) (Canning et al., 1997). The differences that existed within this sample from the 'normal' ranges had indicated that in PD, 'normal' responses may be variable. Additionally, these results highlighted the necessity to include samples of larger sizes so that the variable responses of PD can be estimated with reasonable accuracy. A limitation found in this study was the comparison of PD responses to the reported 'normal' ranges that were not actually reported, thus difficult to compare these findings to.

In the study by Stanley et al., (1999) the cardiopulmonary function of 20 PD participants classified by H&Y stages II-III were compared to 23 healthy age matched controls in an incremental protocol. Participants were allotted with 1 minute of warm up prior to starting the exercise test workload of 40 watts, pedalling at 50 RPM. Every two minutes an incremental 20 watt increase was added until participants were unable to maintain the workload or pedal revolutions required. Measurements of $Vo_2$/kg and respiratory exchange ratio were recorded every 20 seconds where heart rate was monitored and recorded in the last 10 seconds of each stage. Once the participants reached the same peak exercise requirements found in the study by Protas et al., (1996), a cool down was allotted. Findings reported that no significant differences in maximum $Vo_2$/kg were found for either men nor women (Stanley et al., 1999). Groups were then separated by gender for an alternative comparison to separated gender age matched controls. Again, findings reported that no significant differences were found between PD males compared to healthy males or for PD females compared to healthy females (Stanley et al., 1999). A major limitation that existed in this study was the lack of report of the HR responses given that these values were collected. The current study will record and report on the HR responses for all participants so that this information is available and comparable for future studies.

In the study by Reuter et al., (1999) the cardiovascular responses from a ramp protocol test compared 15 PD participants to 15 age matched control participants. Groups were provided 1 minute warm up and then the exercise workload began at 25 watts and progressively increased by 25 watts every four minutes up to 150 watts, depending on what could be tolerated. Heart rate was monitored continuously throughout the exercise test. Findings reported that all PD participants attained the 75 watt workload, where 12 PD participants achieved the 100 watt workload and only seven participants managed both the 125 and 150 watt workloads. Alternatively, all control participants managed the 75 and 100 watt workloads, where only 12 could handle the 125 watts and only 9 could handle the 150 watts (Reuter et al., 1999). These performance measurements were expressed in watts/kg and did not significantly differ between the two groups, indicated that both groups were similar in their intensity level performances. Also, a similar rise in HR was observed at each workload for both groups and although non significant, a slightly higher heart rate was observed from the PD group at the low intensity workloads of 25, 50 and 75 watts (Reuter et al., 1999). Overall, these results indicated that the PD group had no problems adapting their HR to the required workloads, although they appeared less efficient at the lower workloads. An evident limitation was therefore the absence of the $Vo_2$ measurement from this test since it may have demonstrated the speculated aerobic efficiency responses. Also, the information from a mix gendered PD group compared to healthy controls would have been beneficial for the oxygen consumption requirements in this population. To best represent the aerobic efficiency change, the current study will therefore include the measurement of oxygen consumption and heart rate in our sub maximal treadmill tests.

## 2.7 Overview of Treadmill Training in PD

Treadmill training is an aerobic rehabilitative strategy in PD is relatively recent. Treadmills have primarily been utilized for gait training for this population since there is the potential for the simultaneous physiological and gait benefits. Potential gait training responses include cardiovascular improvements and increased blood flow to the brain, these responses highlight the necessity for continued study of these relationships in PD. Furthermore, it is an inexpensive and an easy exercise to participate in. Few previous treadmill studies have reported any improvements in motor symptom severity (Cakit et al., 2007; Fisher et al., 2008; Miyai et al., 2000) hence it is important to verify. The treadmill training studies will be discussed according to our characteristic components reviewed in order to provide the rationale for the current exercise study.

### 2.7.1 Treadmill Training Principles: Frequency, Intensity and Duration

In the treadmill training studies to date, a variety of training requirements have been incorporated. In one of two studies by Miyai et al., (2000) participants were divided to receive either four weeks of body weight supported treadmill training (BWSTT) followed by four weeks of PT or in the reversed order. For both programs, participants trained for 45 minute sessions three times weekly for a total four weeks for each treatment type. Prior to the BWSTT, participants were fitted to an overhead harness utilized during training. Participants were required to walk with 0, 10, 20, and 30% of body weight support, where with each amount of support, participants walked at paces of 0.5, 1, 1.5, 2, 2.5 and 3 km/hr depending on what was tolerated (Miyai et al., 2000). Each participant chose their most comfortable speed and utilized the most comfortable body weight support option that was at 20% for all participants. Each training session therefore began with 20% body weight support for 12 minutes of training that was followed by 4.5 minutes of rest. Next 12 minutes at 10% body weight support was utilized with another 4.5 minutes of rest. Lastly, 12 minutes at 0% of body weight support was utilized. To enhance the treadmill speed, training began at 0.5 km/hr and increased in increments of 0.5 km/hr to a maximum speed of 3 km/hr over the training sessions (Miyai et al., 2000). Alternatively, the PT program was reported to consist of conditioning, range of motion, activities of daily living and gait training exercises. Additionally over the crossover design, all participants also received occupational therapy sessions for 45 minutes each week during the study. The occupational therapy activities however were not described. An evident limitation included the rest periods that were utilized during treadmill training. Since the speeds were adjusted according to the participants comfort, it was deemed inappropriate to include a rest period at all. The current study will train participants' at their comfortable walking speed and will challenge each participants' endurance through lengthened rather then shortened training times.

In the second study by Miyai et al., (2002) participants received similar exercises found the first study, although in a different design. Participants were allotted to receive only one of either BWSTT or conventional PT training three times weekly for 45 minute sessions for one month. Similar to the first study, participants were fitted to a harness with the same body weight support percent and pace options. The differences that existed between these two studies included a shortened training protocol with only 10 minutes allotted per body weight support option. Additionally, an increased rest time of 5 minutes was allotted between each body weight support training period (Miyai et al., 2002). Given that the same treadmill belt speed options were utilized, participants initialized training at 0.5 km/hr and increased in increments of 0.5 km/hr to a maximum speed of 3.0 km/hr. Similar to the first study, all participants also received additional occupational therapy sessions for 45 minutes a week while the study was in progress. Again, the obvious limitation found in this study was the inclusion and additionally an increased time for rest periods incorporated. Also, the utilization of harnesses at the participants' comfortable walking speeds indicated the study findings may have misrepresented the attainable exercise intensities of this sample. The current study will not utilize harnesses but instead will utilize spotters to encourage independent walking while training. Also, small increases in speed from the initial comfortable walking pace will be incorporated only when deemed comfortable by the participant.

In the study by Pohl et al., (2003) participants were randomly assigned to receive all three forms of gait training and one control intervention in different ordered sequences over four consecutive days. The structured speed-dependent intervention aimed to increase each participant's walking speed at zero percent incline. Prior to training initiation each participant's maximum over ground walking speed was determined and was then halved for the warm up speed over 5 minutes. Next, within two minutes, the speed was increased to the highest that the participant could walk without stumbling. This maximum speed achieved was required to last for 10 seconds and was then followed by a recovery period to return the participants' pulse to resting level. The next phases then either increased or decreased the maximum achieved speed by 10% according to the participants' comfort. Ten seconds at each speed were required, followed by recovery periods to return the participants pulse to resting level. These training phases continued until 30 minutes had elapsed (Pohl et al., 2003). Alternatively, the limited progressive training aimed to maintain the treadmill speed at the participants' initial self-adapted walking speed at zero percent incline. The total walking distance achieved therefore varied among participants and additionally that they were also allotted a minimum of two rest periods over the 30 minute training (Pohl et al., 2003). For both treadmill interventions, harnesses were used, however the body weight support option was not. The last intervention was the conventional gait therapy that utilized proprioceptive neuromuscular fasciculation (PNF) concepts during the training. The detail of the exercises was not provided. This 30 minute training was conducted by two therapists who provided this physiotherapeutic gait therapy (Pohl et al., 2003). Alternatively, the control intervention had participants rest for 30 minutes in either a recumbent or comfortable sitting position without any treatment provided. The limitations of this study included the aggressive nature of the speed dependent protocol utilized and alternatively those that were not sufficiently challenging. The current study aims to provide a comfortable and self selected pace that is then progressively increased accordingly. The consideration was made for this population that may benefit from increased speeds that are maintained, not simply just attained.

In the study by Herman et al., (2007) participants were required to walk on a treadmill at zero grade for 30 minutes, four times weekly for a total period of six weeks (Herman et al., 2007). Prior to program initiation, each participants' comfortable over ground walking speed was determined. This training design was unique since it progressively increased the treadmill speeds for all participants through weekly evaluations of speed. From the original gait velocity, training was initialized at 80% of this speed and increased to 90%

for the second week of training. At the third week all participants had attained their comfortable speed and from this point onward, the gait speed was gradually increased to 5% to 10% (Herman et al., 2007). This progressive training protocol allowed for greater treadmill belt speeds to be reached when compared to baseline. However, the use of lower walking speeds then the participants' comfortable pace for 1/3 of the total training time may have minimized the effectiveness of this program. Future studies should consider initializing training at the participants' comfortable speed with continued increases throughout training only. The current study will therefore encourage participants to begin and maintain their comfortable walking pace at a minimum. To appropriately challenge to our sample the participant will be held accountable to maintain the speed that they had originally attained.

In the study by Cakit et al., (2007) participants in the exercise group trained for 8 weeks, twice weekly for 30 (±5) minutes each session (Cakit et al., 2007). Prior to treadmill training without an incline, the maximum tolerated walking speed was determined and this speed was halved for the five minute warm up. After the warm up, the belt speed was increased in increments of 0.6 km/h every five minutes until the fastest speed for each participant was reached. The achieved speed was maintained for the five minute period and was then decreased also in 0.6 km/h increments (Cakit et al., 2007). Each participant's treadmill speeds therefore fluctuated dependent on what could or could not been maintained for the reduced speeds. If the reduced speed was maintained for five minutes the speed would be increased again, where if the speed was not maintained the speed would then be decreased. Each participant trained according to their capabilities although, this protocol aimed to promote increased speeds every five minutes. The evident limitation for this study was the speed increments of 0.6 km/h that were utilized and this may be too difficult and therefore intimidating for severe participants. Further, the twice weekly training frequency is just less then that recommended for weekly aerobic exercise, be completed three times weekly thus it may not have allowed for adequate training effects to be produced. The current study will therefore include speed increments of 0.2 km/h to tailor our protocol to all participants. Training requirements are set for three times per week to ensure that our results are a reflection of adequate aerobic training in our sample.

In the study by Fisher et al., (2008) the participants were randomly allocated into three groups, two exercise groups and one control group. The exercised participants were divided into high and low intensity groups that were required to train 3 times weekly over 8 weeks for 45 minutes each session (Fisher et al., 2008). The high intensity group was trained solely on a treadmill with a minimum of 10% body weight support. The exercise intensity aim was to reach greater then 3 METS, or up to 75% of the participants age predicted maximal heart rate (Fisher et al., 2008). The end goal of training was to have participants attain 45 minutes of continuous exercise at the intensity requirements described, although rest periods were permitted if and when necessary. Several methods were incorporated to enable the participants to attain the required exercise intensity. These methods included to decrease either the amount of body weight support or the physical assistance if provided, or to increase either the treadmill speed or the total time they exercised. Alternatively, the low intensity group exercise occurred on both the treadmill and with PT exercises provided. The expectation was to train below 3 METS or below 50% of the participants age predicted maximal heart rate for both sets of exercise training (Fisher et al., 2008). The treadmill exercises incorporated the same progressions to increase intensity describe above. The PT exercises included low to moderate intensity activities that were grouped into six different categories. Each session included activities from each category that were individualized dependent on the identified impairments. In the zero intensity group incorporated six hour long presentations on relevant issues for the PD population. Participants in this group were asked to maintain their current exercise routines and were required to monitor their daily exercise by keeping record in a journal. The lack of consistency for the treadmill intensity changes was considered a major limitation in this study. The differences in altered intensity had created unnecessary variation when comparing the treadmill training groups. Since the intensity was altered in several ways, a greater consistency for the increased or decreased intensity could have been established. The current study aims to better regulate the exercise intensity changes, such that rules are included for exercise intensity progression that all participants are required to follow.

### 2.7.2 Treadmill Training and Sample Sizes Utilized

In the first study by Miyai et al. (2000) 10 recruited participants were divided evenly, such that 5 participants received each crossover order of BWSTT and PT training (Miyai et al., 2000). In the second study by Miyai et al., (2002) 24 participants were recruited for their randomized controlled trial design, where participants were randomized to receive either the BWSTT or the PT training over the study period. Due to changes in medication, only a total of 20 participants' data was included in their analysis. Therefore, a total of 11 participants were included in the BWSTT group and 9 participants for the PT training (Miyai et al., 2002). An alternative approach for training allocation was utilized in the study by Pohl et al.,

(2003) who recruited 17 participants with early PD. All participants were randomly assigned to receive all three gait training interventions and one control intervention in different sequences (Pohl et al., 2003). Alternatively, the study completed by Herman et al., (2007) utilized the same protocol for all 9 mild to moderately affected participants. In study by Cakit et al., (2007) groups were randomized into training or control groups and after drop outs, only a total of 31 participants completed this study design (Cakit et al., 2007). The non-exercising control group consisted of 10 participants where 21 completed the exercise training. In the most recent treadmill training study completed by Fisher et al., (2008) a total of 30 participants completed their program. However, participants were divided into three groups of 10 to complete each of their three training programs (Fisher et al., 2008). Therefore, only a total of 20 participants actually completed physical exercise, where 10 participated in the interest talks that were provided.

### 2.7.3 Treadmill Training and Motor Symptom Severity Measurement

Motor symptom severity has been a measurement of interest in most treadmill training studies. In the first study by the authors Miyai et al., (2000) motor symptom severity was measured by the motor subscale of the UPDRS. Participants were all classified by H&Y stages II-III prior to training. Assessments occurred at baseline and immediately after the four weeks of either BWSTT or PT training offered. Findings demonstrated a significant main effect was found for the type of therapy ($p<0.0001$) but not for the order of therapy (Miyai et al., 2000), suggesting that BWSTT was more effective then the PT for improvements in the total UPDRS score. Specific to motor symptom severity, a significant main effect demonstrated greater reductions for the motor score occurred after four weeks of

BWSTT (18.2 (±1.4) to 15 (±1.3)) when compared to PT (p=0.0002) (Miyai et al., 2000). The current study will encourage continuous exercise at an intensity the participant can maintain without body weight support to determine if similar motor symptom severity benefits can be attained.

In the second study by Miyai et al., (2002) again, motor symptom severity was assessed by the UPDRS motor subscale and participants again were categorized by H&Y stages II-III. Given that this study design was a randomized controlled trial, participants received either BWSTT or PT for one month of training. Assessments occurred at baseline and immediately after training and again 2, 3, 4, 5 and 6 months after. These authors reported that no significant changes occurred for the total UPDRS or the motor symptom severity subscale between the groups (Miyai et al., 2002). Differences could have been due to the changes in the treadmill training protocol where increased rest and decreased training times occurred per session. These changes obviously limited the amount of time allotted for participants to excel at their respective training speeds. The current study aims to promote continuous training and will also provide training goals that promote increased speeds.

The study by Pohl et al., (2003) did not include a measurement of motor symptom severity after training. Interestingly, all participants were categorized according to the UPDRS at baseline. This was a major limitation because this information could have been insightful for this respective form of training.

In the study by Herman et al., (2007) assessments for motor symptom severity utilized the UPDRS motor subscale. Participants ranged from H&Y stages I-III and were tested before and after the six weeks of training and again four or five weeks after training was completed. These authors reported that from baseline to immediately after training significant changes in motor symptom severity occurred from 29 (±9.3) to 22 (±11.1) ($p=0.043$) (Herman et al., 2007). Interestingly, the motor scores found continued to reduce at follow up to 19.7 (±6.4) and had remained significantly lower then when compared to baseline ($p=0.027$) (Herman et al., 2007). The personalized and progressive nature of this treadmill protocol was beneficial although, the use safety harnesses may have limited the totality of achieved benefit. The harnesses were used without body weight support and but may still have provided a false sense of independence. The current study will therefore exclude the option for harnesses and instead for safety will provide spotters when assistance is required.

The authors Cakit et al., (2007) also measured motor symptom severity with the UPDRS motor section. The participants were assessed at baseline and after the eight weeks of training. However, the motor symptom severity change was only provided through a variety of correlations with alternate tests that were assessed. These authors correlated the motor score to the Berg Balance Test, the Dynamic Gait Index and the Falls Efficacy Scale, the history of falling, the use of assistive devices and to disease duration. These authors reported that the UPDRS motor subscale scores negatively correlated with the Berg Balance Test and the Dynamic Gait Index scores ($p<0.001$, $r= -0.683$, $p<0.05$, $r= -0.567$, respectively) (Cakit et al., 2007). The UPDRS motor subscale also correlated positively with the history of falls ($p<0.01$, $r= 0.643$) (Cakit et al., 2007). The exclusion of the distinct motor symptom severity measurement after training limited the determination of the true effectiveness of this training protocol. Thus, the current study will independently report motor symptom severity in order to facilitate the development of future successful protocols.

In the study by Fisher et al., (2008) the motor symptom severity of participants was recorded at baseline and after the eight week training program was completed. Although, this preliminary trial that had aimed to assess the responsiveness of the population at different exercise intensities, failed future research since these scores were not statistically analyzed. Nonetheless, the means and standard deviations of the motor symptom severity were reported. All intensity groups demonstrated reductions from baseline to the post training assessment. The high intensity group scores reduced from 27.6 (±10.3) to 24.8 (±9.0) where the low intensity group scores reduced from 30.5 (±8.7) to 26.7 (±7.5) and even the non-exercising, zero intensity group showed a reduction from 27.6 (±7.3) to 24.9 (±8.8) (Fisher, 2008). The lack of statistical analysis was a limitation given that meaningful group differences could have been established. The current study will therefore include the measurement and analysis of motor symptom severity for each assessment period.

### 2.7.4 Treadmill Training and Measurement of Gait

Gait was a primary outcome measure in all the treadmill studies reviewed. In the first study by Miyai et al., (2000) gait measurements assessed included the walking endurance (m), gait speed (sec/10m) and the number of steps (steps/10m) after either order of BWSTT or PT training. These authors reported that a significant main effect existed for the type of therapy but not for the order of therapy, for gait speeds and the number of steps required to complete a 10m walk ($p=0.0291$ and $p=0.0099$, respectively) (Miyai et al., 2000). The reported time to complete the 10 m walk was determined to be faster after BSWTT (before: 10.0 (±0.9), after: 8.3 (±0.7)) then after the PT training (before: 9.5 (±0.9), after: 8.9 (±0.9)) (Miyai et al., 2000). Also, the number of steps required to complete the 10 m walk was less after BWSTT (before: 22.3 (±2.3), after: 19.6 (±2.2)) then after the PT training (before: 21.5 (±2.3), after: 20.8 (±2.4)) (Miyai et al., 2000). These results suggested that BWSTT provided greater improvements in both the gait speed and stride length then after the PT training. Interestingly, the gait endurance did not significantly differ between the groups and although the participants were asked to walk fast for all gait measures, these authors failed to detail how the over ground ambulation endurance was obtained. Apparent limitations from this study included the hand calculations for the gait measurements, since these authors noted that both the time and the number of steps were measured simultaneously. These calculations would therefore be prone to human error and future studies would benefit from more advanced calculations of gait. If these are unavailable, it would be beneficial if clarification was provided to detail the attempts to prevent miscalculations. The current study will utilize the advanced GaitRITE® carpet to appropriately measure and record the gait of each participant.

In the second study by Miyai et al., (2002) only the variables of gait speed (sec/10m) and the number of steps (steps/10m) was included in this analysis. These authors reported that the BWSTT group had significantly faster gait speeds immediately after training when compared to the PT group (8.5 (±0.7) and 10.8 (±1.8), respectively; $p<0.005$) (Miyai et al., 2002). Additionally, fewer steps were taken in 10 m by the BWSTT group when compared to the PT group. These improved stride lengths from the BWSTT group relative to the PT group were reported immediately after training (20 (±2.1) and 22.7 (±2.0), respectively; $p<0.005$), 2 months later ((19.5 (±1.7) and 22.4 (±1.8), respectively; $p<0.005$), 3 months later (20.1 (±1.9) and 23.1 (±2.1), respectively; $p<0.005$) and 4 months later (20.1 (±1.9) and 23.1 (±2.1), respectively; $p=0.006$) (Miyai et al., 2002). These results suggested that treadmill training benefited PD gait greater then the PT exercises in both the short and long term. The current study has thus included only a treadmill training component to determine whether changes are observed and whether they are maintained in the longer term.

In the study by Pohl et al., (2003) the self-adapted walking speed (m/s) and the stride length of the self-adapted walking speed (m) were assessed. Findings reported that significantly improved self-adapted walking speeds occurred after the structured speed-dependent treadmill training (before: 1.37 (±0.23), after: 1.56 (±0.23); $p<0.001$) (Pohl et al., 2003). Additionally, stride length also significantly increased (before: 0.72 (±0.12), after: 0.78 (±0.14); $p<0.001$). Similarly, after the limited progressive treadmill training, the walking speeds increased (before: 1.35 (±0.21), after (1.52 (±0.2); $p<0.001$) and also did the stride lengths (before: 0.71 (±0.1), after 0.77 (±0.09); $p<0.001$) (Pohl et al., 2003). There was no significant gait change after either the conventional gait therapy or the control interventions. Thus, for gait improvements, the protocols that aimed to increase either the training speed or the total distance were sufficient. The limitation found in this study included the lack of measurement of the step lengths achieved, a valuable insight to determine whether participants with early PD showed differences in step lengths of the clinically most affected side. The current study will only measure the most affected side step length to accurately determine the effect of training on gait change experienced in our sample.

The study by Herman et al., (2007) assessed gait speed (m/s), stride length (m), stride time variability (%), average swing time (%) and swing time variability (%). Results reported that immediately after six weeks of training, the participants' gait speeds significantly increased from 1.11 (±0.17) to 1.26 (±0.16) m/s (p=0.014), where similarly so did stride length from 1.17 (±0.22) to 1.25 (±0.22) m (p=0.012) (Herman et al., 2007). A trend for an increased percent of swing time variability was also observed from 3.5 (±1.9) to 5.3 (±3.8) % (p=0.066) (Herman et al., 2007). The variables of stride time variability and average swing time did not significantly change after training. Improvements that were maintained at follow up relative to baseline occurred for both gait speed and stride length. The gait speeds were faster 1.16 (±0.24) m/s (p=0.028) and the largest steps were also observed 1.26 (±0.21) m (p=0.043) (Herman et al., 2007). The remaining gait variables had reverted back similar to those attained at baseline. The current study has noted the importance of the follow up measurement in this population, since gait may change after training has been stopped. A six week follow up assessment will be included to accurately conclude the long term effectiveness of our training on participants' gait.

The study by Cakit et al., (2007) assessed the treadmill walking distance (m) and the walking speed (km/h) at both baseline and after the eight week program. Findings reported that the walking distance of the trained group significantly increased from 266.45 (±82.14) to 726.36 (±93.1) m after the sixteenth and final training session (p<0.01) (Cakit et al., 2007). Similarly, the maximum tolerated treadmill walking speed also significantly increased after the training sessions from 1.9 (±0.75) to 2.61 (±0.77) km/h ($p<0.01$) (Cakit et al., 2007). These results encourage the use of the treadmill training in PD. However, an evident limitation was the inclusion of the maximum tolerated treadmill speed measurement. This outcome was undoubtedly research specific, given that the personal benefit would be limited in most PD participants because they would be unable or it would be unsafe to train at their maximum pace. The benefit attained from this outcome is uncertain and the current study will therefore focus on gait measurements that are also feasible in a practical application for this population. Therefore the relative differences that exist for gait velocity and step length will be included to best assess the observed changes in gait.

In the study by Fisher et al., (2008) the participants' were required to walk for 10 m at both the self selected gait speed and quickly at both baseline and immediately after 8 weeks of training. At each assessment, participants' walked for three trials in each condition that were then averaged. Gait parameters that were assessed included the average gait velocity (m/s), step length, cadence (steps/min) and cadence (number of steps/min). Results reported that the most consistent improvements the gait parameters were found only for the high intensity trained participants. Their observed gait improvements for the self selected condition included an increased gait speed, stride length and step length after the 24 sessions by 4.4%, 4.7% and 5.8%, respectively (Fisher et al., 2008). Additionally, improvements found in the fast velocity condition included increased stride and step lengths by 4.8% and 5.6%, respectively (Fisher et al., 2008). If statistical analysis was completed, the observed changes would have provided the necessary information to establish the anticipated differences at such training intensities. The current study will statistically analyze our participants' gait parameters to provide greater certainty for any group differences that are found.

## 2.8 Prologue Summary Table

| Author | Participants | Type of Training | Training: F/D/I | Outcomes | Results |
|---|---|---|---|---|---|
| Ashburn, (2007). | 142 | Home Based | 24 weeks/1*week/I:T | Falling Rates, Fxnal Reach, Euro QOL | ↓Fall Rate: 8 weeks & 6 months, ↑Fxnal Reach & QOI |
| Nieuwboer, (2006) | 153 | Home Based-Cueing | 3 weeks/9 sessions/30 minutes | P-G Score, Gait Speed, Step length | ↓P-G Score, ↑ Gait Speed & Step length |
| Calgar, (2005) | 30 | Home Based | 8 weeks/Daily/10 sets, 3*daily | 10 & 20 m walk, Time around chair | ↓10&20m times |
| Lun, (2005) | 19 | Home Based | 8 weeks/2*week/1hr | MSS-UPDRS | ↓MSS |
| Hurwitz, A. (1989) | 29 | Home Based | 32 weeks/daily | Rigidity | ↓Rigidity Right Arm |
| Dibble (2006) | 29 | Resistance-High Intensity | 12 weeks/3* week/46-60 minutes/Borg RPE | Mobility, Muscle volume: More/Less affected limb | ↑ mobility & muscle volume both limbs |
| Dibble (2006) | 10 | Resistance-Max Strength | 12 weeks/3* week/5 sec max contractions | Max isometric quad strength, 6 minute walk, stair accent/descent | ↑ quad strength, Eccentric: ↑ distance 6 min, ↓stair times |
| Hass(2007) | 20 | Resistance-endurance | 9 exercises/1 set: 8-12 reps | # Reps/Failure, Leg extension | ↑Strength leg ex, ↑ endurance: both grou |
| Hirsch (2003) | 15 | Resistance-Balance | 3 weeks/30 minutes/12 reps*4 maximal | Weight Lifted, SOT test | ↑ Weight lifted and SOT/combined grou |
| Carne (2005) | 49 | Multidisciplinary-PADRECC | 1-3 yrs total duration/I:T | MSS-UPDRS, gait: computerized posturography | ↓MSS, no gait differences responders/non |
| Patti (1996) | 28 | Multidisciplinary | 4 weeks/I:T | MSS-UPDRS, speed ambulation, amplitude step, | ↓MSS, ↑ speed & amplitude |
| Comella (1994) | 19 | Multidisciplinary | 4 weeks/3*week/60 mins-69 exercises | MSS-UPDRS | ↓MSS |
| Schenkman (2007) | 51 | Goal Specific-flexibility | 10 weeks/3*week/30-45 minutes | MSS-Duke U scale, 6 min, 10m | MSS not reported, n change 6 min &10 n |
| Farley (2005) | 18 | Goal Specific-amplitude training | 4 weeks/4*week/I:T | V, SdL, C: preferred & fast | ↑SdL & V: preferred, ↑SdL: fast |
| Schalow (2004) | 8 | Goal Specific-coordination dynamics | 10 weeks/4 hrs week/20 minutes/I:T | Forward/Backward turning | 62% ↑ Turning, Remaining ↓ |
| Jobges (2004) | 14 | Goal Specific-balance | 10 days, twice/daily, 20 minutes/I:T | SpL, V | ↑SpL&V immediatel |
| Pendersen (1990) | 10 | Goal Specific-gait | 12 weeks/twice weekly/60 minutes/I:T | 10m:SF,SdL, V | ↑SdL&V |
| Mitchell | 7 | Goal Specific- | 8 weeks/1 week/60 | MSS- | ↓PFAT, no change |

| | | | | | |
|---|---|---|---|---|---|
| (1987) | | flexibility | minutes/<METs: walking | PFAT:Columbia U scale, PPFS | PPFS |
| Reuter (1999) | 15 PD/15 HC | Cycle Ergometry | Test: 25W:↑25W/4 mins until 150W. | HR, workload attained | PD: all- 75W 12-100W, 7-125 & 150V HR: similar to HC |
| Stanley (1999) | 20 PD/23 HC | Cycle Ergometry | Test: 20W, 50 RPM: ↑20 W/2 mins | Peak HR, RER, Vo2/kg | PD: Max Vo2/ for M or F. Gender Analys no Diffs PD M to MH( or PD F to FH |
| Canning (1997) | 16 PD/HC 'ranges' | Cycle Ergometry | Test: 20W 50-60 RPM: ↑10,20 or 30 W/min until max (total time: 12 mins) | Peak HR RER, Vo2, 10 m walk: V & SdL | PD: Peak Vo no Diff HC; M V no diff th avg, fast V diff the avg. M StL < predicted |
| Protas(1996) | 8 PD/7 HC | Cycle Ergometry | Test: 40W then ↑20 W/2 mins until peak | Peak HR, RER, Vo2 | PD: Peak HF RER, Vo2: No Diff HC |
| Landin (1974) | 6 male/HC | Cycle Ergometry | Tolerance: 33, 67, 98W Test: 40 min | HR: (5, 10, 15, 20, 30, 40 mins); Vo2 & RER: Rest & 10 & 40 mins | PD: > HR rest exercise @ = workloads the HC; PD < Vo2 at e exercise the HC; PD RER > during Ex |
| Fisher (2008) | 30 | Treadmill | 8 weeks/3* week/45 mins | MSS: UPDRS; Gait: 10m walk: V, StpL, C | Gait: Self selec ↑ speed, Stpl Fast conditio ↑StpL |
| Cakit (2007) | 31 | Treadmill | 8 weeks/2* week/30 mins | MSS: UPDRS; Gait distance (m), speed (km/h) | Correlations +ve: MSS with histo ve: MSS with B DGI; Gait: ↑ distance speed |
| Herman (2007) | 9 | Treadmill | 6 weeks/4* week/30 mins | MSS: UPDRS; Gait speed (m/s), StdL (m), StrTV (%) | ↓MSS immediately/follow ↑Speed |
| Pohl (2003) | 17 | Treadmill | Evaulated: 3 Training/30 mins: SSD, LPT, CGT & Control | Gait speed (m/s), StdL (m) | SSD: ↑Speed & Stc ↑speed and St CGT & Contr No change |

| | | | | | |
|---|---|---|---|---|---|
| | | | internvetion/4 days | | |
| Miyai (2002) | 24 | Treadmill-Training | 4 weeks/3*week/45 mins: BWSTT or PT | MSS: UPDRS; Gait speed (sec/10m) & # steps (steps/10m) | No diff MSS; ↑speed/↓ # steps after BSWTT |
| Miyai (2000) | 10 | Treadmill-Training | 4 weeks/3*week/45 mins crossover: BWSTT & PT | MSS: UPDRS; Gait:endurance (m), speed (sec/10m), # steps (steps/10m) | BSWTT > PT: ↓MSS; ↑speed/↓# steps. Ga endurance not differ |

### 2.8.1 Prologue Summary Table Codes

↑- Increase ↓-Decrease
M-Mean
Avg-average
W-watt
MSS-Motor symptom severity
I:T-Intensity Individually Tailored
HC-Age matched Healthy Control
C-Cadence
SF-Stride Frequency
SpL-Step Length
V-velocity
SdL-Stride Length
StrTV-Stride Time Variability
HR-Heart Rate
Vo2-Oxygen consumption
PFAT-Parkinson's functional Assessment Tool
PPFS-Parkinson's Perception of Function scale
UPDRS-Unified Parkinson's disease Rating Scale
PT-Physiotherapy
BWSTT: Body weight Supported Treadmill Training
SSD-Structured Speed-Dependent
LPT-Limited Progressive Training
CGT-Conventional Gait Therapy
DGI: Dynamic Gait Index
BBT: Berg Balance Test

## 2.9 A Basis for the Current Study

The aerobic BioDex BioStep® study completed at the Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University provided incentive to further investigate the affect of aerobic exercise interventions in this population. The responses to this program suggested that the coordination of the limbs with a more rigorous protocol was required. It was determined that it is necessary to specifically target the gait disturbances observed in PD. Prior to the detailed description of the current exercise design, the purpose, hypothesis and conclusions from our previous aerobic study will be discussed.

### 2.9.1 Purpose of BioDex BioStep® Research

Previous aerobic exercise research that has been completed in the PD population has typically involved the use of bicycle ergometers. A benefit of this research includes that the workloads achieved were clearly outlined. The use of the largest muscle group in the body had logically provided adequate aerobic responses to this exercise. Overall, the capabilities of this population were underestimated because higher workloads were attained then expected in PD. Since then, aerobic training research has evolved to incorporate both upper and lower limb coordination. Due to the impaired balance and stability experienced by this population, the ideal exercise might be one that involves sitting, for example on a semi-recumbent cycle ergometer. This seated full body workout incorporated both the upper and lower extremities and was thought to specifically target the impaired coordination in PD. The participants were seated, thus ensured the safety of the participant and since this exercise is aerobic in nature, the attained aerobic capacity and efficiency responses would also be gained.

The purpose of this study was to examine the effect of a 12 week all extremity aerobic exercise program. Specifically, individuals work capacity, which was determined by attainable workload and on oxygen consumption, which was determined by efficiency achieved at each workload was assessed. In particular, the work capacity of individuals was measured by the watt level achieved and by the rate of perceived exertion (RPE) measured by the Borg CR-10 Scale®. The variables of aerobic efficiency were determined through the measurement of oxygen consumption ($Vo_2$/kg), respiratory exchange ratio (gas exchange of oxygen consumption/carbon dioxide production) (RER) and heart rate (HR). This study included the aerobic responses of a sample of PD participants that ranged from mild to moderate disease severity and additionally aimed to determine whether motor symptom severity would be influenced from this form of aerobic exercise. Each participant's motor symptom severity was assessed prior to the initiation of the training program and immediately after program completion.

### 2.9.2 Hypotheses of BioDex BioStep® Research

It was hypothesized after 12 weeks of exercise training, three times weekly for 30 minute sessions that individuals would be able to withstand higher watt levels after training. It was also expected that after individuals trained, the RPE would decrease while they became more comfortable with the protocol demands. It was hypothesized that the variables measuring aerobic efficiency would decrease because individuals' efficiency per kilogram of weight would improve through greater uptake, transport and utilization of oxygen. Decreased heart rate and blood pressure was also anticipated after 12 weeks of training because individuals would become more aerobically fit, thus able to sustain the protocol workload for a greater period of time. Lastly, it was hypothesized that the UPDRS motor symptom severity sub score would decrease after the BioDex BioStep® training. These results were anticipated since the required coordinated cyclical contra-lateral movements showed promise to help individuals with balance impairments for both unilateral and bilateral weaknesses. It was expected that if training would target impairments experienced in PD, then motor symptom severity may respond with improvements.

### 2.9.3 Findings of BioDex BioStep® Research

The BioDex BioStep® research findings indicated that aerobic efficiency significantly improved after training. A significant main effect was found for heart rate ($p=.045$) that suggests participants improved their efficiency after training. Further, a significant main effect found for oxygen consumption relative to body weight ($p=.0019$) also demonstrated improved efficiency through less oxygen utilized at post test for the same workloads of 20, 35 and 50 watts. A significant group by time interaction was also found for respiratory exchange ratio from pre to post test ($p=.049$). The response to the 20 watt warm up for the separately plotted pre-test and post-test group averages demonstrated the warm up was significantly lower at the post-test assessment. An important non significant finding was a lack of motor symptom severity improvement after training. It was speculated the lack of change was due to the intensity demands of the protocol that were not individually tailored (the maximum accomplished workload was 50 watts for all participants). Since our study did not specifically target the achievable intensity of training for each participant, it is concluded our protocol was not demanding enough. For future aerobic studies, the incorporation of personalized intensity goals may enhance individuals' aerobic capacity and efficiency improvements to a greater degree and thus may be required in order to show evidence of decreased motor symptom severities.

### 2.9.4 Future aerobic research & the use of visual cues

An innovative consideration for future aerobic studies is to include the utilization of visual feedback while walking to minimize the gait impairment experienced in PD. Previous studies have demonstrated that gait velocity and stride length can be normalized with the utilization of visual cues (Azulay et al., 1999, Bagley et al., 1997, Nieuwboer et al., 2007). The incorporation of visual feedback might therefore not only improve the spatio-temporal characteristics of PD gait but also potentially increase the intensity of exercise and benefits to cardio-respiratory function. An apparatus that has the potential to improve cardio-respiratory function and has shown to normalize PD gait is a treadmill (Cakit et al., 2007, Fisher et al., 2008, Herman et al., 2007, Pohl et al., 2003, Miyai et al., 2002, Miyai et al., 2000). However, PD treadmill training studies have not only omitted or been very selective with the cardio-respiratory responses attained, but is also limited by study length, small participant sample sizes and by the lack of blinded evaluators for symptom severity assessments. Furthermore, treadmill training studies have been limited since the combined strategies of this gait training tool with the incorporation of visual cues has yet to be studied. This thesis will therefore improve upon previous research designs. In particular, this thesis will provide the longest study duration of 12 weeks; the greatest sample size of 42 participants; include representative cardio-respiratory measurements; and will utilize a blind evaluator. Additionally, to advance research on the effectiveness of treadmill training in PD, this thesis will pioneer the inclusion of concurrent visual feedback during training. Specifically, the visual feedback will be individually tailored, such that the visual step targets will promote increased exercise intensity is attained.

Therefore, this thesis will evaluate the influence of treadmill training with and without the utilization of concurrent visual feedback on PD motor symptom severity, physiological efficiency and on spatio-temporal characteristics of gait. To ensure our treadmill training program was the best possible, this thesis included several unique components. First, this thesis has innovatively combined two previously successful gait training strategies into one intervention. The inclusion of concurrent visual feedback during treadmill training provided a simplistic however specific visual representation of each step taken during training. Thus, the dynamic nature of these visual cues provided these participants with simultaneous knowledge of performance that enabled corrections in their steps as required. Secondly, for all trained participants, this thesis included individually tailored protocols during both training and testing periods. Specifically, the training protocol incorporated the participants' comfortable, self selected walking speed. To encourage a progressive increase in exercise intensity, small speed increments of 0.2 km/h were utilized rather then large 0.5 km/h or greater that have been limiting in previous PD treadmill studies. Overall, personalized training goals for continuous exercise were integrated while encouraging independent walking, thus without the reliance on harnesses.

The goal of this thesis was to provide a comprehensive evaluation of PD responses after treadmill training, both with and without the inclusion of concurrent visual feedback. The purpose of this thesis is aimed at determining whether utilizing a novel treadmill training intervention is an effective rehabilitative strategy for PD.

### 2.9.5 Primary Research Questions

1. Does treadmill training benefit PD motor symptom severity? Do differences exist in the motor symptom severity responses of those participants that were provided with additional concurrent visual feedback during treadmill training? What are the longer-termed motor symptom severity responses of all participants when evaluated six weeks after the completion of our treadmill training program?

2. Does treadmill training improve aerobic efficiency and capacity in the PD population? Do aerobic responses differ in the group that trained with additional concurrent visual feedback? What are the longer-termed aerobic responses of all participants when evaluated six weeks after the completion of our treadmill training program?

3. Does treadmill training benefit the spatio-temporal characteristics of PD gait, specifically gait velocity and step length of the most affected side? Do differences in the evaluated spatio-temporal aspects of gait exist in the group that was provided with additional concurrent visual feedback during training? What are the longer-termed responses of the evaluated spatio-temporal gait characteristics for all participants six weeks after the completion of our treadmill training program?

### 2.9.6 Primary Research Hypotheses

1. Motor symptom severity scores will improve (decrease) for all treadmill trained participants although, greater improvements will be found for the visual group immediately after training. Six weeks after the completion of training it is expected that all participants' motor symptom severity scores will revert back towards baseline scores.

2. Aerobic efficiency is expected to improve in both groups immediately after training. It is anticipated that relative to the same workloads, oxygen consumption relative to body weight, respiratory exchange ratio and heart rate will decrease in both groups immediately post training. It is further anticipated that greater differences in efficiency will exist for the visual group relative to the control group. It is expected that the efficiency improvements in both groups immediately post training will revert back to baseline values.

3. It is anticipated that the spatio-temporal characteristics of gait will improve immediately after training relative to pre-test. Specifically it is anticipated that longer step lengths and faster velocities for both groups although, it is anticipated that the visual group to demonstrate greater changes relative to the control group immediately after training. The anticipated improvements for both groups are then expected to revert back towards baseline after six weeks without treadmill training relative to the attained improvements at post-test.

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# Chapter 3: The Influence of Concurrent Visual Feedback during Treadmill Training in Parkinson's disease

## 3.1 Abstract

Research has shown individuals with Parkinson's disease (PD) that train with visual cues can exhibit short-term gait improvements (Azulay et al., 1999; Bagley et al., 1997; Nieuwboer et al., 2007). The purpose of our study was to determine the short and long-term effects of concurrent visual feedback on PD gait while participants trained on a treadmill. Specifically, two groups were compared; one group trained with concurrent visual feedback through the use of step cues, while the other group trained without visual cues. Forty-two participants were recruited from the Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University and trained for 12 weeks, three times weekly, for 26 minute sessions. Twenty-three participants (69.3 (±8.5) yrs, 180.9 (±29.7) kg, 7 female) completed training with concurrent visual feedback and nineteen participants (66.4 (±9.2) yrs, 168.9 (±37.5) kg, 9 female) completed regular, non-cued training. The GaitRITE® carpet measured step length and gait velocity while Polar heart rate monitors and the Exp'Air® Metabolic software captured physiological responses. Motor symptom severity was evaluated with the Unified Parkinson's disease Rating Scale. There were three assessment periods: the first at baseline, the second after 12 weeks and the third was six weeks after the program was completed. Both groups' post-test showed decreased heart rate ($p<0.0009$) and $Vo_2$/kg ($p<0.012$) at any incline workloads and increased step length ($<0.045$) and velocity ($p<0.027$) thereby confirming the training effectiveness of the treadmill training. However, the UPDRS

measurement deteriorated immediately after training. At six weeks post training the group that trained with concurrent visual feedback lost most improvements where the regular, non-cued training group maintained most.

**Key Words**: Parkinson's disease – Treadmill training –Visual Feedback

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## 3.2 Introduction

Parkinson's disease (PD) is a neurodegenerative disorder, in which the progressive loss of dopamine producing substantia nigra neurons results in movement impairments (Palmer et al., 1986). Particularly devastating is the deterioration of gait experienced presented by difficulty with gait initiation and termination, shortened step length, maintenance of gait speed and coordination of upper and lower limb movement. Strategies to improve gait included the use of visual cues that have provided normalized gait initiation, step length and gait speed (Azulay et al., 1999; Bagley et al., 1997; Nieuwboer et al., 2007). However, visual cues in everyday environments are not practical and therefore alternative methods to incorporate the benefit of visual cues into daily life are required. Improved gait training techniques are necessary since the experienced gait disturbances lead to increased instability thus the risk for falls in PD (Ashburn et al., 2006; Bloem et al., 2001; Boelen et al., 2007; Hely et al., 1999; Jobges et al., 2004; Lun et al., 2005; Wood et al., 2002). Thus the process of disease progression that includes slowed and inconsistent movement with additional increased risks of injury inevitably deprives individuals of their physical independence. This inactivity further deteriorates individuals' physical condition (Bergen et al., 2002) beyond that which is typically experienced immediately after diagnosis (Fertl et al., 1993; Saleem et al., 2005). Therefore, rehabilitative strategies must develop methods that enhance the motivation for increased physical activity and fitness in this population while specifically targeting the gait disturbances experienced. In particular, rehabilitation that combines gait specific strategies together with an aerobic component will target both the gait disturbances and deterioration of cardio-respiratory fitness and thus is under continued investigation.

Benefits offered from aerobic exercise include improved respiratory and cardiac function (Kluding et al., 2006), thus physically activity may provide improved cardio-respiratory fitness (Bridgewater et al., 1996; Nieuwboer et al., 2007). Additionally, aerobic exercise may also promote brain plasticity. Previous animal research has suggested that aerobic exercise provides increased levels of trophic factors, molecules that support neuron growth and survival (Woodlee et al., 2006). In rodent treadmill study it was demonstrated that exercised mice had increased blood calcium levels that in turn increased dopamine synthesis in the brain. These results suggested treadmill exercise can possibly lead to modifications in brain function (Sutoo et al., 2003). However, a human based study by Sage et al., (2009) showed that aerobic exercise did not influence motor symptom severity scores immediately after the 12-week study period and six weeks later (Sage et al., 2009). However, the remaining uncertainty is whether human treadmill training studies have adequately trained individuals with PD to assert whether this form of training can provide benefit.

PD treadmill training literature has been limited in the documentation of the subsequent physiological responses that occur. However, in one study by Werner et al.,

(2006) the sub-maximal and peak responses of PD participants' vital signs were tested during a Modified Bruce Protocol and were compared to healthy age matched controls. These authors found that only half of the PD participants could attain peak exercise and no difference was found when they were compared to healthy aged-matched controls (Werner et al., 2006). These findings are indicative that most individuals with PD are capable of sub maximal exercise on a treadmill, while only some are capable of reaching maximal physiological response via treadmill exercise. Interestingly, PD $Vo_2$/kg responses have not yet been reported in treadmill literature thus, a comprehensive evaluation that includes the physiological responses before and after treadmill training is required.

Treadmill training has primarily been considered a beneficial rehabilitative strategy for gait training in PD (Cakit et al., 2007; Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000; Miyai et al., 2002; Pohl et al., 2003). Specifically after treadmill training, gait improvements have included increased gait speed (Cakit et al., 2007; Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000; Miyai et al., 2002; Pohl et al., 2003) and larger stride lengths (Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000; Pohl et al., 2003). Since treadmill training can benefit PD gait, the question remains whether this rehabilitative strategy can benefit PD motor symptom severity.

Improved (decreased) motor symptom severity scores have been found after treadmill training although, reported only by few (Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000). However, the study by Fisher et al, (2008) did not statistically analyze their recorded motor symptom severity scores and thus their assertion for improvements is not supported. This study did however prompt the necessity that any increase in exercise intensity be regulated. The authors Fisher et al., (2008) had raised the exercise intensity by several options that included decreased amounts of body weight support or physical assistance or through increased treadmill belt speeds or the total time they exercised in no particular order. Greater regulation for exercise intensity progression would be achieved through a particular sequence utilized. For example, the removal of the body weight support or physical assistance would be the first logical goal for appropriate exercise intensity progression. Next, an increased duration of continuous exercise would be a suitable and then followed by increased speed utilized while training. The current training program will therefore incorporate these predetermined sequences to ensure exercise intensity progression occurs in the same manner for all participants.

Consequently without the statistical analysis of motor symptom severity in the previously mentioned study, the established effectiveness of treadmill training is presently reported from two alternate studies (Herman et al., 2007, Miyai et al., 2000). The improvements found may be in response to these individually tailored protocols. For instance, these protocols utilized the participants' comfortable walking speed with additional and progressively increased speeds according to the participants' ability. However, the maximum speed limits set to 3 km/hr (Miyai et al., 2000) and the initiation of training at 80% and 90% of the participants comfortable walking pace (Herman et al., 2007) may have decreased the participants' self-sufficiency and thus limited the improvements demonstrated. Of interest to note was that in both of these studies the utilization of a blind examiner was not reported. The current study will improve upon these past studies as an individually tailored training protocol that incorporates progressively increased treadmill belt speeds from training initiation will be provided without a maximum speed restriction. It was also determined that a blind examiner is essential for the evaluation of the motor symptom severity change to verify whether similar improvements are found to those previously documented.

Similarly, to develop the most effective treadmill training protocol, the consideration of flaws from previous study protocols is necessary. A major flaw from previous training protocols was the minimized possibility for cardio-respiratory endurance gains. Examples include the incorporation of non-weight bearing (Herman et al., 2007; Pohl et al., 2003) and weight bearing harnesses (Miyai et al., 2000; Miyai et al., 2002), mandatory rest periods within training (Fisher, 2008; Miyai et al., 2000; Miyai et al., 2002) and short training durations of six weeks or less (Herman et al., 2007; Miyai et al., 2000; Miyai et al., 2002; Pohl et al., 2003). These factors all contribute to a reduction in the intensity of exercise achieved, thus the possibility for cardio-respiratory gains within such a limited time frame. Further, given that most treadmill training studies have primarily focused on gait they have failed to measure (Cakit et al., 2007; Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000; Miyai et al., 2002) or report (Fisher et al., 2008; Pohl et al., 2003) on the aerobic responses of the studied participants. The current study will improve upon past training protocols by encouraging independent walking, thus without the use of body weight support. The exercise intensity will be dependent upon the participants' ability and will be continually evaluated. Further, the training duration will extend beyond the current standard of 8 weeks (Cakit et al., 2007; Fisher et al., 2008). Finally, an innovative adaptation will integrate concurrent visual feedback with treadmill training.

The purpose of this study was to determine whether the concurrent visual feedback generated greater aerobic and gait responses in comparison to regular, non-cued treadmill training. Furthermore, our study aimed to verify if improvements in the motor symptom severity of the sample studied were found over the 12 week training duration.

## 3.3 Methods

### 3.3.1 Participants

Fifty-two participants with PD were recruited from the Movement Disorders Research and Rehabilitation Centre's (MDRC) database at Wilfrid Laurier University. The testing and training components and requirements of the intensity, duration and frequency of the program were outlined. Participants were required to treadmill train 3 times a week for 12 weeks. Each treadmill session took twenty-six minutes where warm up and cool down was determined by the participants self-selected comfortable walking pace. To be considered eligible, interested participants were required to be capable of independently ambulating and were comfortable walking on a motorized treadmill, regardless of the documented disease severity stage. Termination of training occurred if participants missed more then three consecutive sessions or over five sessions in total. Participants were excluded if they had known medical conditions that included but were not limited to uncontrollable blood pressure or diabetes, previous cardiac complications, asthma, or other co-morbidities made worse by exercise. All participants were asked to seek permission from their family physicians prior to participation.

There was a total of 42 participants that completed their respective training programs, (n=19) completed control training and (n=23) completed the visual cued training. Across all program locations a total 10 participants withdrew at various times. Relevant reasoning for the discontinuation of the program included wait-listed operations (n=1), severe joint pain (n=3), recommendation from family doctors (n=2), lack of incentive or personal obligations (n=4). Recruited PD participants were randomly divided into treatment or control groups dependent upon the ease of training location and time of allotted training sessions. There were three locations utilized for treadmill training that included the MDRC and two local YMCA's. The control group was subdivided into three training groups where four participants completed training at the Kitchener YMCA, seven completed training at the Cambridge YMCA and the remaining eight completed training at the MDRC location. The Research Ethics Board at Wilfrid Laurier University approved the study. All participants agreed to and completed an informed consent document.

The descriptive statistics of the sample studied are reported by the mean ± standard deviation. The sample was characterized with respect to age, gender, height, weight, UPDRS motor score, and medication use and treadmill handrail holding (Table 1). The three assessment periods incorporated included pre-test, prior to training initiation, post-test, after training was completed and six weeks post training.

### 3.3.2 Procedures

**Pre and Post and Six weeks post training Assessment Protocol**

All participants were familiarized with the testing procedures prior to data collection. Motor symptom severity of participants was rated utilizing the Unified Parkinson's disease rating scale (UPDRS) by two qualified and blinded evaluators. To validate each examination, the evaluator examined the same participants over each assessment period. Each participant was also required to complete a questionnaire from the UPDRS I-II subsections. A gait velocity and step length of the most affected was measured over five trials completed by each participant by use of GaitRITE® carpet. Participants were asked to walk at their comfortable walking pace for the consecutive trials at each assessment. The average velocity of the pre-test trials was calculated and utilized for the self selected pace for the treadmill testing at the three assessment periods. Weight and height measurements obtained were recorded. Prior to initiation of this test, individuals were strapped with a dampened Polar® Heart Rate monitor chest strap and corresponding wristwatch. A mesh headpiece attached to a mask was placed on each participant that covered the mouth and nose to capture ventilation. Prior to treadmill testing with a consistent protocol to evaluate the aerobic measures, the participant data and ambient conditions (test room barometric pressure, relative humidity and temperature) was entered into the Exp'Air® Software. Calibration of the Medisoft® metabolic cart was completed using a 3 L syringe and a cylinder of mixed gases ($O_2$ =16%, $CO_2$ = 0.03%). Prior to test initiation, the appropriate treadmill protocol adjustment for comfortable walking speed for each participant was input into the predetermined treadmill protocol. To control for possible variation in efficiency response, all participants were required to hold handrails if they did so at pre-test.

The testing protocol incorporated previous aspects of previous treadmill protocols with additional consideration of the impaired gait experienced in the PD population. The current protocol incorporated five-minutes of warm up and cool down that occurred at 0% incline. Once prepared, each participant warmed up for 1 minute at 1.61 km/h, another minute at 2.41 km/h and then increased to the comfortable walking speed for three additional minutes. The initialized speeds aimed to familiarize the participants with the motorized treadmill where the small speed increments were adapted from the Naughton Treadmill Protocol (Naughton et al., 1973). The remaining stages were three minutes in duration adopted from the recommendations by the ACSM treadmill guidelines, which occurred at the comfortable walking pace of the individual (Balady et al., 2005). The continuous three-minute treadmill stages utilized were adopted from the Bruce Protocol (Bruce, 1971). The consistent treadmill belt velocity utilized was adopted from the Balke Protocol (Balke et al., 1959). Treadmill incline increased per 3-minute stage in order to establish the steady state HR, $Vo_2$ and RER responses at each stage. These variables are commonly utilized for exercise monitoring and prescription and thus were deemed appropriate (Balady et al., 2005). Percent incline of the treadmill changed according to each stage. To increase intensity the treadmill workloads first stage rose from ground level to 1% incline (0.9° ) the second to 3% incline (2.7° ) , the third to 5% incline (4.5° ), the fourth to 6% incline (5.4° ), the fifth to 7% incline (6.3° ), the sixth to 8 % incline (7.2° ), the seventh to 9% incline (8.1° ) (Appendix 1: Testing protocol). The desired sub maximal exercise intensity goal was greater then 65% but no higher then 85% of the participants' maximum heart rate utilizing the revised age-predicted heart rate regression equation (Tanaka et al., 2001). During testing HR was also recorded at each stage steady state, determined in the last 30 seconds of each stage. Once participants reached 85% HR or volitional fatigue, the 5-minute cool down at zero percent incline began. Again, 3 minutes was completed at the comfortable walking speed, then 1 minute at 1.61 km/h, then 1 minute at 2.41 km/h. For the three testing periods, each participant was scheduled and assessed at the same time of day to ensure consistency testing and corresponding medication dosage. All participants that used medication were asked to continue their schedule of normal intake. Further, as the evaluation at six weeks post training was an assessment to determine the carry over effects from our program, participants were requested to maintain the same exercises (if any) that were completed throughout the duration of our training. It was requested that participants avoided the introduction of any new physical activities immediately following our program until their six week post training assessment.

**Training Protocol**

This protocol was individually tailored such that each participant was encouraged to attain their personal best throughout training. No participant would be required to complete an intensity that was not deemed comfortable, thus this personalized approach was applicable to all participants. The same scheduled training times were assigned to each participant over the 36 sessions. Upon arrival, attendance was taken and participants were strapped with dampened Polar® HR chest strap monitor and corresponding wristwatch. Participants allotted to the visual cued group had their demographic information input into the BioDex GaitTrainer® where the step length was calculated in order to provide individualized visual step cue targets while training. Participants' step lengths were recorded for the following sessions. Prior to initiation, all participants positioned themselves on the treadmill (depending on comfort either standing directly on the belt or on the side panels) prior to initiating each session.

The comfortable walking paces of each individual were used in the five minutes of both warm up and cool down. Participants trained with no increases in incline, but instead were encouraged to increase the belt speed in small increments (minimum of 0.2 km/h) from their comfortable walking speed (Appendix 2: Training protocol). Granted the goal to complete the entire 26-minute protocol was attained, participants could then increase their belt speed at each stage. To promote a progressively increased belt speed a simple rule was incorporated. The rule stated that the belt speed attained at the second stage of training would become the speed for first stage of training at the next session. This way, participants would continuously increase their belt speed for each training session in accordance with their own ability. With this rule, each individual trained at various belt velocities in attempts to attain their personal best. Once participants attained their personal best velocity, they continued training at this speed for the remaining sessions. At the end of each treadmill stage participants HR was recorded. Once the four-4 minute stages were completed, the individual began cool down. Five minutes at the comfortable walking pace was used. Any participant that required assistance or was uncomfortable with the training for any reason had a spotter allotted to them for the duration of the session.

During the training there was a period of time whereby the training times between the groups had overlapped or crossed-over. There were therefore a few participants that had the opportunity to observe the differences in the training protocols as evident by the differences in the footfall screen that presented the concurrent visual feedback. Furthermore, communication between the groups was not controlled for during this overlapped time or outside the laboratory. The differences that existed between the two types of training and the potential value of added visual step cues could therefore have been discussed. There is therefore a chance that participants in the regular, non-cued program may have developed their own method of visual step cues in their home, or paid greater attention to environmental step cues during the training period. Such external influences may have affected our results since instructions to prevent this were not provided.

Finally, as the six weeks post training evaluation aimed to determine the carry over effects from our program, each participant was requested to continue the same exercises (if any) that were completed throughout the duration of our training. It was requested that participants avoided the introduction of any new physical activities immediately following our program until their six week post training assessment.

### 3.3.3 Table 1: Baseline characteristics of the sample studied

**Table 1: Data presented with means (±SD).**

| Groups | Control | Visual |
|---|---|---|
| Total | n=19 | n=23 |
| Gender | 10 M, 9 F | 16 M, 7 F |
| Age | 66.4 (±9.19) | 69.34 (±8.47) |
| Height (cm) | 163.58 (±14.06) | 167.77 (±14.4) |
| Weight (kg) | 168.92 (±37.5) | 180.95 (±29.7) |
| UPDRSm | 30.11 (±11.24) | 28.30 (±28.09) |
| Medication | 2-no medication | 3-no medication |
| Handrail Holding | 16 Holding | 19 Holding |

UPDRSm: Motor sub-score of the Unified Parkinson's disease rating scale

## 3.4 Statistical Analysis

**Baseline Comparison**

A baseline comparison of gait, physiological and UPDRS variables was conducted to determine whether statistical differences existed between the two groups. A repeated measures analysis of variance (ANOVA) was performed. Pre-test HR, $Vo_2$/kg, averaged step length and velocity, UPDRS motor symptom severity scores and averaged gait scores were compared to determine whether homogeneity of groups existed prior to the initiation treadmill training.

**Physiologic Variables**

The pre-test HR and $Vo_2$/kg samples were attained in the first thirty seconds of the treadmill test since all participants walked at a constant velocity of 1.41 km/h at 0% incline.

**Kinematics Variables**

Gait variables included step length of the more affected side and velocity. The utilization of the first of five total trials of the GaitRITE® pre-test was analyzed for the baseline measure.

**UPDRS**

Assessments included the motor sub section of the UPDRS. The gait components of the gait score consisted of the score for the left and right leg, arising from a chair, posture and gait and body bradykinesia.

**Specified Analysis**

The within-subjects design of the treadmill training program required that participants were analyzed relative to their own performance. Statistical analyses therefore incorporated various ANOVAs dependent on the variable under investigation. Each statistically significant finding was presented along with Tukey's honest significant difference (HSD) post hoc for unequal sample sizes. All data is presented with means (± SD). For all variables a repeated-measures ANOVA was performed with the constant factors of group (Control and Visual) × time (Pre-test, Post-test and Six weeks Post training). The additional condition/trial factor that was included in each analysis is outlined:

Physiologic Variables of HR, $Vo_2kg$& RER

× Trials (7 inclined treadmill stages).

Calculation of Absolute data to Relative % Change for HR & $Vo_2/kg$

Each participant was tested at different intensities due to the individualized comfortable walking velocities utilized during the treadmill assessments. Thus, since workload attainment was dependent upon each participant's ability and the absolute values would not have provided meaningful information, the HR and $Vo_2$ data required standardization. The calculation of the difference in each participant's relative performance was needed to best represent the change across the assessment periods. To do so, a percent change was calculated from the steady state values at each inclined stage for all three assessment period comparisons. The assessment period comparisons included the observed change from Post-test to Pre-test, from Six weeks post training to Post-test and from Six weeks post training to Pre-test. For each participant, percent change was calculated (post-test value- pre-test value)/pre-test value × 100.

Analysis for % Change by Group, Assessment Period & Inclined Stages for HR & $Vo_2$/kg

Across the assessment period comparisons the completion rates for the seven inclined treadmill stages varied. These variations prompted an analysis to include only participants who successfully completed the steady state requirements for all seven inclined stages. This analysis was necessary in order to represent the participant's successful completion of our treadmill test protocol.

For participants that completed all treadmill inclined stages a repeated measures ANOVA evaluated the group (Control & Visual that completed all inclines) × time (Pre-test, Post-test & Six weeks post training) × trial (7 inclined stages). Additionally, for a closer examination of differences in a variable population of PD participants, a planned comparison allowed us to analyze the assessment periods separately (Pre-test to Post-test, Post-test to Six weeks post training and Six weeks post training to Pre-test).

Since all participants were unable to complete all inclined stages, in order to incorporate all participants' responses it was also necessary to standardize the data according to each inclined workload. Repeated measures ANOVAs were completed for group (Control and Visual) × time (Post-test – Pre-test, Six weeks Post training – Post-test, Six weeks Post training – Pre-test) × incline (1%), (3%), (5%), (6%), (7%), (8%) and (9%) separately. The assessment period with the smaller sample size determined the participants who were included in analysis. For example, if fewer participants completed pre-test then post-test, the participants that completed the pre-test would then be compared at post-test.

Kinematics Variables: Step Length & Velocity

× Trials (5 GaitRITE® trials)

*Where required, ANOVAs were also performed with only two assessment periods*

Baseline Comparison between Visual and Control Groups

It was determined that the control and visual groups were statistically homogeneous from baseline for all measures, except for the mean velocity that was faster in the control group (Table 2).

## 3.5 Results

### 3.5.1 Table 2: Baseline Comparison between Control and Visual groups

**Table 2: Data presented with mean (± SD).**

| Groups | Control | Visual | |
|---|---|---|---|
| Pre-test Measure | Mean (±SD) | | Significance |
| Heart Rate (bpm) | 80.47 (±13.38) | 85.04 (±12.63) | N/S |
| $Vo_2$/kg (ml/min/kg) | 7.93 (±1.92) | 7.01 (±1.66) | N/S |
| Mean Step Length (cm) | 57.24 (±10.59) | 53.49 (±13.64) | N/S |
| Mean Velocity (km/h) | 4.10 (±0.75) | 3.69 (±0.95) | $p<0.0002$ |
| Testing Velocity (km/h) | 3.68 (±0.99) | 3.53 (±0.82) | N/S |
| UPDRS Motor score | 30.11 (±11.24) | 28.30 (±10.08) | N/S |
| UPDRS Gait Score | 5.25 (±3.08) | 6.14 (±4.06) | N/S |

*Mean Velocity: Average of 5 Pre-test GaitRITE® trials

*Testing Velocity: Average of Pre-test comfortable walking speeds

**Cardio-respiratory Measures:**

**Heart Rate Data (beats per minute)**

When both groups heart rates were combined for all inclined treadmill stages across the three assessment periods, a significant main effect of assessment time was found ($F_{(2, 32)} = 13.69$; $p<0.0001$). Post hoc analysis revealed that the absolute heart rates for all inclined treadmill stages reduced across all workloads in post-test, compared to pre-test ($p<0.0009$). Also, heart rate remained lower at six weeks post training, compared to pre-test ($p<0.0001$). It was observed that reduced heart rate responses occurred at post-test for both groups, where only the visual groups' heart rate was lower at six weeks post training. The heart rate means observed over the three assessment periods for the control group was (120.85 (±15.94), 113.14 (±16.5), 113.4 (±16.45)) and for the visual group were (112.13 (±17.57), 103.46 (±13.67), 99.64 (±12.26)) (Table 3).

### 3.5.2 Table 3: Absolute Heart Rate Responses for Control and Visual groups combined at Pre-test, Post-test and Six weeks Post training

**Table 3: Data presented with mean (± SD).**

| **Assessment** | **Groups** Control | Visual | Combined | **Significance** |
|---|---|---|---|---|
| Pre-test | 120.86 (±15.94) | 112.13 (±17.57) | 116.49 (±16.75) | Pre-Post: p=0.00094 |
| Post-test | 113.14 (±16.5) | 103.46 (±13.67) | 108.3 (±15.09) | Post-Six: p=0.66 |
| Six weeks Post | 113.43 (±16.45) | 99.64 (±12.26) | 106.54 (± 14.36) | Six-Pre: p=0.00018 |

**Heart Rate: Analysis of % Change**

To represent the relative change per individual, analysis of the differences in the relative performances for each individual involved the standardization of absolute data into percent change. All participants who completed all inclined stages were included in this analysis. In the pre-test to post-test comparison a significant main effect of group was found ($F_{(1, 20)} = 18.77$; $p<0.0003$). Similarly, from post-test to six weeks post training a main effect of group was found ($F_{(1, 27)} = 5.94$; $p<0.022$). This demonstrated that across the collapsed inclined treadmill stages, relative to the control group, the visual group had greater reductions in percent change.

These findings prompted the analysis of only the participants that completed all the inclined treadmill stages to demonstrate the responses of participants that successfully completed the ramp protocol. A significant main effect of group was found from pre-test to post-test ($F_{(1, 19)} = 21.00$; $p<0.0002$). Similarly, from post-test to six weeks post training a main effect of group was found ($F_{(1, 20)} = 4.89$; $p<0.039$). These findings established that relative to the control group, the visual group heart rate percent change reductions were greater (Fig. 1, see also Table 4).

A subsequent analysis was completed to contrast heart rate change using only inclines of 1% and 8%. A significant main effect of group was found ($F_{(1, 20)} = 13.76$; $p<0.0014$). This demonstrated the visual group exhibited greater reductions in heart rate percent from pre-test to post-test. Post hoc analysis revealed the visual group showed significantly greater percent improvement in heart rate ($p<0.002$) for both 1 % and 8% inclines.

**3.5.3 Figure 1: Heart Rate % Change from Pre-test to Post-test for participants that completed all inclined treadmill stages**

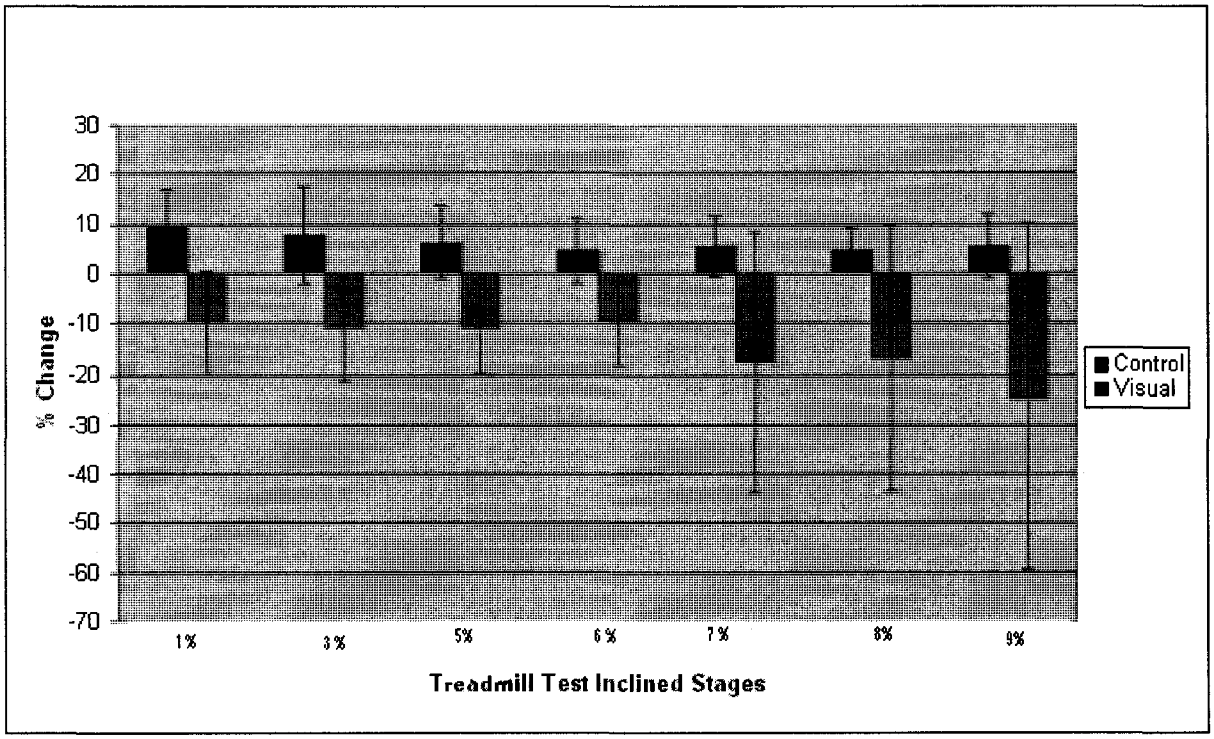


**Figure 1: Presented with SD bars. Significant differences found between the groups for the collapsed incline stages, p<0.001.**

### 3.5.4 Table 4: Analysis of Heart Rate % Change Means

**Table 4: Presented with mean (± SD).**

| GRADE | CONTROL | VISUAL |
|---|---|---|
| PRE –POST TEST | Mean(± SD) | Mean(± SD) |
| 1% | 9.1(7.62) | -9.96 (10.34) |
| 3% | 7.58 (9.75) | -11.04 (10.1) |
| 5% | 6.14 (7.11) | -10.96 (8.75) |
| 6% | 4.40 (6.67) | -9.86 (8.34) |
| 7% | 5.24 (5.97) | -17.81 (26.12) |
| 8% | 4.59 (4.62) | -16.95 (26.57) |
| 9% | 5.32 (6.34) | -24.62 (34.94) |
| POST- 6 WEEKS TEST | | |
| 1% | -0.23 (9.23) | -3.51 (7.43) |
| 3% | 0.33 (10.13) | -4.89 (8.12) |
| 5% | 0.02 (9.33) | -5.45 (8.16) |
| 6% | 0.04 (9.56) | -4.68 (8.62) |
| 7% | 12.40 (28.97) | -2.66 (8.52) |
| 8% | 11.75 (29.16) | -2.24 (6.69) |
| 9% | 12.15 (29.61) | -10.91 (34.24) |
| 6 WEEKS - PRE TEST | | |
| 1% | -10.52 (11.74) | -16.09 (9.54) |
| 3% | -10.06 (8.99) | -15.31 (9.63) |
| 5% | -7.63 (6.81) | -13.69 (8.17) |
| 6% | 3.28 (34.4) | -2.88 (29.84) |
| 7% | 4.56 (34.18) | -2.63 (29.38) |
| 8% | 13.25 (45.52) | 17.71 (51.84) |
| 9% | 24.61 (51.51) | 16.54 (53.01) |

*HR % change reductions for Control and Visual groups. Negative terms represent greater % change*

**Heart Rate % Change per Inclined Stage**

The participants differed in the workload attained and therefore a subsequent analysis was required to specify the completion of each inclined treadmill stage. This separation sought to capture the relative comparison between the groups at each inclined treadmill stage. The analysis revealed that significant main effects were found for all treadmill inclines in the pre-test to post-test comparison and at 5% incline from six weeks post training to pre-test. The visual group heart rate reductions were greater relative to the control group except for at the post-test to six weeks post training comparison at 3% and 9% incline (Table 5).

### 3.5.5 Table 5: Analysis of HR % change at each inclined treadmill stage separately

**Table 5: The relative performances between the groups across the assessment time comparisons are included.**

| | MAIN EFFECT <0.01? | VISUAL | CONTROL |
|---|---|---|---|
| Incline completed | Pre-test to Post- test | | |
| 1% (0.9°) | **Yes**, p<0.000 | low (n=22) | high (n=19) |
| 3% (2.7°) | **Yes**, p<0.000 | low (n=19) | high (n=18) |
| 5% (4.5°) | **Yes**, p<0.000 | low (n=19) | high (n=18) |
| 6% (5.4°) | **Yes**, p<0.000 | low (n=16) | high (n=13) |
| 7% (6.3°) | **Yes**, p<0.000 | low (n=15) | high (n=10) |
| 8% (7.2°) | **Yes**, p<0.001 | low (n=11) | high (n=9) |
| 9% (8.1°) | **Yes**, p<0.006 | low (n=13) | high (n=6) |
| | Post-test to 6 weeks post training | | |
| 1% (0.9°) | No, NS | low (n=21) | high (n=18) |
| **3%** (2.7°) | No, NS | low (n=21) | lowest (n=17) |
| 5% (4.5°) | No, NS | lowest (n=21) | low (n=16) |
| 6% (5.4°) | No, NS | low (n=19) | high (n=13) |
| 7% (6.3°) | No, NS | low (n=18) | high (n=11) |
| 8% (7.2°) | No, NS | low (n=14) | high (n=12) |
| **9%** (8.1°) | No, NS | low (n=13) | lowest (n=9) |
| | 6 weeks post training to Pre-test | | |
| 1% (0.9°) | No, NS | lowest (n=22) | low (n=17) |
| 3% (2.7°) | No, NS | lowest (n=20) | low (n=17) |
| 5% (4.5°) | **Yes**, p<0.006 | lowest (n=19) | low (n=16) |
| 6% (5.4°) | No, NS | low (n=17) | high (n=12) |
| 7% (6.3°) | No, NS | lowest (n=15) | low (n=10) |
| 8% (7.2°) | No, NS | lowest (n=11) | low (n=9) |
| 9% (8.1°) | No, NS | lowest (n=11) | low (n=7) |

*HR reductions for Control and Visual groups are relative to each other at each stage. Low-terms represent negative % change *

**$Vo_2$/kg (ml/kg/min)**

The steady state $Vo_2$/kg values of all participants were obtained at each inclined treadmill stage .When both groups Vo2/kg were combined for all inclined treadmill stages across the three assessment periods, a significant main effect of assessment time was found ($F_{(2, 36)} = 7.26$; $p<0.0023$). Post hoc analysis revealed that the absolute $Vo_2$/kg for all inclined treadmill stages significantly reduced for the control group (16.62 (±7.22), 14.62 (±6.46), 13.93 (±6.96)) and visual group ((18.58 (±6.48), 15.32 (±6.71), 15.2 (±5.08)) from pre-test to post-test ($p<0.012$).

**$Vo_2$/kg Analysis of % Change**

To represent the change in each participant, analysis of the differences in the relative performances involved the standardization of the absolute data into percent change. Participants included in this analysis completed all inclined treadmill stages. A main effect for assessment time was found in the six weeks post training to pre-test comparison ($F_{(6,168)} = 5.68$; $p<0.000$). Post hoc analysis revealed differences in the inclined treadmill stages. The inclined stage of 1% differed from 7 % ($p<0.012$), 8% ($p<0.004$) and 9% inclines ($p<0.000$). Also, the 3% incline was differed from the 8% ($p<0.036$) and 9% ($p<0.002$) inclines. Lastly, the incline of 5% was significantly different then the incline of 9% ($p<0.024$) (Fig. 2). These significant differences found highlighted the necessity to investigate how each group responded at each inclined treadmill stage separately.

A secondary analysis was completed to contrast $Vo_2$/kg change using only inclines of 1% and 8%. A significant interaction of group and time was found in the pre-test to post-test comparison ($F_{(1, 21)} = 9.22$; $p<0.006$). The reductions in $Vo_2$/kg means were greater for the visual group ((-7.27 (±31.63) to -24.84 (±31.67)) then the controls ((-26.54 (±21.97) to 4.72 (±35.42)) but only in the higher inclined stage of 8%.

**3.5.6 Figure 2: $Vo_2$/kg % Change from Six weeks Post training to Pre-test for participants that completed all inclined treadmill stages**

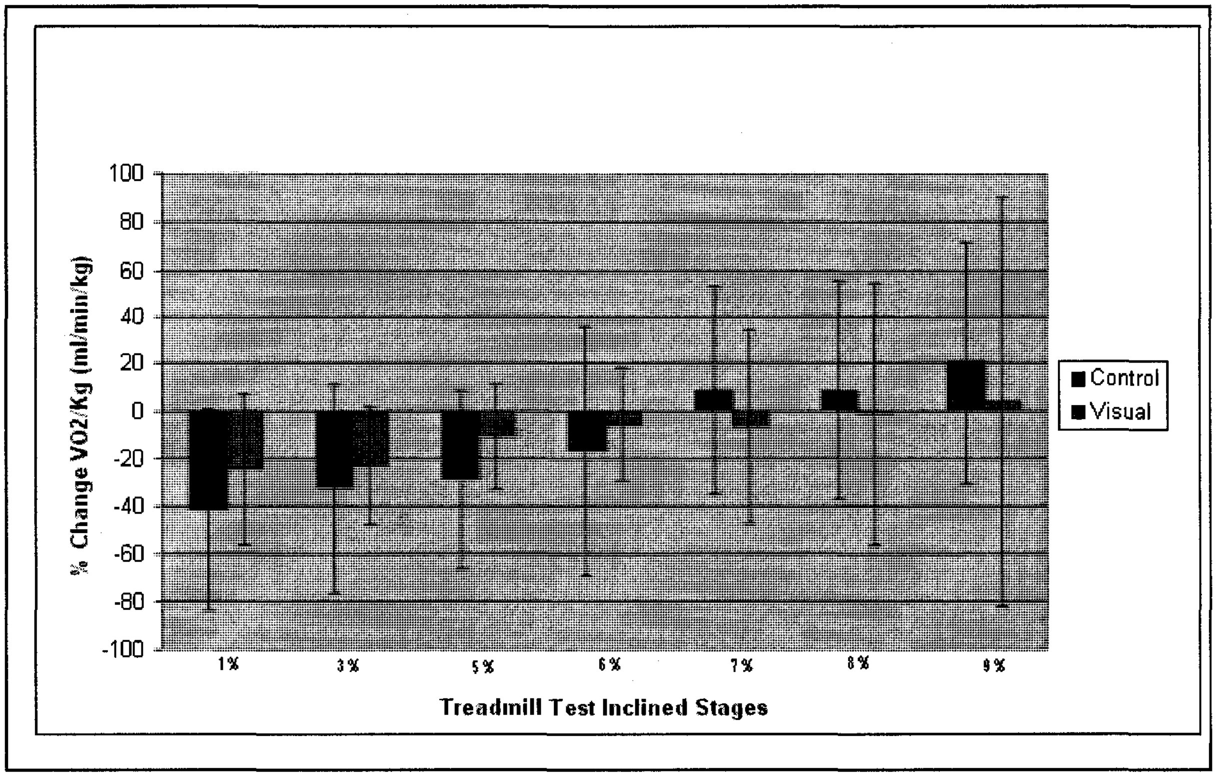


**Figure 2: Presented with SD bars. Significance level (*): p<0.005. Remaining levels: p<0.05.**

**$Vo_2/kg$ % Change per Inclined Stage**

The participants' differed in the workload that was attained and therefore a subsequent analysis was required to assess the inclined treadmill stages achieved. This separation sought to capture the relative comparison between the groups at each inclined treadmill stage. The analysis revealed that across all assessment period comparisons only two significant main effects were found. Significant main effects of time were found from the pre-test to post-test ($F_{(1,23)} = 10.75$; $p<0.003$) and from six weeks post training to pre-test ($F_{(1,36)} = 8.34$; $p<0.0065$). The analyses demonstrated the visual group showed greater reductions in $Vo_2/kg$ at 7% incline from pre-test to post-test where the control group showed greater reductions at 1% incline from 6 weeks post training to pre-test (Table 6).

### 3.5.7 Table 6: Analysis of $Vo_2$/kg % change at each inclined treadmill stage separately

**Table 6: The relative performances between the groups across the assessment time comparisons are included.**

| | MAIN EFFECT <0.01? | VISUAL | CONTROL |
|---|---|---|---|
| Incline completed | Pre-test to Post-test | | |
| 1% (0.9°) | No, NS | lowest (n=22) | low (n=19) |
| 3% (2.7°) | No, NS | lowest (n=19) | low (n=18) |
| 5% (4.5°) | No, NS | lowest (n=19) | low (n=18) |
| 6% (5.4°) | No, NS | lowest (n=16) | low (n=13) |
| 7% (6.3°) | **Yes, p<0.003** | lower (n=15) | higher (n=10) |
| 8% (7.2°) | No, NS | lowest (n=11) | low (n=9) |
| 9% (8.1°) | No, NS | lowest (n=13) | low (n=6) |
| | Post-test to 6 weeks post training | | |
| 1% (0.9°) | No, NS | high (n=21) | higher (n=18) |
| 3% (2.7°) | No, NS | low (n=21) | higher (n=17) |
| 5% (4.5°) | No, NS | high (n=21) | higher (n=16) |
| 6% (5.4°) | No, NS | high (n=19) | higher (n=13) |
| 7% (6.3°) | No, NS | high (n=18) | higher (n=11) |
| **8%** (7.2°) | No, NS | higher (n=14) | high (n=12) |
| 9**%** (8.1°) | No, NS | lowest (n=13) | low (n=9) |
| | 6 weeks post training to Pre-test | | |
| 1% (0.9°) | **Yes, p<0.006** | low (n=22) | lowest (n=17) |
| 3% (2.7°) | No, NS | low (n=20) | lowest (n=17) |
| 5% (4.5°) | No, NS | low (n=19) | lowest (n=16) |
| 6% (5.4°) | No, NS | low (n=17) | high (n=12) |
| 7% (6.3°) | No, NS | lowest (n=15) | low (n=10) |
| 8% (7.2°) | No, NS | lowest (n=11) | low (n=9) |
| 9% (8.1°) | No, NS | high (n=11) | higher (n=7) |

*$Vo_2$/kg for the Control and Visual groups are relative to each other at each stage. Low-terms represent negative % change *

**Respiratory Exchange Ratio (RER)**

A significant main effect of assessment time was found for RER ($F_{(2, 66)} = 8.2$; $p < 0.0007$). Post hoc analysis revealed the differences driving this main effect was from reductions in RER for both groups from pre-test to post-test ($p<0.004$) and from pre-test to 6 weeks post training ($p<0.001$). The observed means for each assessment period for the control group (0.98 (±0.06), 0.95 (±0.05), 0.95 (±0.06)) and the visual group (0.97 (±0.08), 0.94 (±0.06), 0.94 (± 0.06)) are illustrated (Fig. 3).

**3.5.8 Figure 3: Respiratory Exchange Ratio at Pre-test, Post-test and Six weeks Post training**

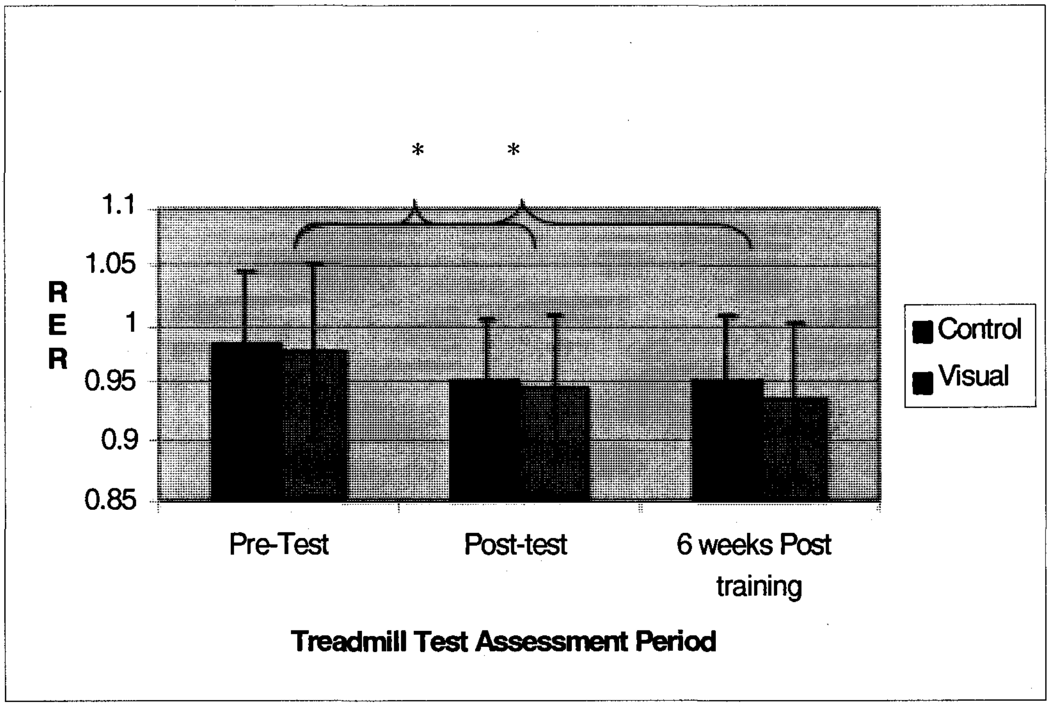


**Figure 3: Presented with SD bars. Significance level (*): p<0.005.**

**Kinematics**:

**Step Length of Affected Side (cm)**

A significant main effect of assessment time was found ($F_{(2, 80)} = 4.10$; $p<0.02$). Post hoc analysis revealed the differences existed from both pre-test to post-test and six weeks post training to pre-test ($p<0.045$ and $p<0.034$, respectively). The means observed for the combined groups were 56.27 (±11.59) at pre-test, 57.96 (±12.35) at post-test and 58.04 (±11.24) at six weeks post training. An interaction of group and time was also found ($F_{(2, 80)} = 3.46$; $p<0.036$). Post hoc analysis revealed the visual group had increased step lengths immediately after visual cued treadmill training at post-test ($p<0.017$) where the control group step length was statistically unchanged from pre-test (Fig. 4).

In a subsequent analysis that included separated assessment period comparisons a significant interaction of group and time was found ($F_{(1, 40)} = 5.29$; $p<0.027$) in the six weeks post training to post-test comparison. Post hoc analysis revealed a trend that indicated the control group step length was larger at the six weeks post training assessment ($p<0.072$).

**3.5.9 Figure 4: Step Length of Affected side at Pre-test, Post-test and Six weeks Post training**

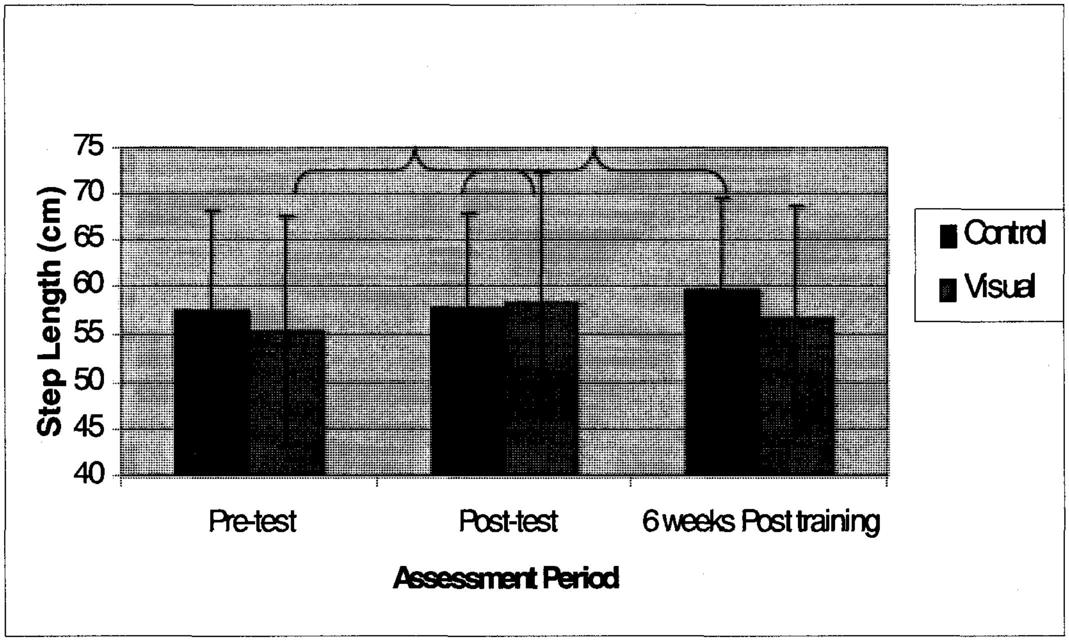


**Figure 4: Presented with SD bars. Significance level: p<0.05.**

**Velocity (cm/s)**

A significant main effect of assessment time was found ($F_{(2, 80)} = 5.14$; $p < 0.08$). Post hoc analysis revealed the difference driving this effect was from pre-test to post-test assessment period ($p<0.027$). At pre-test the combined group means observed were 108.60 (±24.89), at post-test groups increased velocity to 113.17 (±28.16) and maintained a similar velocity of 113.64 (±26.56) at six weeks post training.

A significant interaction of group and time was also found for velocity ($F_{(2, 80)} = 4.65$; $p<0.012$). Post hoc analysis revealed the control group (114.62 (±20.6), 116.01 (±24.65), 121.73 (±24.93)) had faster velocity then the visual group (102.59 (±26.78), 110.34 (±30.64), 105.54 (±25.66)) at both pre-test and six week post training ($p<0.0003$ and $p<0.0001$, respectively). Thus the visual group was slower

In a separate analysis of assessment periods a significant interaction of group and time was found ($F_{(1, 40)} = 8.88$; $p<0.005$) from six weeks post training to post-test. Post hoc analysis revealed the control group exhibited faster velocity then the visual group at six weeks post training ($p<0.005$). The attained velocities for both groups at each assessment period are illustrated (Fig. 5).

**3.5.10 Figure 5: Velocity at Pre-test, Post-test and Six weeks Post training**

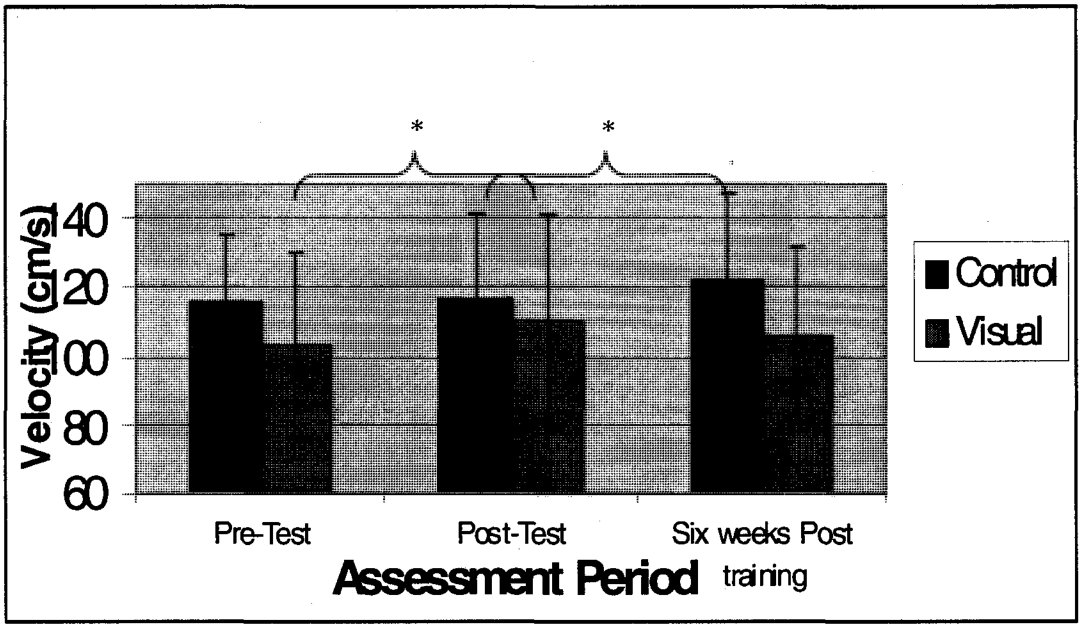


**Figure 5: Presented with SD bars. Significance level: p<0.001.**

**Parkinson's disease Symptom Severity:**

**UPDRS motor sub-score**

There were no significant differences between the control and visual groups found in the analysis that included all assessment periods. Secondary analysis included the pre-test to post-test and post-test to six weeks post training comparisons. In the pre-test to post-test comparison, a significant main effect of time was found ($F_{(1, 40)} = 4.72$; $p<0.036$) where groups increased motor symptom severity immediately after training (Fig. 6).

**3.5.11 Figure 6: UPDRS motor symptom severity score at Pre-test, Post-test and Six weeks Post training**

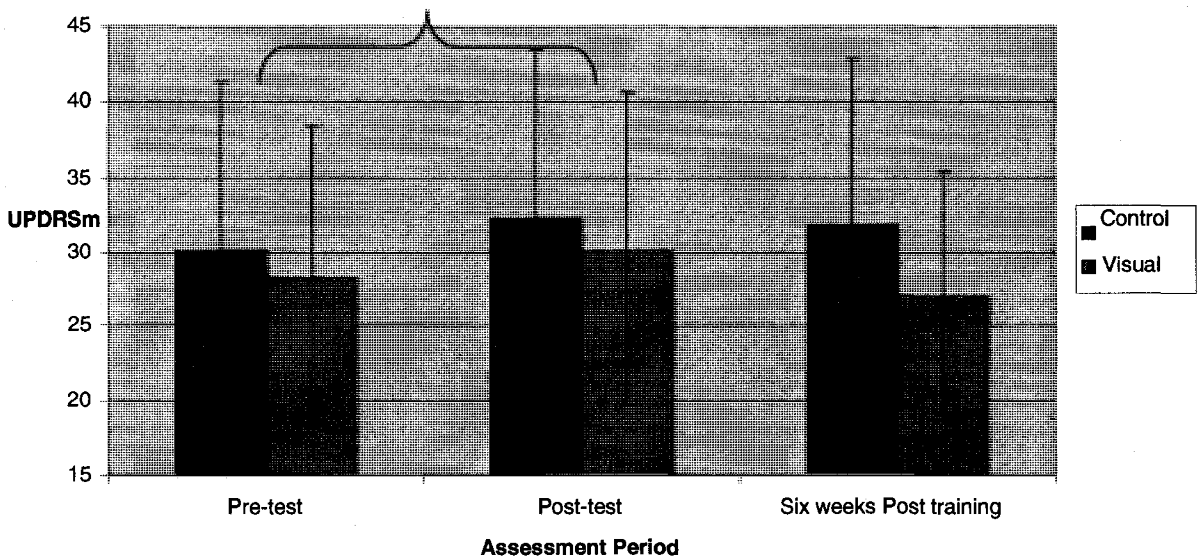


**Figure 6: Presented with SD bars. Significance level: p<0.05.**

**Subjective Walking Score (UPDRS)**

There was no significant change observed in the analysis of the subjective walking score. However, an interesting trend warranted subsequent comparisons. The analysis that incorporated the post-test to six week post training scores demonstrated a trend towards a significant main effect of group ($F_{(1,40)} = 3.11$; $p<0.086$). This trend indicated the control group rated their walking score closer to 'normal' then the visual group after six weeks without treadmill training.

## 3.6 Discussion

This study was the first to evaluate how PD participants might be influenced by treadmill training with and without the influence of concurrent visual feedback presented in the form of visual step cues. It was hypothesized that the visual group would respond with greater reductions in motor symptom severity scores, demonstrate greater reductions in the physiological and gait outcomes assessed immediately after training. It was also hypothesized the control group would also demonstrate reductions in motor symptom severity, physiological and gait outcomes, however to a lesser extent then the visual group. Further, for all outcomes it was anticipated the visual group would maintain their improvements at six weeks post training. These evaluations are the first to document the responses of a PD sample after 12 weeks of treadmill training in both the short and longer-term.

Efficiency changes after Treadmill Training:

This study demonstrated that treadmill training benefited all of our PD participants through improved movement efficiency. These improvements were determined by the comparison of each group's relative performances with the same treadmill protocol and therefore workloads. Specifically, after treadmill training greater aerobic efficiency was demonstrated by lowered $Vo_2$/kg values at the same treadmill workloads when compared to the previous assessment periods. Our results agree with previous studies that have documented that individuals with PD successfully completed aerobic exercise and attain aerobic benefits (Bridgewater et al., 1996; Burini et al., 2006). Further our findings also agree with previous studies that have reported that PD participants responded to training with less oxygen consumption required for each kilogram of body weight at each workload (Bergen et al., 2002; Burini et al., 2006).

Our study findings suggest that the demonstrated improvement in aerobic efficiency also influenced the change in the spatio-temporal characteristics of gait. Specifically, immediately after the concurrent visual feedback treadmill training our participants expectedly showed improved gait by both larger step lengths and faster velocities. The response of velocity is comparable to previous studies that have demonstrated similar improvements. Specifically, increased velocity has occurred after only 30 minutes of speed dependent or limited progressive treadmill training (Pohl et al., 2003) and after four (Miyai et al., 2000; Miyai et al., 2002) and six weeks of treadmill training (Herman et al., 2007). The findings of the control group were unexpected and somewhat peculiar thus require some elaboration. The groups had differed in the times that the improvements in the spatio-temporal characteristics of gait occurred over our two post training assessment periods. Our findings will be discussed according to the separate group observations over our assessment periods.

The Visual Group:

The visual group primarily showed greater efficiency changes immediately after treadmill training. Relative to their pre-test performance, these participants demonstrated greater reductions in our physiological outcomes of HR and $Vo_2$/kg immediately after training. The HR responses indicated that greater aerobic efficiency was achieved in this group that trained with concurrent visual feedback. Specifically, the relative differences in the percent change data demonstrated greater HR reductions occurred at all treadmill inclines when the post-test values were compared to those attained at pre-test. Further, greater HR reductions were also shown at the 5% incline when the visual groups' six-week post training assessment was compared to the post-test. Relative to the control group, the visual group demonstrated greater reductions in HR at post-test and six weeks post training for both the preliminary and the percent change HR data.

The greater aerobic efficiency of the visual group was also demonstrated through less $Vo_2$/kg required at the same workloads at post-test relative to pre-test. Specifically, at post-test less $Vo_2$/kg was required at the treadmill workloads of 8% incline (two-stage comparison) and the 7% incline (separated inclines). The differences in $Vo_2$/kg required at these high workloads indicated that relative to pre-training, less work was required to accomplish the same treadmill inclines immediately after training. Further, relative to the control group, a greater aerobic efficiency was demonstrated since less $Vo_2$/kg was required by the visual group at the post-test. It was speculated that the concurrent visual feedback required participants to minimize any extraneous movements, including tremors and dyskinesias that would have inhibited them from achieving the goal for increased exercise intensity. Of interest was the comparison of our exercise intensity goals to the two alternate treadmill training studies that demonstrated improved motor symptom severity after training. In the study by Miyai et al., (2000) the training speed was capped at 3 km/h, where our participants achieved higher speeds thus greater exercise intensities. Specifically, in comparison to our warm up speed that began at 1.61 km/h, this related to their 1.5 km/h speed option, where our second warm up speed of 2.41 km/h was close to their second highest training speed of 2.5 km/h. Clearly, the exercise intensity attained in our study was greater since our warm up requirements were similar to their highest speeds included. Similarly, in the alternate study that demonstrated improved motor symptom severity by Herman et al., (2006) the training intensity was progressively increased, although only by the third week of their six week training program. The specific treadmill belt speeds were not described however, it is unlikely that greater exercise intensity was achieved in this study. Specifically, their study provided the opportunity for increased exercise intensity over only 16 sessions versus the opportunity provided over our 36 sessions. In our study an interesting trend was observed for greater aerobic efficiency demonstrated at the higher workloads by the visual group relative to the control group. These observations suggest that the concurrent visual feedback had provided greater incentive for increased exercise intensity. Additionally, the relative differences that occurred from six weeks post training to pre-test also showed that concurrent visual feedback training had carried over, since the efficiency improvements for

$Vo_2$/kg had not worn off at the lower workloads. This suggests that the visual group was still more efficient at the lower inclines after six weeks without training then when compared to prior to training initiation. Alternatively, from six weeks post training to pre-test, the visual group required slightly more $Vo_2$/kg at the higher treadmill inclines which suggest a possible ceiling effect for improvements was reached.

Overall, the visual groups' greater improvements in efficiency were expected and attributed to the influence of the concurrent visual feedback. Previously, visual cues have been utilized as targets to be stepped on or over and have produced larger steps in PD (Azulay et al., 1999). Visual cues have therefore promoted normalized gait in this population (Azulay et al., 1999; Bagley et al., 1997; Nieuwboer et al., 2007). Our study suggests that training with concurrent visual feedback had potentially improved the participants efficiency of gait since the observed changes corresponded with the greater aerobic efficiency achieved. The visual group gait improvements included larger step length and faster velocity immediately after training. These findings advance beyond those of Nieuwboer et al., (2006) who reported that visual cues increased the short-term consistency of step length in PD immediately after testing (Nieuwboer et al., 2006). Our findings demonstrated an improvement in step length as an effect of weeks of training. It was interesting to observe that the visual groups' gait improvements did not wear off at six weeks post training. Maintenance of the gait improvements suggests that the concurrent visual feedback contributed to this effect. This assertion can be made for gait velocity in particular, since the control group had a slightly faster mean velocity than the visual group at baseline. Since differences existed in the groups' velocity at pre-test, the observed change could reflect two possibilities. The greater velocity immediately after training observed in the visual group could have been representative of the responses from the training tool, the treadmill. Otherwise, the increased velocity may have revealed the influence of the visual cues during training, given that this has been previously observed (Nieuwboer et al., 2006). If the first possibility were most accurate, then it would be expected that the control group would also show a similar increase in velocity after training, which did not occur. This is in agreement with the studied conducted by Cakit et al., (2007). Our protocol promoted increased walking speeds and concluded that the opportunity for increased velocity during training was the same for both groups. It is therefore asserted that the contribution of the concurrent visual feedback was responsible for the increased velocity of the visual group immediately after training. Further, even after the removal of the visual cues once training had finished, these gait benefits attained had not worn off.

The Control Group:

The greatest aerobic efficiency improvements demonstrated by the control group were observed from pre-test to six-week post training. Although the control group demonstrated lowered HR responses after training, significant reductions occurred only from pre-test to six weeks post training, at the 3% and 9% treadmill workloads. These significant HR reductions were unexpected because improvements in efficiency occurred only after regular, non-cued treadmill training.

Similarly, an unanticipated improvement was found in the $Vo_2$/kg required by the control group when the six-week post training workloads were compared to those at pre-test, specifically at the treadmill inclines of 1%, 3% and 5%. These changes may be attributed to the differences that existed in training. The control group increased their training intensity without the influence of concurrent visual feedback, thus would instead be dependent only on their subjective comfort. It is possible that the control group trained with greater consistency at the lower workloads since there was less incentive to push oneself when training without visual cues. Therefore, the motivation to achieve greater exercise intensity would have been less, in comparison to the visual group hence the control group may have remained only within their comfort zone of training. However, the intensity reached was still sufficient for less $Vo_2$/kg required at the lower workloads. Thus, since the control group demonstrated $Vo_2$/kg improvements at six weeks post training suggests their training had transferred easily to outside the laboratory.

Similarly, improvements in gait efficiency were suspected in the control group when considered in combination with the aerobic efficiency changes observed. The control group lengthened their steps (on the most affected side) and demonstrated faster gait velocity at six weeks post training. These unexpected findings suggest that the gait training completed may have transferred into daily practice after the training portion of our program was completed. These results are in agreement with those of Miyai et al., (2002) and Herman et al., (2007). The study by Miyai et al., (2002) demonstrated a continued improvement for the number of steps taken in 10 m at 2, 3 and 4 months after the body weight supported treadmill training had ended. Similarly, the authors Herman et al., (2007) reported that when compared to baseline, the follow up assessment 4 weeks later strides were larger then those attained at baseline. Therefore, support is gained for the concept that gait improvements may be transferred into weeks and months after training is completed. A lingering uncertainty found in these two studies however was the gait outcomes they assessed. It is important to note that both of these studies measured stride length, which averages the clinically most and least affected sides of the body. These measures therefore included compensation steps from the least affected side which may not accurately represent the gait changes that were found. Our study focused on analyzing the most affected side step length, with the notion that the greatest improvement would be captured on the most affected side (ie. The non-affected side would be expected to show little improvement since it is not impaired in the first place). A significant improvement in the most affected side was achieved at follow up for the control group. These findings support the use of the treadmill to train and improve step length of the most affected side.

The controls groups' velocity was also unexpectedly faster from pre-test to six weeks post training. These changes after post-test suggest a possible change in 'normal' activity levels. Further, training without the influence of concurrent visual feedback may have possibly led to greater emphasis on intrinsic learning in this group. Thus with the greater emphasis on the proficiency of gait during training, the activities of daily living after the training period could have even been completed with greater ease. In contrast, in the study by Herman et al., (2007) where after six weeks of treadmill training, gait speed improved that was then maintained at four weeks follow up. A possible explanation could include the difference in their training protocol since speed was increased similarly for all participants, regardless of their individual capabilities. Specifically training began at 80% of the participants' over ground walking speed that then increased weekly until speeds 5-10% higher was reached (Herman et al., 2007). Our training protocol did not improve the control groups' velocity immediately after training however, this group showed faster gait at six weeks post training and suggests our training may have influenced more efficient activity after our program was completed.

Respiratory Exchange Ratio:

As expected, a reduction in RER was observed at both post-test and six weeks post training in comparison to the pre-test values. This reduction highlighted that the metabolic efficiency had improved in both the visual and control groups. These results suggest that our training led to adaptations to the mitochondrial content in the exercised skeletal muscles. Specifically, with greater exercise intensity achieved, greater mitochondrial content was likely to provide the necessary energy to the exercising muscles. This adaptation was observed through the RER reductions since the relative contribution of fat was higher then the contribution of carbohydrates for the primary fuel utilized for energy burn. Interestingly, the effects of treadmill training were maintained, which is supported by the continuation of lowered RER six weeks later.

Motor Symptom Severity after Training:

The motor symptom severity responses were unexpected since both groups' scores increased immediately after treadmill training. These findings may be an indication that these responses are typical and may instead represent the normal progression of PD. An alternate explanation may be that the increased scores suggest treadmill training harmed rather then helped the participants' disease severity. However, two studies have found improvements in motor symptom severity after treadmill training, although in much smaller samples. The study by Herman et al., (2007) reported improved motor symptom scores in their 9 moderately affected individuals immediately after six weeks of treadmill training and again four weeks later (Herman et al., 2007). Similarly, in the study by Miyai et al., (2000) improved motor symptom severity scores were reported in their 10 participants after only 4 weeks of treadmill training (Miyai et al., 2000). However, our study involved a much larger sample and achieved a power of ~80%. Thus our findings are a greater representation of PD motor symptom severity change after treadmill training. Further, it is uncertain in the studies mentioned above whether a blind evaluator completed the motor symptom severity assessments. This highlights the potential for experimenter bias, where one questions if the evaluator remains completely objective in their evaluations. This is a concern since it would defeat the purpose of determining if treadmill training is an effective rehabilitation strategy in PD . It was also interesting that the second study by Miyai et al., (2002) agreed with our findings, since motor symptom severity responses were not improved. They reported no significant motor symptom severity changes existed for any post training period (1, 2, 3, 4, 5 & 6 months post training). Despite the conflicting results from previous treadmill studies, the current study observed a potentially important trend for symptom severity change in PD after treadmill training. The visual group demonstrated a trend for reduced motor symptom severity scores six weeks after training ended, whereas the control groups' scores remained essentially unchanged. These trends suggest that the use of concurrent visual feedback provided the potential for symptom severity benefits that will not wear off. Given that the visual groups' motor symptoms increased (worsened) after treadmill training but showed a trend for improvement 6 weeks later suggest that for concurrent visual cues to be effective, a practical component may also be required. This trend implied that possible over-flooding of visual information might have interfered with the motor symptom severity improvement immediately after training.

Subjective Impressions on Gait after training:

The subjective classification of walking ability was not statistically significant, although it was important to consider the participants' impressions of treadmill training. It was interesting that the gait improvements identified in the control group from post-test to six weeks post training were also subjectively perceived. A trend indicated the control group felt their walking was closer to normal at six weeks post training compared to immediately after training.. However, it was difficult to compare the subjective impression of walking to previous studies since this same tool has not been utilized in previous studies (in spite of this questionnaire being the gold standard for the assessment of PD). Nonetheless, the subjective responses indicated that the improvements in gait that occurred were also perceived.

**Study Limitations:**

This study had a number of limitations. A lack of standardization of the treadmill testing speeds increased the difficulty of comparison and hence the relative percent differences were required in our analysis. It was noted that if individuals were categorized according to disease severity, and tested at predetermined velocities, the testing could have been more uniform. However, previous studies that have categorized participants have only utilized individuals that primarily exhibit only mild disease severity. Instead, our study opted to provide an opportunity for each participant to improve the intensity of training and thus present representative changes in efficiency.

An additional study limitation included the randomization process that was utilized. Our study could have been more effective with superior group matching techniques a priori. This was difficult because participants were allocated according to location and feasibility of training time due to medications or other commitments. This study incorporated a large sample size and our priority was aimed to attain equal sample sizes for the most meaningful comparisons.

Also, a noted limitation was the use of handrail holding during treadmill training since this effect could have easily changed the energy expenditure of participants. Our study controlled for handrail holding during our testing periods, where participants were required to remain consistent with their first treadmill test. However, during training it was deemed more important to encourage rather then discourage participants to wean off of the utilization of handrails when they felt safe. Our study considered that the difference in training versus testing conditions that could have influenced the parameters measured and efficiency responses attained.

**Conclusions**:

For a sufficient aerobic exercise that can also benefit to PD gait disturbances, treadmill training is recommended however, it is considered an inadequate rehabilitative strategy to improve PD motor symptom severity. The utilization of concurrent visual feedback during treadmill training offered greater aerobic and gait benefits immediately after training then did the regular, non-cued training. The responses of the visual group were intriguing as the improved effects did not wear off at follow up six weeks after training had ended. Thus, participants that desire improvements in aerobic efficiency and/or lengthened or faster gait, the utilization of concurrent visual feedback during training is recommended. These sustained improvements found were highlighted the carry-over achieved after treadmill training with concurrent visual feedback.

The current study determined that our PD sample was capable of treadmill training without the use of a safety harness or body weight support. However, given the great importance of safety, it is recommended individuals with PD are at least initially supervised when using this form of equipment. Further, the visual cues appeared to motivate individuals to achieve greater exercise intensities. Thus, the consideration of more practical, less expensive visual cue components is a direction for future research. In a laboratory setting, it is of interest to determine if a similar training effect would occur if step cues were utilized intermittently during training. Overall, treadmill training may be discarded as a rehabilitative strategy for motor symptom severity change however, benefits in aerobic function and gait can be attained.

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# Chapter 4: Functional outcomes in Parkinson's after Treadmill Training with & without Concurrent Visual Feedback

## 4.1 Abstract

Previous research has indicated that treadmill training may improve gait in Parkinson's disease (PD). Visual cues have also been shown to normalize gait in this population. However, the effect of combining strategies of concurrent visual feedback together with treadmill training must be established. The purpose of our study was to determine how the subjective rating of perceived exertion (RPE), the response of mean arterial pressure (MAP), the Timed Up-and-Go (TUG) test and Layfayette's pegboard test might be influenced by treadmill training in two groups. One group had integrated concurrent visual feedback and the other did not. **Methods**: Forty-two participants were recruited from the Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University. Twenty-three participants (69.3 (±8.5) yrs, 180.9 (±29.7) kg, 7 female) completed training with concurrent visual feedback and nineteen participants (66.4 (±9.2) yrs, 168.9 (±37.5) kg, 9 female) completed regular, non-cued training. Participants trained for 12 weeks, three times weekly, for 26-minute sessions. Assessments occurred at baseline, after twelve weeks of training and again after six weeks without training. The RPE measured the perceived exercise intensity of our treadmill protocol where the MAP captured a composite blood pressure score before and after each treadmill test. Gross functional performance of the lower extremities was measured with the TUG test where the Lafayette Pegboard measured fine motor skill of the upper extremities. **Results**: Significantly faster Pegboard insertion and removal times for both groups were found from baseline to six weeks post training ($p<0.002$ and $p<0.0003$,

respectively). Only the removal times were significantly faster immediately post training ($p<0.004$). MAP values also significantly decreased for both groups immediately after training ($p<0.012$) with trends for reductions at six weeks post training ($p<0.053$). A trend for faster TUG times was observed immediately after training for both groups ($p<0.076$) where a trend for lowered RPE scores for both groups occurred at six weeks post training ($p<0.052$). Our findings encourage the continued investigation of treadmill training in PD.
**Key Words**: Parkinson's disease – Treadmill training – Concurrent Visual Feedback

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## 4.2 Introduction

Aerobic exercise has been argued to be an important physical therapy for Parkinson's disease (PD). Research has suggested that it has the potential to improve cardio-respiratory gains (Bridgewater et al., 1996) through improved cardiac and respiratory function (Kluding et al., 2006). Other positive responses to aerobic exercise in an injured CNS or brain also include increased cerebral blood flow that has been argued to activate neural plasticity through natural and non-invasive methods (Vaynman et al., 2005). Studies have demonstrated that motor symptom severity responses of PD participants have been maintained after aerobic exercise. Results have reported that after 12 weeks of aerobic Aquafit exercise, motor symptom severity did not significantly change, nor did these scores differ six weeks later (Sage et al., 2008). After aerobic treadmill training studies motor symptom severity has also exhibited improvements (Fisher et al., 2008; Herman et al., 2007; Miyai et al., 2000). These training studies have all incorporated goal-oriented and individualized training concepts that may be responsible for the demonstrated symptom severity improvements. A trend observed included the incorporation of the participants' comfortable walking pace into training with additional progressively increased belt speeds throughout (Herman et al., 2007; Miyai et al., 2000). Alternatively, target exercise intensity goals above and below 75% of age appropriate maximal heart rate have been also elicited these improved motor symptom severity effects (Fisher et al., 2008). Improved motor symptom severity has been attained with treadmill training alone and it is therefore of interest to establish whether greater improvements are found with additional concurrent visual feedback incorporated into training. These effects are necessary to establish given that visual cues single-handedly have demonstrated to benefit increased step lengths, gait velocity and improved gait initiation in PD (Azulay et al., 1999; Bagley et al., 1997; Nieuwboer et al., 2007). Furthermore, the effectiveness of treadmill training in PD with and without the influence of concurrent visual cues is required in order to distinguish if differences in training effects exist. Additionally, the treadmill training influence on clinically relevant outcome responses that have been previously considered in exercise studies should also be assessed.

The rating of perceived exertion (RPE) a subjective measurement of exercise intensity has been minimally documented during aerobic exercise studies and has not been documented after treadmill training in PD. The aerobic training studies that have included RPE have included this measure to assess the perceived intensity of exercise during six minute walk tests using the Borg Category Ratio scale® (CR-10), where reductions in perceived intensity were found (Burini et al., 2006; Koseoglu et al., 1997). However, the RPE ratings are required for treadmill protocols since these protocols are early in development. Thus for treadmill protocols this population to evolve, the achieved workloads and corresponding perceived intensity rating would be beneficial to document. Interestingly, a previous study that documented the RPE during an sub maximal cycle ergometer test at specified work rates did not produce lowered RPE scores (Hooker et al., 1996). The comparison of RPE ratings was completed over two days only and therefore the non significant differences at any workload were not surprising. This study had indicated that adequate aerobic training is necessary when the determining the appropriateness of a protocol, because practice is required in order to expect significant aerobic training responses. Therefore the inclusion of RPE scores in the current study was necessary to determine whether our training produced meaningful subjectively rated differences and further to highlight the longer-term effects of our programs effectiveness on the subjective aerobic capacity gains in our sample. The current study anticipated that after treadmill training, reductions in RPE ratings would occur at our post test assessment followed by increased ratings obtained once training ended, at our six week post assessment.

An additional physiologically and clinically relevant measurement in the PD population is blood pressure. Fluctuations in blood pressure have been observed in this population and thus for safety first and foremost, this measurement was important to be considered before and after aerobic exercise testing. In PD, the confounding effect of medication has complicated the blood pressure responses obtained. It has been determined that participants who exhibited the wearing off phenomenon of medication experienced greater fluctuations in blood pressure (Pursiainen et al., 2007). Further, the greatest fluctuations in blood pressure were observed when participants' motor performance worsened and alternatively decreased when motor performance improved (Pursiainen et al., 2007). Therefore, provided that our participants' medication states were uniform during testing, such that motor performance was stable, the response of blood pressure would be representative of the effect of the treadmill training exercise. An additional consideration was described by differences in blood pressure responses that were reported after a tilt test in PD and healthy controls. The largest drop in systolic and diastolic blood pressure was recorded immediately, one and two minutes after the test and results demonstrated that PD participants responded with deficient blood pressure reactions to the tilting. Specifically, the systolic blood pressure fall that occurred in PD participants immediately after tilting was still present two minutes later (Kallio et al., 2000). These findings suggested that marked blood pressure differences have existed in PD and therefore greater value may be obtained through a measurement that incorporates the combined scores of the systolic and diastolic components. Therefore the utilization of the mean arterial pressure (MAP) score was deemed the most efficacious value to evaluate in order to consider the overall effect of treadmill training on blood pressure. Thus, the inclusion of the MAP response from our participants before and after each treadmill test aimed to provide a profile for expected values and is considered a requirement to document for the participants safety. It is necessary to detail that surprisingly to date, the majority of PD aerobic exercise studies has not reported on obtained blood pressure values (Fisher et al., 2008; Hooker et al., 1996; Pohl et al., 2003) if this measurement was included at all. The applicability for future work is lost without the report of the obtained measures and thus particularly in this clinical population, this information should be provided. The current study will examine the MAP responses of our participants and it was anticipated that after treadmill training this value will decrease at our post test assessment followed by increased scores, similar to those obtained at baseline at our six weeks post training assessment.

An outcome measure that has been observed in previous research is the Timed Up-and-Go (TUG) test, an assessment of gross lower extremity functional performance. The TUG test has been considered a reliable measure of mobility in PD (Podsiadlo et al., 1991) given that the time it takes for participants' to stand, walk three meters, turn and return to sitting, quickly although without running. Furthermore, the TUG test has been regarded to be sensitive to different phases of medication experienced in PD (Morris et al., 2001), which supports the appropriateness to document this measure. However, the TUG test responses have not been consistent in previous exercise research. In a crossover design study with three weeks of cueing training with a preferred modality, no immediate significant differences between the two groups was reported after the crossover however, the median TUG times for both groups had reduced at the six week follow up assessment (Nieuwboer et al., 2006). Our study incorporated only concurrent visual feedback within training in order to accurately decipher if faster functional performance times were also attained. Our study also aimed to determine whether these responses were slower when the concurrent visual feedback was not incorporated. Additional exercise studies have demonstrated that the TUG times did not significantly change immediately after exercise training or at the follow up assessments (Ashburn et al., 2006; Lun et al., 2005). However, in the study by Lun et al., (2005) the participants were pooled immediately after training, where some had continued exercising where others did not (Lun et al., 2005). The collapsed groups may have therefore masked the true effects at that follow up assessment. Our study therefore requested that all participants maintain their regular level of physical activity after our training program, so that our six week follow up assessment would be an accurate representation of their daily lower extremity functional performance.

The results obtained in the study by Hong et al., (2007) were of particular interest since they depicted the possible benefits of training specificity on treadmills that was shown in their sample of two PD participants who consistently exhibited freezing of gait. These participants were trained for one day on a rotating circular treadmill and following the training for leftward turns, the direction of turning difficulty for each, neither participant froze while walking. Further, the responses to the TUG test included a left turn was faster post-training, where the time did not change for the right turn TUG test (Hong et al., 2007). These results signified that focused training aims may be the most effective for this population to improve gross lower extremity functional performance measures. The current study rationalized that our individually based aims for progressive treadmill speed increases may result in mobility benefits through faster TUG times. However, there are exercise studies that have tested mobility and/or balance change in participants through alternate tests. The responses of timed tests that include the time required to turn around a chair (Calgar et al., 2005), or the time it took to walk around a square perimeter of two meters (Patti et al., 1996) are not very useful because these measures are uncommon. Although these outcomes assessed mobility and balance changes in each sample, it was determined that the implementation of standardized and recognized measurements for example, the TUG test would enhance the knowledge of changes experienced in PD. The current study anticipated that treadmill training will benefit the gross motor performance captured by the TUG test, because faster TUG times are anticipated immediately after training with slower times expected at the six-week post training assessment.

A recognized and established assessment of the fine motor coordination in PD has previously been obtained through pegboard tests. The fine motor dexterity change, thus the severity of bradykinesia or overall slowness of movement experienced in PD is assessed through pegboard tests. Additionally, this measurement is an indicator of the complex integration and corresponding coordination that is required to produce fine motor movements by both the most and least clinically affected sides of the body. The times to completion required are provided by the pegboard insertion and removal phases of this task and therefore a greater understanding of the fine motor abnormalities experienced in PD may be attained. However, although the majority of exercise research provides information on the gross motor function in PD, there is limited inclusion for the upper extremity, fine motor task information obtained by pegboard tests. The exercise studies that have incorporated this outcome measure have included the study by Calgar et al., (2005) where the response to a nine-hole pegboard test at baseline and after the first and second month of training were documented. The response of both the right and left hands had significantly differed from baseline to the first month assessment and also to the second month assessment (Calgar et al., 2005). Since neither the description of the most affected side or hand dominance was provided, these results indicated that the training provided improved the fine motor dexterity, although the detailed change of the clinically most affected side of participants may have been more useful to document. Similar results were found in the study by Reuter et al., (1999) where the fine motor dexterity training was assessed by the 20-pin Perdue pegboard at 7 weeks, at 14 weeks (end of training) and at 20 weeks follow up. The authors observed that both the right and left hand times improved significantly immediately after training, although slower times for both hands was observed at the 20 week follow up assessment (Reuter et al., 1999). These results suggested that exercises that have intentionally incorporated the upper limbs had a substantial effect on the fine motor control experienced. These results also indicated that once training had stopped, the improvements were discontinued. The current study aimed to determine if similar carry over effects would be elicited through the transferability from gross motor treadmill training to the fine motor task of the pegboard. It was rationalized that treadmill training could improve the coordination required for the upper limbs that could transfer to benefit the fine motor coordination of the hands. Specifically, our study aimed to determine whether the pegboard task of the most affected side of the body would improve after training. It was deemed necessary to document only the clinically most affected side to determine the effect of training on this fine motor task. It was anticipated that both the insertion and removal phases would respond with faster times immediately after training followed by slower times observed at the six-week post assessment.

The current research design sought to determine the responses of the clinically relevant outcome measures that have been discussed in order to evaluate the overall effectiveness of our individually tailored treadmill training program. The incorporation of concurrent visual feedback for one group only aimed to delineate whether greater effectiveness was found for faster times and lower scores with this additional training influence. Our evaluations intended to provide both the immediate and long-term responses of each outcome measure through the assessments that occurred immediately after 12 weeks of treadmill training and again 6 weeks later after no exercise training. Thus the central purpose of this study was to provide clinically relevant outcomes to provide future treadmill exercise recommendations. It was hypothesized that the positive effects of training will be demonstrated through decreased TUG and Pegboard test times and lower RPE and BP scores after 12 weeks of training. It was further hypothesized that greater reduction for all outcomes will occur in the visual group. Also it was anticipated that the reductions obtained will be discontinued after six weeks without training given that the test times and scores are expected to increase back to the baseline status for all outcomes assessed.

## 4.3 Methods

### 4.3.1 Participants

Fifty-two participants were recruited from the Movement Disorders Research and Rehabilitation Centre (MDRC) database at Wilfrid Laurier University. The requirements for both the testing and training for our treadmill study were described. Participants were recruited to join our 12-week treadmill training program that included 3 sessions a week, each for 26 minutes in duration. Participants' warm up and cool downs were determined according to their comfortable walking pace. To be eligible for participation, interested individuals were required to be capable of independently ambulating and feel comfortable walking on a motorized treadmill, regardless of disease severity. An attendance policy was incorporated where treadmill training termination would occur if participants missed more then three consecutive sessions or over a total of five sessions. Exclusions for participation were made for participants that had known medical conditions that included but were not limited to uncontrollable blood pressure or diabetes, asthma, cardiac or additional co-morbidities that would be made worse by exercise. All participants were asked to seek permission from their family physicians prior to participation.

A total of 42 participants completed their respective control (n=19) or visual cue (n=23) treadmill training programs. The 10 participants that withdrew discontinued the program due to newly scheduled operations (n=1), unbearable joint pain (n=3), family doctor request (n=2) and from loss of incentive or for personal reasons (n=4). Participants were randomly divided groups dependent on the ease of training location and time of training sessions. Three locations were utilized for training that included the MDRC and two local YMCA's. The control training was subdivided into the Kitchener (n=4) and Cambridge (n=7) YMCA locations and the MDRC location (n=8). The Research Ethics Board at Wilfrid Laurier University approved this study. All participants agreed to and completed an informed consent document.

The descriptive statistics of the sample studies are reported with mean ± standard deviation. The sample was characterized with respect to age, gender, height, weight, medication use and handrail holding (Table 1). The three assessment periods incorporated included pre-test, prior to training initiation, post-test, after training was completed and six weeks post training.

### 4.3.2 Procedures

**Pre and Post Assessment Protocol:**

Participants' were described the testing procedures prior to data collection. Prior to treadmill testing, participants' height and weight were recorded. The participants' comfortable walking speed was obtained from the average of five walking trials from the GaitRITE® carpet. Participant data along with the ambient conditions of room temperature, barometric pressure and relative humidity were input into the Exp'Air Software®. Calibration of the Medisoft® metabolic cart was completed using a 3 L syringe and a cylinder of mixed gases ($O_2$ = 16%, $CO_2$ = 3%). Blood pressure was taken at rest, while participants sat and was recorded by the automatic OMORON® blood pressure cuff. To control for possible variation in exercise response, all participants were required to hold handrails if they did so at pre-test.

The treadmill test protocol created had incorporated aspects of previous protocols with additional consideration of the gait impairments experienced in the PD. Our protocol included five-minute warm up and cool down at zero percent inclines. Once ready, the warm up belt speed was set at 1.61 km/h for the first minute, 2.41 km/h for the second minute and then was increased to the self selected comfortable walking speed, which remained until test completion. The initial small increments in speed were aimed to familiarize participants with the treadmill and were adapted from the Naughton Treadmill Protocol (Naughton et al., 1973). The remaining protocol stages lasted three minutes in duration, recommendations adopted from the ACSM treadmill guidelines (Balady et al., 2005). The continuous three-minute stages were adopted from the Bruce Protocol (Bruce et al., 1971), where the consistent belt velocity utilized was adopted from the Balke Protocol (Balke et al., 1959).

Grade increased per stage from 1% (0.9°), 3% (2.7°), 5% (4.5°), 6% (5.4°) , 7% (6.3°), 8% (7.2°) and 9% (8.1°) (Appendix 1: Testing protocol). Participants were required to complete all the graded stages possible. In the last 30 seconds of each stage participants' provided their rate of perceived exertion using the Borg CR-10 scale® (Borg, 1982). This category-ratio scale deemed the intensity of '0' similar to the exertion at rest and '10' similar to maximal exertion. Treadmill test termination occurred only with a reported RPE of 9, volitional fatigue, or by participants' request. Once the participant completed the amount of possible graded stages, the cool down began at again at 0% grade. Five minutes of cool down was allotted where the velocity decreased opposite to that of the warm up. After the treadmill test, participants were again seated and blood pressure was recorded. Once prepared, participants were seated again and the TUG test was performed twice with a rest period in between. Upon the 'go' signal participants were required to stand, walk three meters, turn and return to sitting (test occurred in the fastest time possible without running). Participants were then seated to perform the 25-pin Lafayette pegboard test. This timed test was completed twice on both hands in an alternating fashion. The insertion and removal phases for each hand were recorded separately. For each of the three assessment periods, participants were scheduled at the same time of day to ensure consistency of testing and corresponding medication doses.

**Training Protocol:**

Each participant was allotted the same training time for the 36 sessions of the program. Participants allotted to the visual cued group had their demographic information input into the BioDex GaitTrainer® where the step length was calculated in order to provide individualized visual step cue targets while training. Attendance was recorded upon arrival and blood pressure was taken prior to training initiation. The training protocol initialized at each participants comfortable walking pace in the five minutes of warm up and cool down. Training occurred at zero percent inclines, although increased belt speeds per 4-minute stage was encouraged (minimum of 0.2 km/h). The first goal for training was the completion of 26 minutes of continuous walking followed small increments of increased belt speeds (Appendix 2: Training Protocol). To promote progressively increased belt speeds a policy was created where the speed attained at the second stage of training would become the first stage speed at the next session, granted participant approval was provided. Once the personal best velocity was reached, this was maintained until training completion. In the last 30 seconds of each treadmill stage the RPE was recorded. After the four stages of four minutes, participants cooled down for five minutes, again at the comfortable walking pace. If participants required assistance or was uncomfortable with training for any reason, a spotter was allotted to them for the duration of their training session.

### 4.3.3 Table 1: Baseline characteristics of the sample studied

**Table 1: Presented with mean (± SD).**

| Groups | Control | Visual |
|---|---|---|
| Total | n=19 | n=23 |
| Gender | 10 M, 9 F | 16 M, 7 F |
| Age | 66.4 (±9.19) | 69.34 (±8.47) |
| Height (cm) | 163.58 (±14.06) | 167.77 (±14.4) |
| Weight (kg) | 168.92 (±37.5) | 180.95 (±29.7) |
| Medication | 2-no medication | 3-no medication |
| Handrail Holding | 16 Holding | 19 Holding |

## 4.4 Results

### 4.4.1 Statistical Analysis

All outcome measures were analyzed with repeated measure analysis of variance (ANOVA). Each analysis was performed with the constant factors of group (Control × Visual) × time (Pre-test × Post-test × six weeks Post training). This within subjects design required participants were analyzed relative to their own performance. Additional factors within specified analyses included:

RPE:

× Trials (7 inclined treadmill stages: only participants that completed all stages)

BP (MAP):

× Trials (Before and after each treadmill test)

TUG test:

× Trials (Two tests completed at each assessment period)

Lafayette Pegboard:

× Trials (most affected hand had two insertion and two removal phases)

Each statistically significant finding was presented along with Tukey's honest significant difference (HSD) post hoc for unequal sample sizes. All data is presented with means (± SD).

*Where required in analysis, ANOVAs were also performed with only two assessment periods*

**Rate of perceived exertion (RPE) using Borg CR-10 Scale®**

The RPE was taken at the end of each inclined stage of treadmill testing. A trend towards a significant main effect of time was found across assessment periods ($F_{(2, 26)} = 3.31$; $p<0.052$). Post hoc analysis revealed the greatest difference was from pre-test to six weeks post training ($p<0.0293$). The control group RPE means were higher (4.23 (±1.58), 3.8 (±1.81), 3.34 (±1.66)) across all assessment periods when compared to the visual group (3.6 (±1.88), 3.17 (±1.6), 2.81 (±1.37)) (Fig. 1).

**4.4.2 Figure 1: Rate of Perceived Exertion at Pre-test, Post-test and Six weeks Post training**

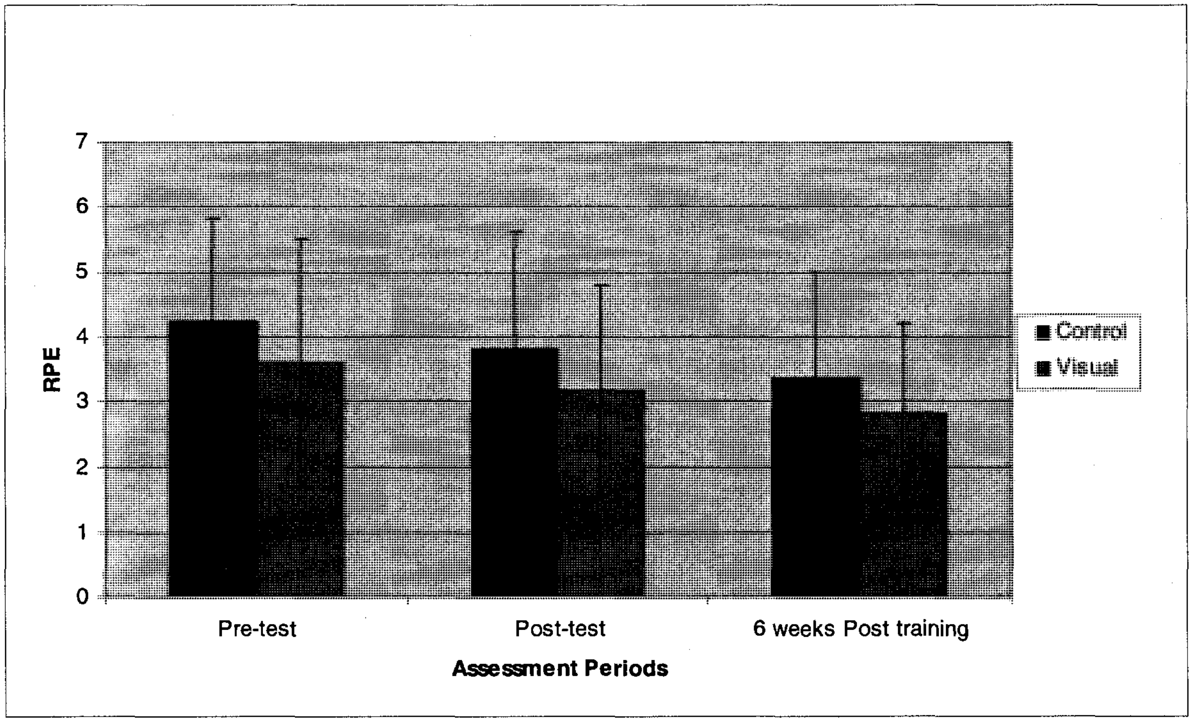


**Figure 1: Presented with SD bars.**

**Blood Pressure (Mean Arterial Pressure (MAP)) (mm HG)**

The difference in average blood flow per cardiac cycle was calculated before and after each treadmill test. A significant main effect of time was found for MAP values taken before treadmill testing for the three assessment periods ($F_{(2, 80)} = 4.78$; $p<0.011$). Post hoc analysis revealed MAP decreased from pre-test to 6 weeks post training ($p<0.012$) with a trend for decreased MAP from pre-test to post-test ($p<0.053$). The MAP means for the control group were lower only at pre-test and post-test (100.93 (±16.35), 94 (±16.11), 95.56 (±13.76)) compared to the visual group (102.15 (±13.14), 98.84 (±12.32), 94.83 (±11.15)) (Fig. 2).

### 4.4.3 Figure 2: Mean Arterial Pressure at Pre-test, Post-test and Six weeks Post training

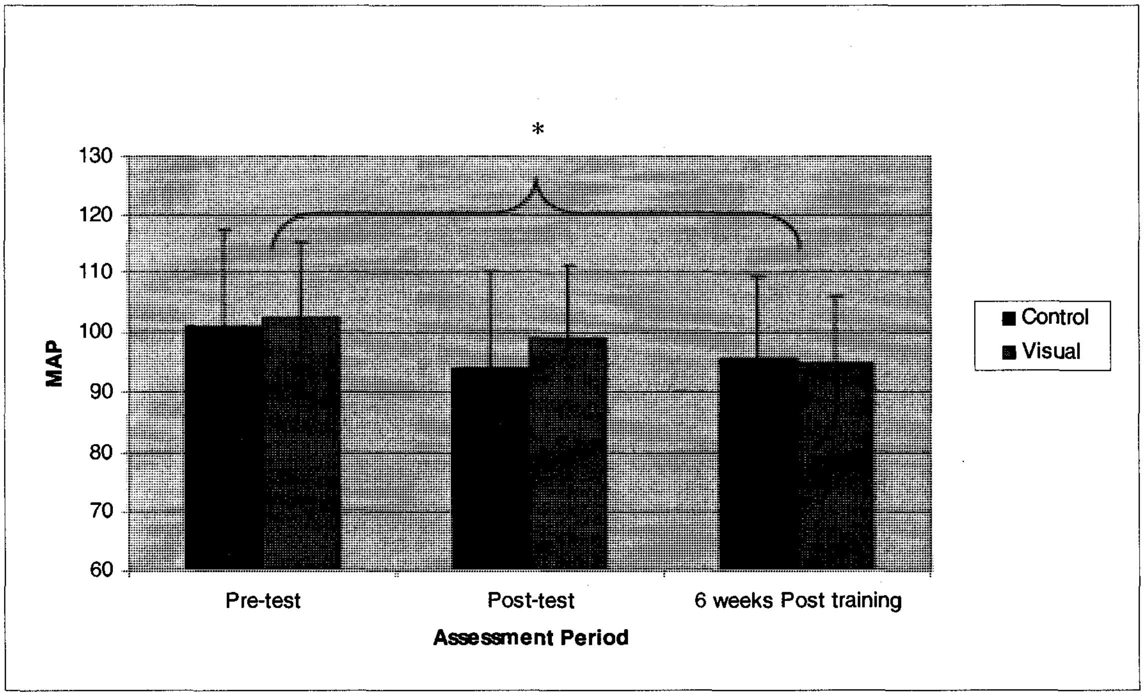


**Figure 2: Presented with SD bars. Significance level (*): p<0.05.**

**Timed-Up-and-Go (TUG) Test (seconds)**

A significant main effect of trials ($F_{(1, 40)} = 5.60$; $p<0.022$) was found for the TUG test times across the assessment periods. Post hoc analysis revealed the second test times decreased for the both groups (10.19 (±7.03), 9.81 (±7.41)) ($p<0.0224$). Additionally, significant main effects of trials showed faster TUG times were found for the second test from both pre-test to post-test ($F_{(1, 40)} = 7.3$; $p<0.01$) and post-test to six weeks post training ($F_{(1, 40)} = 4.53$; $p< 0.0395$).

In the preliminary analysis a trend towards a significant effect of assessment period ($F_{(2, 80)} = 2.66$; $p<0.076$) was found since groups TUG times decreased at post-test. The control group was faster in mean test times for each assessment period (9.2 (±3.67), 7.89 (±2.12), 8.70 (±2.62)) compared to the visual group (11.81 (±9.75), 10.60 (±7.18), 11.80 (±10.49)) (Fig. 3).

### 4.4.4 Figure 3: Timed Up-and-Go test at Pre-test, Post-test and Six weeks Post training

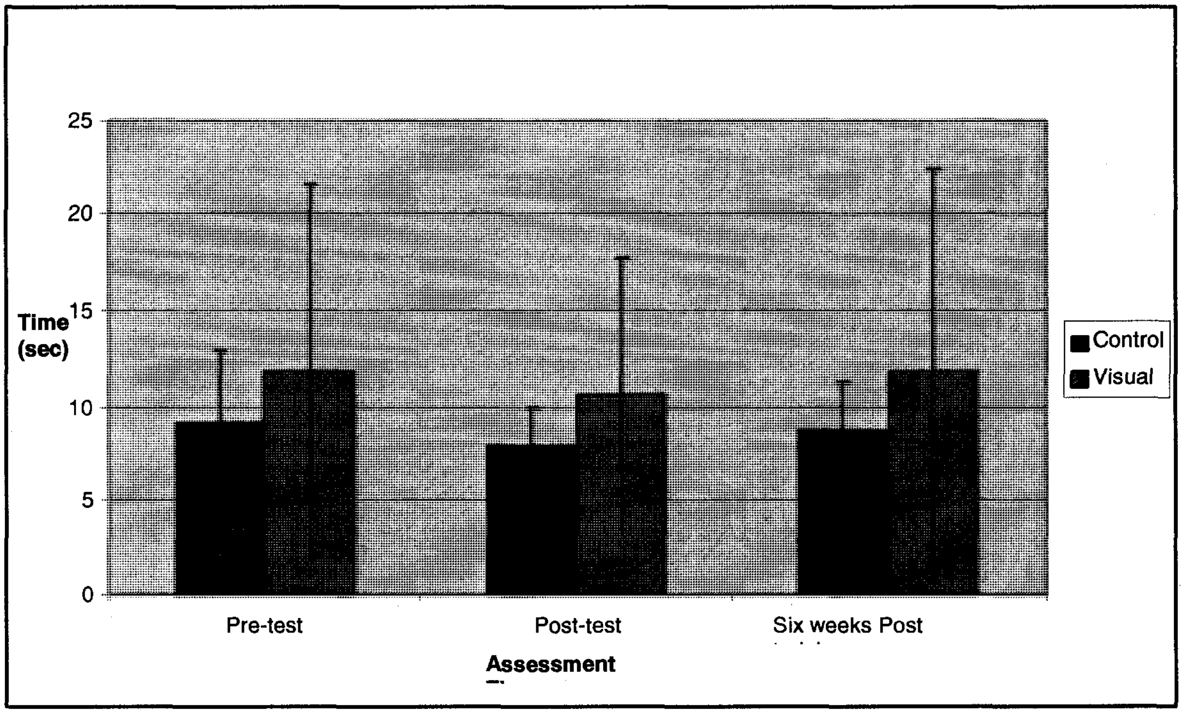


**Figure 3: Presented with SD bars.**

**Lafayette Pegboard test (seconds)**

The two pegboard movement sequences of insertion and removal phases were analyzed separately for this task. Further, for each component of this task only the clinically most affected side was measured. For the insertion phase, a significant main effect of assessment time was found ($F_{(2, 80)} = 3.45$; $p<0.037$). Post hoc revealed the mean insertion times decreased for the control group (152.32 (±64.56), 146.16 (±67.88), 141.23 (±61.69)) and the visual group (134.80 (±62.03), 127.07 (±60.67), 120.98 (±52.85)) from pre-test to six weeks post training ($p<0.0027$). The insertion times at the three assessment periods are illustrated (Fig. 4).

Subsequent analysis for the pegboard insertion times compared separated assessment periods. Significant main effects of trial were demonstrated for both the pre-test to post-test ($F_{(1,40)} = 15.23$; $p<0.0004$) and post-test to six weeks post training ($F_{(1,40)} = 20.79$; $p<0.000$). Slower insertion times were found in the first trials (146.43 (±63.41), 139.28 (±64.35) compared to the second trials (133.74 (±64.35), 128.44 (±57.56) for both assessment period comparisons.

For the removal times, a significant main effect of assessment time was found ($F_{(2, 80)} = 9.69$; $p<0.0002$). Post hoc revealed the differences from pre-test to both post-test and six weeks post training was found ($p<0.004$ and $p<0.0003$ respectively). The mean removal times for the control group (29.5 (±6.85), 26.79 (±6.65), 26.87 (±9.68)) were slower then for the visual group (27.20 (±8.61), 24.78 (±7.00), 23.32 (±8.41)) over the three assessment periods (Fig. 5).

A subsequent analysis for the pegboard removal times compared separated assessment periods. A significant main effect of assessment time was found from pre-test to post-test ($F_{(1, 40)} = 15.80$; $p<0.0003$). Post hoc revealed both groups were faster at post-test ($p<0.0003$). There was no significance found for the post-test to six weeks post training assessment comparison.

**4.4.5 Figure 4: Pegboard Insertion phase for affected side at Pre-test, Post-test and Six weeks Post training**

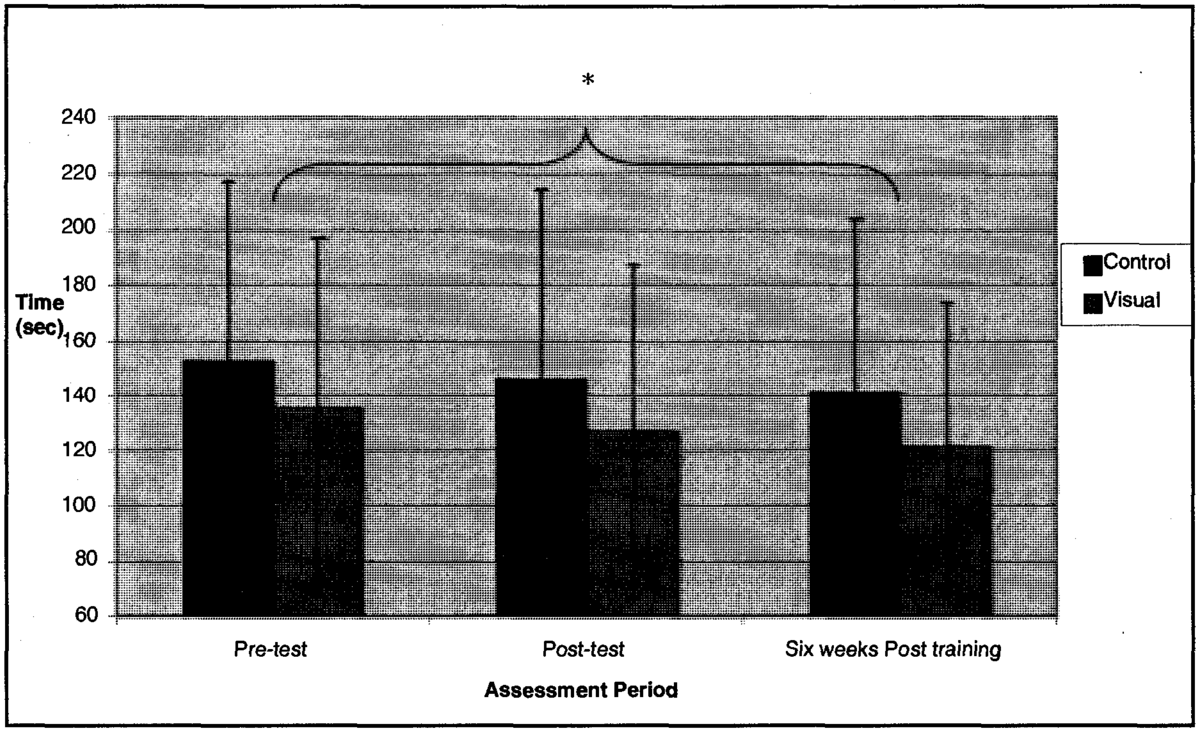


**Figure 4: Presented with SD bars. Significance level (*): p < 0.01.**

**4.4.6 Figure 5: Pegboard Removal times for affected side at Pre-test, Post-test and Six weeks Post training**

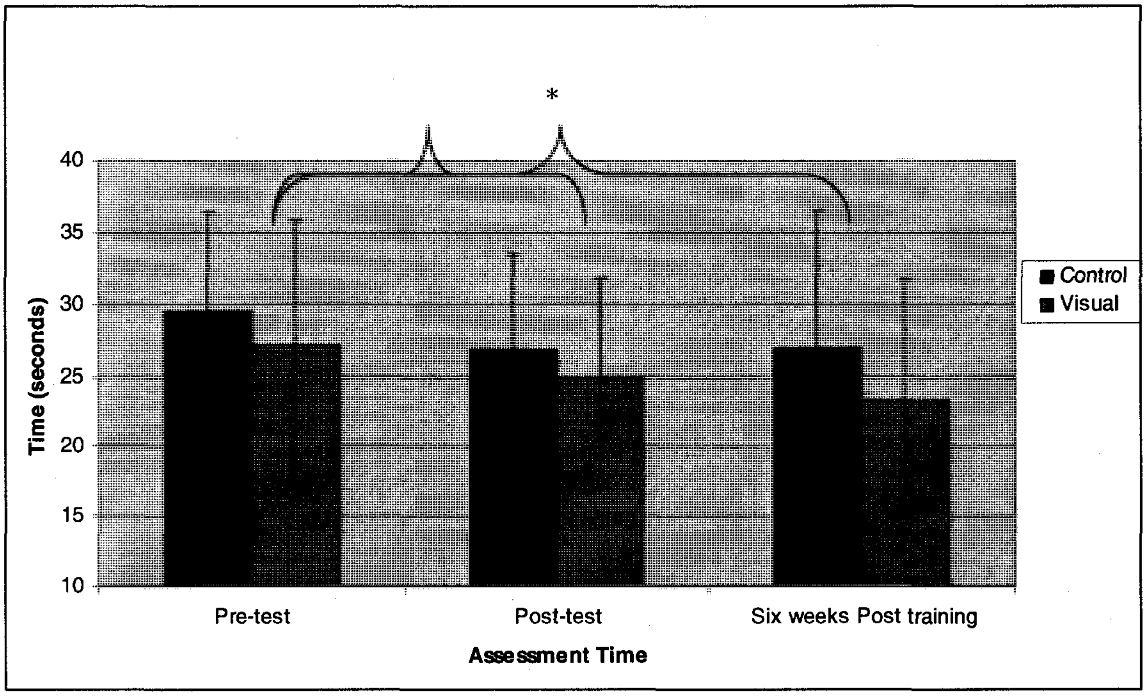


**Figure 5: Presented with SD bars. Significance levels: (*): p <0.001. Remaining: p<0.01.**

### 4.5 Discussion

The central purpose of this study was to assess whether differences existed between two groups that treadmill trained for 12 weeks, with only one group that was provided with concurrent visual feedback during training. Specifically, the differences in outcome measures of clinical interest included the responses of RPE, BP, the TUG and the Lafayette Pegboard tests that were evaluated both immediately and six weeks after training had ended. The assessments conducted aimed to gain understanding of the effectiveness the rehabilitative strategy of treadmill training for PD.

The RPE, the perceptual exercise intensity response was lowered in both groups immediately after the completion of 12 weeks of treadmill training, however unexpectedly a non-significant difference was found relative to the values at pre-test. These results conflicted to those of Burini et al., (2006) who found a significant difference in the RPE scores at specified workloads after only 20 aerobic training sessions. The significantly different RPE scores observed in their study may have been elicited from training the participants at standardized work rates on the cycle ergometer since this may have provided more explicit aerobic intensity aims that were then perceived by participants' compared to our individually tailored intensities on the treadmill. Our study found that the hardest perceived exercise intensity rating across both groups and all assessment periods was 'somewhat hard', a 4 on the Borg CR-10 scale® which indicated that our target exercise intensity was achieved. Interestingly, our study revealed an unanticipated significant difference in RPE scores existed for both groups when the pre-test scores to those attained at the six week post training assessment were compared. These findings indicated that our trained groups demonstrated longer-term carry-over effects after treadmill training had ceased for six weeks given that both groups responded similarly to the absence of training. These observations suggest that our moderate treadmill training exercise intensity had challenged participants sufficiently, however the significant reductions in perceived exertion ratings were time elapsed. The obtained reduction in perceived exertion levels significantly decreased only after our training had ended. These findings highlighted that the enhanced efficiency of movement attained was then transferred into the participants' real world applications. It was speculated that when participants were tested at six weeks post training they approached this treadmill test with a greater sense of aerobic capacity and more experience that translated into less difficulty perceived for the exercise intensity attained. An additionally interesting finding was the lowered perceived exertion ratings that were demonstrated by the visual group across all assessment periods. Since both groups were homogeneous at baseline, these findings suggest that the use of concurrent visual feedback enabled greater achievement in exercise intensity, with minimal difficulty perceived. Alternatively, training without the concurrent visual feedback resulted in an increased perceived difficulty of training of the control group, possibly all movements were 'sensed' without an external stimuli to focus on. Thus, regular, non-cued treadmill training may not have facilitated the achievement of greater exercise intensity, an assertion that was confirmed by the responses of lower perceived exertion scores.

An unanticipated finding was the response of our alternate physiological measurement, blood pressure, reported by mean arterial pressure (MAP). This evaluation aimed to provide an estimated average of the arterial pressure that occurred over a single cardiac cycle in our participants and although both groups' MAP was lowered after treadmill training, these demonstrated reductions did not significantly differ from the values attained at pre-test. Instead, the observed trends towards significance indicated that treadmill training has the potential to lower, thus possibly regulate blood pressure in PD. This potential benefit of treadmill training was supported by the unexpected significantly lowered MAP values observed when the values attained from pre-test to those from six weeks post training were compared. The maintained MAP reductions after six weeks without training indicated that the protective influence provided by aerobic treadmill training may not be an immediate, but instead influential in the longer-term. Our study considered the results of Pursiainen et al., (2007) who showed that the greatest fluctuations in blood pressure occurred when participants were wearing off medication. Our study had emphasized the strict adherence of medication intake for all participants to avoid such possible complications. Further, the results of Kallio et al., (2000) observed that deficiencies in blood pressure were different dependent on disease onset were difficult to compare to since our study focused on the differences that existed after the influence of concurrent visual feedback or regular, non-cued treadmill training. These concepts described however would be enticing areas to establish for future treadmill training research in PD.

Another fascinating finding observed in the current study included the faster TUG test times that were demonstrated immediately after treadmill training. However, the anticipated significantly faster completion times were not significantly improved from pre-test. Interestingly, the control group exhibited faster completion times for both TUG trials across the three assessment periods. These findings minimized the support for the supposed superiority of visual cued training in terms of the transferability of training into functional performance gains attained in PD. Instead, the improvements by the control group suggest that greater effectiveness was demonstrated by the transferred gross motor performance achieved with the regular, non- cued treadmill training. It was interesting that our findings contradicted the faster TUG test times demonstrated in the study by Nieuwboer et al., (2007). This study presented the concept that regardless of the order of the exercise or rest periods in their crossover design, the participants demonstrated faster times when cueing of their preferred sensory modality was incorporated into training (Nieuwboer et al., 2007). This observed difference could be attributed to the option that participants had for their external cueing modality, where our study only incorporated the external stimuli of concurrent visual feedback. Since the effect and benefits of treadmill training continue to be established, the influence of longer-term concurrent visual feedback during training and the corresponding transferability into functional skills requires further investigation.

An anticipated finding in the current study was demonstrated by faster pegboard insertion and removal times of the most affected hand across the assessment periods. However, only the hypothesized reduction of faster removal phase times immediately after training was accurate. The time to remove all pegs significantly decreased for both groups at post test and six weeks post training when compared to pre- test. However, an unanticipated finding was exhibited by the significant differences demonstrated for both phases in the comparison from pre-test to the six weeks post training assessment period. The separation of the two phases of the pegboard task is a recent development in the analysis of this data and therefore the comparison to previous literature can be achieved through similar trends observed. Our obtained findings are similar to those of Calgar et al., (2005) who also showed faster times for the completion of the pegboard task at the follow up assessment periods, 1 and 2 months after training. This analysis had separated both right and left hands, opposed to by the clinically most affected side that our study had incorporated. Our analysis of the most severely affected side provided specific information on the transferability of skills from treadmill training to the fine motor control that was measured. Our study was also comparable to the improvements observed by Reuter et al., (1999) even though these authors trained participants with specified simple motor sequences. This study demonstrated that faster pegboard times were observed immediately after training, at 14 weeks, however these improvements were not maintained at the 20-week follow up (Reuter et al., 1999). Alternatively, our findings demonstrated that the improved times to completion for both phases of this task occurred at our follow-up. These results suggest that fine motor improvements were attained through the gross motor treadmill training provided. There is a possibility of a practice effect to explain our results however, given the time delay of 12 and 6 weeks between our assessment periods, our study deemed that a practice effect from the overall limb coordination rather then that of the pegboard task was responsible for this effect.

### 4.5.1 Study Limitations

This study had a number of limitations that may have altered our findings. Our major limitation was also the most unique aspect of this study. During training participants were motivated to surpass their personal best training velocity, hence, our study offered individually tailored training and differences therefore existed in the testing and training intensities that were attained. This study could have provided standardized training intensities that were categorized according to disease severity to ensure that greater similarity was attained amongst the exercise groups.

Another limitation was the lack of our follow up evaluation for the exercises that were completed by our participants after the treadmill training was completed. The documented levels of exercise or activity could have benefited this research so our study could specifically conclude the significant differences obtained at the six week post training assessment were due to the carry-over effects from our program. This inference therefore loses credibility due to the lack of report obtained from participants, thus is considered a study downfall.

Additionally, the majority of our results have indicated that greater benefits were achieved by the control group suggests that our study design was limited. Our findings are contradictory to previous research that has indicated the utilization of visual cues has provided greater benefits in PD compared to without this external cueing. In retrospect, the incorporation of a crossover design would have been beneficial to then verify the effects that were demonstrated by the control group. Otherwise, it was asserted that more advantageous improvements occurred after treadmill training without the additional concurrent visual feedback provided.

### 4.5.2 Conclusions

This study concludes that treadmill training can provide lasting benefits in the PD population. The current individually based training demonstrated trends for decreased RPE, MAP, TUG and the pegboard tests times immediately after training, with significant changes that occurred at follow up when compared to pre-test. It was concluded that treadmill training can effectively improve timed gross and fine motor skills in this population in the longer-term. It was also concluded that the perceived exercise intensity may be lowered when treadmill training incorporates concurrent visual feedback. Further, reductions in MAP indicated that treadmill training may provide a protective influence for blood pressure in this population, particularly in the longer-term. These results are particularly intriguing, since they have promoted the continued investigation of both the short and long-term effects of this exercise form in this population. For future work, it is suggested that similar outcome variables of clinical relevance be incorporated.

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# Chapter 5: Grand Discussion

## 5.1 Overview

The overall objective of this thesis was to provide a thorough investigation of the influence of treadmill training on a number of physiological, gait and functional measures in PD. Additionally, this thesis attempts to determine whether the provision of concurrent visual feedback has any specific influences on symptomatic outcomes in PD. Two groups followed identical training programs on a BioDex GaitTrainer® however, the concurrent visual feedback presented through step targets according to each participant' step lengths were provided for only the experimental group. The participants' all trained with a treadmill protocol that promoted a progressively increased treadmill training speed over the 36 sessions. Our evaluations occurred at baseline, immediately after training and again six weeks later to accurately assess and interpret the effectiveness of treadmill training in PD.

## 5.2 Aerobic Efficiency Improves after Treadmill Training in PD

After treadmill training, our participants' improved their aerobic efficiency as observed by both HR and $Vo_2$/kg responses. The HR improvements were identified relative to pre-test and although both groups HR was lower immediately after training, significant reductions occurred only for the visual group. This suggests the group that treadmill trained with concurrent visual feedback attained a greater intensity of exercise relative to the regular, non-cued training group. The immediate aerobic efficiency improvements found at post-test were comparable to previous studies that have exhibited similar improvements in PD after aerobic training was provided (Bridgewater et al., 1996; Burini et al., 2006). In the crossover design study by Burini et al., (2006) the aerobic component occurred on a cycle ergometer and targeted the specified HR zones between 50-60% of the participants' maximum HR reserve. This study reported that non-significant HR reductions occurred after both aerobic components of their design (Burini et al., 2006). These results suggest that although HR reductions can be expected in PD after aerobic training, a greater intensity of exercise may be required to provide significant effects. Our groups trained at greater intensities of exercise, specifically between 65-85% of their age-predicted maximal HR. It was hypothesized that our visual group would exhibit significantly greater reductions in HR relative to the control group immediately after training due to the inclusion of visual feedback. The utilization of visual step cues has previously facilitated greater step lengths in PD (Azulay et al., 1999; Morris et al., 1996; van Wegen et al., 2006). The concurrent visual feedback was deemed responsible for the lengthened steps, faster velocities, greater workloads attained and also the greater reductions in HR achieved. Furthermore, the visual group also demonstrated a continuation of aerobic efficiency improvements as indicated by their lowered HR at the same workloads from post-test to six week post training. It was interesting to note the related findings from the subjective rating of perceived exertion, where the visual group perceived the treadmill tests as less difficult with each successive assessment period. These findings suggest the visual group trained at greater exercise intensity revealed through their greater improvements in aerobic efficiency.

Alternatively, the control group did not demonstrate significantly lowered HR immediately after training thus their aerobic efficiency improvements were less then those achieved by the visual group. However, the control groups' improvement was demonstrated by their significantly lowered HR when pre-test workloads were compared to those achieved at six weeks post training.. The improved aerobic efficiency demonstrated by this group suggests that these improvements were in response to our training program.. Similar sustained aerobic efficiency improvements have also been observed previously in the study by Bridgewater et al., (1996) where exercising participants' walking increased from 20 to 30 minutes over 12 weeks. In this study, the Bruce protocol had measured the participants' HR at baseline, immediately after the program and again four weeks later. In the comparison to a non-exercising control group, these authors did not report on HR specifically, but the mean stress test duration at each assessment period. They reported the exercise group had significantly increased their test duration immediately after training ($p<0.05$) with trends for lengthened test durations presented by both groups at four weeks follow up ($p>0.05$) (Bridgewater et al., 1996). Overall, these findings suggest that the aerobic efficiency attained from training was sustained in these participants with early PD however the improved control group responses at follow up must be explained. It was suggested that motivation was increased by the interest talks provided for the control group. It is plausible that if greater levels of motivation were reached, this may have led to greater activity undertaken by this group. In our study, the control group improved only after exercise training was completed. It is suspected that during training the control group focused specifically on their gait impairments that transferred into more efficient walking after treadmill training was finished. Therefore the lowered HR of the control group from pre-test to six weeks post training may be attributed to a greater ease and thus increased level of activity after the completion of training, versus a carryover effect from our program specifically. It was interesting to note that rating of perceived exertion levels were higher in the control group relative to the visual group across all three assessments. Specifically, a non-significant reduction in the perceived exertion rating was found from post-test to six weeks post training. These findings suggest that the aerobic efficiency achieved after 6 weeks of treadmill training were also perceived. Such findings are meaningful given that the training outcomes differed between our groups. Greater reductions occurred immediately after training for the visual group implying that treadmill training with concurrent visual feedback is beneficial for immediately lowered HR responses in PD. Alternatively, training without the reliance on concurrent visual feedback demonstrated that lowered HR responses were achieved at a later time. For the benefit of future studies a post hoc effect size evaluation for our heart rate change data from Pre-test to Post-test was conducted. The effect size ($\delta$) = 3.02 found indicated a small amount of overlap occurred for the two population means. This large effect size confirms the differences that existed between our groups HR responses. Nonetheless, it was necessary to document the effect size since there has been no report on these after PD treadmill training.

All participants responded to training with less oxygen consumption per kilogram of body weight ($Vo_2$/kg) required at each post-test workload relative to pre-test, however only the visual group exhibited significant improvements immediately after training. The aerobic efficiency improvements found were comparable to previous PD studies that have documented participants required less oxygen at the same workloads after aerobic training (Bergen et al., 2002; Burini et al., 2006). In the study by Burini et al., (2006) immediately after both aerobic components of cycle ergometry training in their crossover design, participants' required significantly less $Vo_2$/kg at the same workloads ($p$=0.009) (Burini et al., 2006). Similarly, in the study by Bergen et al., (2002) after the combination treadmill and cycle ergometry training, the aerobic exercise group demonstrated significantly less oxygen intake was required at the same workloads when compared to the non-exercising PD controls (Bergen et al., 2002).

In the current thesis the $Vo_2$/kg efficiency changes solely after treadmill training in a much larger sample of PD participants was examined. Significant improvements in $Vo_2$/kg were revealed by the visual group immediately after training relative to pre-training. The greater attention needed to focus on the concurrent visual feedback may have minimized the amount of external work, or extraneous movements typically found at sub-maximal workloads in PD. The findings indicated the visual group was more efficient at each sub maximal workload since extraneous movements were minimized to a greater extent in this group. It was interesting to observe once the external visual stimulus was removed after post-test, no improvements in relative $Vo_2$/kg were obtained at the six weeks post training. These results suggest that the originally attained efficiency at more difficult workloads was lost after detraining. Similarly, a loss of aerobic efficiency once achieved at higher workloads was demonstrated from pre-test to the six weeks post training assessment. However, in this relative comparison, the visual group exhibited greater aerobic efficiency only at the lower treadmill workloads. These findings suggest that PD participants who train with concurrent visual feedback may be limited in their aerobic efficiency after a period of detraining. Furthermore, these results support the notion that the visual group did not incorporate or benefit from additional external cues in their daily environments because the improvements originally achieved were not maintained.

Alternatively, the control groups' required $Vo_2$/kg at post-test was not significantly different from those attained at pre-test. This indicated that extraneous movements may have occurred in this group during training to a greater extent. However, it was very interesting to observe that the required $Vo_2$/kg at the same workloads from pre-test to six weeks post training were significantly lower. These aerobic efficiency improvements exhibited by the control group at the lower workloads suggest one of two possibilities. Either the totality of the aerobic training effects took much longer to become evident in this non-cued group, or that continued activity after training was accountable for these effects that were sustained. Since both groups' demonstrated a trend for less required $Vo_2$/kg at post-test workloads, this suggests the entirety of the training effects had occurred. Further, evidence can be seen from the reduction in the groups' respiratory exchange ratio. Therefore the influence of continued physical activity after our program was suspected to have maintained the $Vo_2$/kg efficiency improvements in this group. Overall, our results indicate that treadmill training can offer benefits of improved aerobic efficiency in PD.

Anticipated reductions in respiratory exchange ratio (RER) occurred in both groups immediately after training. However, the RER values at six weeks post training were unexpectedly still lower then those obtained at pre-test. These results indicated that treadmill training improved the participants' metabolic efficiency immediately that did not wear off at six weeks post training. The differences in RER across our assessment periods highlighted the adaptation that occurred in our participants. Our participants became more efficient in their utilization of energy sources thus suggesting the corresponding adaptations of increased mitochondrial density had occurred. Further, since the fat contribution was greater relative to carbohydrate across the assessment periods, this demonstrated that indeed participants became more efficient after treadmill training. The RER values obtained suggest that our program offered the intended moderate intensity of training, because fat utilization is known to occur with less intense exercise. It was determined that our training goals were therefore sufficient because participants' demonstrated an efficient metabolic response. Our results are the first to show that treadmill training may benefit the metabolic efficiency in PD.

The subjective exercise intensity was evaluated by the rating of perceived exertion (RPE). These scores demonstrated an unexpected non-significant reduction in both groups immediately after training and opposed the findings of Burini et al., (2006). These authors reported significant reductions in RPE scores occurred after only 20 aerobic training sessions on a cycle ergometer at specified work rates (Burini et al., 2006). Our study differed because individually tailored workloads were incorporated, according to the participants' ability. The highest reported intensity across both of our groups was a ratio of 4, 'somewhat hard' on the Borg CR-10 scale®. This response suggests that our intensity aims had met our target goal for moderate exercise intensity. If our participants described their exertion with values that were any higher, this would have indicated our protocol had pushed them too hard since an intensity of 5 or greater enters into the maximal exertion rating zone. Nonetheless, after six weeks without training both groups RPE scores had significantly decreased when compared to pre-test. This suggests that both groups responded similarly to the absence of training and perceived no difference in exertion then at post-test. However, a notable trend was that in comparison to the visual group, the control group responded with higher RPE responses across all assessment periods. This trend indicated that the control group perceived our treadmill tests as harder then the visual group and subsequently signified that treadmill tests may be accomplished with less perceived difficulty with the addition visual cues.

The likelihood that the exercise intensity achieved by both groups during training was not overly challenging was also demonstrated through the obtained mean arterial pressure (MAP). An unanticipated non-significantly lowered MAP value was found for both groups immediately after training ended. Overall, this trend supported the utilization of treadmill training for decreased if not regulated blood pressure in PD. This trend could be confirmed only if a greater intensity was attained by either group, since it is rationalized that the lowered scores may then have been significant. These findings demonstrated that the influence of our program was successful overall because improved or lowered MAP scores were maintained. Given that this thesis is the first study that has reported the blood pressure responses in PD after treadmill training it is asserted that this form of aerobic training has the potential to provide a protective influence for blood pressure fluctuations in this population.

## 5.3 Spatio-Temporal Charactertisitcs of PD Gait Improves after Treadmill Training

Our study indicated that treadmill training with and without the use of concurrent visual feedback increased the participants' efficiency of movement observed through gait changes. It was interesting that the time for the change in step length had differed between the groups at the two post assessment periods. The visual group exhibited significantly improved step length immediately after training. These findings are consistent with previously reported step length increases that have occurred immediately after testing with visual cues (Nieuwboer et al., 2007). A particularly fascinating finding was that the lengthened steps observed in the visual group immediately after training was unchanged six weeks later. Interestingly, the findings reported by Nieuwboer et al., (2007) opposed ours where their cueing training improvements achieved had deteriorated in the long term. This six week crossover design incorporated cueing of a preferred modality into two intervention groups that both showed a loss of improvements in their once significant step length at the six week follow up ($p<0.001$) (Nieuwboer et al., 2007). Our study indicated that the concurrent visual feedback was an effective addition to training since gait improvements were maintained weeks later. Additionally in our study the trend for significantly lengthened steps on the most affected side was observed in the control group only from post-test to six weeks post training. This indicated that the longer-term gait change for step length existed in the group that treadmill trained without the influence of concurrent visual feedback. Two possible explanations may describe these unexpected findings. The first possibility is that training the control participants became more comfortable, thus confident in their walking ability. Given that these participants selected their training velocity and trained without concurrent visual feedback, training without this potential visual distraction is suspected to have enhanced their overall gait proficiency. Instead the control group may have focused to a greater degree on specific aspects of their gait that required improvement. If they had increased their attention to their gait, everyday walking thereafter would have been easier to continue. Although the participants were asked to maintain their normal activity levels after training was finished, the perceived activity of the control group may have been altered after participation in our 12-week program. Therefore, the improvements in step length are attributed to a potential increase in the participants' original activity levels once training was completed. The second possible explanation for the maintained step length improvements of the control group was that the effects of training took much longer to become apparent. This would suggest that a lengthy lag time occurred from gait training 'practice' into gait change captured by our evaluations. However, the control groups' trend for improved step length immediately after training which increased significantly weeks later suggests the possibility for continued walking after our program was responsible for these effects.

All of our participants also presented improved gait velocity immediately after treadmill training when compared to pre-test, although again significant change only occurred for the visual group. Nonetheless, our findings are similar to previous treadmill training programs that have also demonstrated increased gait speeds immediately after training (Herman et al., 2007; Miyai et al., 2000; Miyai et al., 2002). Since our study included an exercising control group, it was interesting that differences existed for the time of improvement in our two groups. The significantly faster velocity observed in the visual group immediately after training signified that the concurrent visual feedback was effective. Furthermore, the visual groups' velocity improvements also were unchanged at six weeks post training. The control group velocity improvements demonstrated that significantly faster velocity was found only from post-test to six weeks post training. A possible explanation for these observed velocity differences may be explained by the disparity between these groups prior to training, where the control group was faster then the visual group at pre-test. However, if this explanation was correct, it would then be expected that the control group would also exhibit significantly increased gait velocity immediately after training, which did not occur. The observed control group improvement is attributed to a greater focus to their gait speed, since without the additional external visual stimuli these participants may have been compelled to a greater extent to rely on their own internal rhythm. To benefit future studies a post hoc effect size evaluation was conducted for the velocity data from Pre-test to Post-test. The effect size ($\delta$) = 0.39 indicated a fairly large overlap in the population means. Next it was decided to complete an analysis to determine the required effect size for our desired amount of power. The calculated sample size included our minimum requirement to attain sufficient power, an effect size ($\delta$) =0.5 at an alpha level ($\alpha$) = 0.05. This calculation determined that future studies would require a minimum of ~34 participants in each exercised group to detect meaningful group differences. This effect size and corresponding sample size estimation was necessary to document since these have yet to be reported after a PD treadmill training study.

An interesting finding was a trend for faster TUG times immediately after training for both groups. Given that treadmill training is gait-focused, the additional components of the TUG test that include rising from a chair and turning may not have necessarily been influenced. However, it was speculated that our training would have influenced the decreased times during the 3 meter walk component, although the separate TUG test components were not analyzed. However differences between the groups' times were found as the post-test times were faster then those obtained at six weeks post training. Of particular interest was that the control group demonstrated faster completion times immediately after training. These findings suggest that training without concurrent visual feedback may have provided a greater transfer of learning for this gross motor task. Furthermore, the lack of significant differences for our visual group indicated that concurrent visual feedback during training did not assist these participants to achieve faster TUG times. Results found by Nieuwboer et al., (2007) indicated that after cueing training the TUG test times also did not improve both immediately and six weeks. These authors reported that the lack of significant differences in TUG test responses occurred for the both the early and late intervention groups in their crossover design (Nieuwboer et al., 2007). It was therefore asserted that treadmill training without the use of concurrent visual feedback may provide a greater response for this functional performance task in PD.

The fine motor task of the Lafayette Pegboard phases demonstrated inconsistent responses. Faster, however non significant completion times were found for the insertion phase in both groups immediately after training. Our study therefore concluded that treadmill training might not have specifically influenced the fine motor requirements to insert these pegs. However, our results indicate that some training influence was evident because both groups presented significantly faster insertion times when the pre-test to the six week post training assessments were compared. These findings demonstrated that our training may have influenced the increased coordination that transferred to this fine motor task. There have been no treadmill training studies that assess the influence of training on pegboard times.

Of particular interest was that our program did influence the pegboard removal times, because both groups' removal times were significantly faster immediately after training when compared to pre-test. The removal times were also significantly faster for both groups when the baseline to the six weeks post training assessments was compared. Similarly, the study by Reuter et al., (1999) reported that significantly faster pegboard times are possible in PD. Their participants' pegboard times were faster immediately after 14 weeks of training and were still faster at six-week follow up when compared to baseline (Reuter et al., 1999). The reductions in the pegboard completion times were however the outcome of their simple motor sequence training. These findings highlight that individuals with PD can respond with fine motor speed improvement after the appropriate training. Our study demonstrated that the coordination required to treadmill train had influenced this fine motor task. An additionally intriguing finding was the slower removal times for the control group across all assessment periods. The influence of the concurrent visual feedback is therefore responsible for the increased removal speeds, thus have concluded that these cues enhanced the transfer of learning to a greater extent. The concurrent visual feedback might have influenced the visual groups' upper limb coordination to a greater extent then that attained by the visual group. In order to present greater removal speeds in the pegboard task, this would require more efficient coordination of the upper limbs. Thus, the greater awareness of contra-lateral limb coordination in the visual group may have translated into faster fine motor control that was exhibited by these removal times.

### 5.4 Motor Symptom Severity does not benefit from Treadmill Training

The motor symptom severity findings indicated that treadmill training with or without the use of concurrent visual feedback was not an effective rehabilitative therapy tool for the PD population as symptoms did not improve. Our groups demonstrated a worsening of motor symptoms immediately following our program. These results were consistent with one other treadmill training study by Miyai et al., (2002) who reported no long-term motor symptom severity improvements after training participants' for 45-minute sessions, three times a week for four weeks (Miyai et al., 2002). Given that our study offered 24 more sessions then this previous study indicated that our findings were a more accurate representation of the effect of treadmill training for this population. Our findings however do contradict previous treadmill training studies that have reported improvements in motor symptom severity after training for four, six and eight weeks in total, respectively (Fisher et al, 2008; Herman et al., 2007; Miyai et al., 2000). However, these findings were questionable as the utilization of blind evaluators was not documented. This is a concern as there would then be the potential for experimenter bias while evaluating the participant's motor symptoms. Thus, since our intervention is the longest PD treadmill training study and the first to include a blind evaluator, our findings have this training was not an effective to improve motor symptom severity.

However, a particularly interesting finding was the trend observed for lowered motor symptom severity in only the visual group six weeks after the completion of training. This trend suggests that the visual cued training might have some motor symptom severity benefit for this population. This trend suggests it is possible that too much visual feedback was provided to this group, where the application in daily life may have elicited the motor symptom change. Since the control group scores varied little six weeks after our program compared to post test indicated that the value of treadmill training alone might not be sufficient to improve motor symptom severity in PD. However, it is necessary that the natural progression of PD is considered prior to making these assertions. Typically in PD, over the course of 12 weeks an individual may increase, or progress in symptom severity by approximately 2-5 points on the UPDRS motor symptom severity sub section. The results of this thesis study are consistent with the typical increase in motor scores and therefore our findings must be interpreted with caution. It is possible that this form of training may not necessarily impact motor symptom severity negatively, or to a greater extent then expected naturally with disease progression. It is important to note that participants did not worsen from Post-test to Six weeks post training which suggests that treadmill training in fact may have neuro- protective qualities. These findings have necessitated the continued investigation into treadmills for training purposes because the typical fitness approach regards them solely on their effectiveness. It is important that our study observations are known as it is has been demonstrated that treadmill training may be limited for improving motor symptom severity in this population. Since disease progression is a concern and reality in PD, it is crucial that possible misconceptions about treadmill training effectiveness become known.

**Study Limitations:**

The current study has provided a framework for the continued investigation of the effect of treadmill training in PD. It was determined that the influence of the concurrent visual feedback resulted in different responses for our two groups' cardio-respiratory, gait and symptom severity measurements examined in our immediate and longer-term assessments. There were however limitations that existed in our study that may have altered our study findings.

An avoidable limitation determined was the inconsistent calibration times of the concurrent visual feedback step targets on the treadmill at the MDRC location. The BioDex GaitTrainer® was calibrated three times over the course of the training period, once at the beginning and twice during the training because the step targets appeared irregular. This was a limitation due to the presentation of the step targets being temporarily slightly larger or shorter for the visual group and thus could have been considered faulty. Although, the

BioDex representative did not recommend that calibrations occurred continually. However, it was determined that our calibrations could have been more consistent, for example on a weekly basis. It is therefore recommend that future work considers pre-planned calibration times to avoid any potential complications during training and well to ensure consistency of the concurrent visual feedback throughout the training.

Another limitation that could have been better controlled for was the difference in training initiation times that existed over our three training locations. The differences in our results could be partly attributed to the seasonal variation when training was completed. Our first training group began in mid winter where our last training group began in late spring. The participants' motivation and/or activity levels may have differed in the winter control groups and thus may have altered their attained responses to testing and training. Future work should establish a greater consistency in training start dates when two groups are compared to avoid any seasonal fluctuations in activity and or motivation that could occur.

Additionally our study determined that differences existed for the auditory influences across the three training locations that could have altered our study findings. The participants that trained at the MDRC treadmill laboratory were provided with musical accompaniment while training, where this was not provided at the YMCA locations. Instead, the gymnasium atmosphere influenced the participants at the YMCA locations while they trained. The consistency of musical accompaniment along with the training environment should be considered for future work. It is recommended that future studies control for these external factors to provide training environments that are similar.

The three training locations presented an obvious limitation for the possibility for differences that existed in the delivery of the program. Prior to training initiation, the control group YMCA supervisors were all trained to become familiarized with the training protocol and the program goals. However, personal representation by the principle investigator to ensure training consistency occurred only for the Kitchener-Waterloo YMCA location. However, correspondence via telephone and email had occurred frequently for both YMCA locations, although variation in delivery may have still existed. Future programs should consider the utilization of only one training location to ensure that protocol requirements are completed without major variations. Otherwise, a greater emphasis should be placed on the alternate trainers, such that weekly or biweekly visits from the principle investigator are incorporated to ensure standardization of the program delivery.

The lack of follow up of the participants' physical activity levels after training had ended was a study downfall. Our conclusions may only be based from logical inferences, because our study did not record whether participants maintained, increased or decreased their physical activity levels after training. It is recommended that future training studies that incorporate a follow up period include a record of physical activity so that greater strength for all conclusions can be established.

Our study lacked control for the consistency of the participants' medication intake. Control for the scheduled medication doses during our assessment periods was attempted however it is difficult to ensure that participants are on schedule. Further, participants were scheduled to be evaluated according to their 'ON' periods, approximately 45 minutes to 1 hour after medication ingestion. However, even with our attempts to control for 'ON' medication periods, it is complicated to determine the compounding factors that include the absorption and metabolism of each medication. Furthermore, the influence of our treadmill training program could have altered the amount of medication that may have been required for our participants. It is possible that with the benefits of aerobic exercise, a reduction in the amount or dose of medication could occur..

Lastly, the analysis utilized to determine effectiveness of our program could have been represented with superior statistical techniques since multiple comparison bias was not controlled for. Our study incorporated various ANOVAs to characterize the changes found between our two groups, across three assessment periods that included outcome measures with many trials or conditions. Future studies might consider the use of a multivariate statistical technique to achieve greater understanding of the data. If such techniques were utilized there is greater likelihood that the effectiveness of our program and/or the factors that would define it may have been presented with greater clarity. The reason the use of a multivariate test is superior is because it protects against the possibility of an inflated alpha level. The individual alpha levels determined in this thesis were not adjusted, despite performing multiple tests of significance on our various dependent variables. The utilization of multivariate tests on the other hand would not provide such protection, thus may have provided more meaningful conclusions. Therefore the analysis utilized and the conclusions presented in this thesis must be considered within the context that there could be correlations within our variables of interest that are not presented.

## 5.5 Summary and Overall Conclusions

### 5.5.1 Treadmill Training Improves Aerobic Efficiency in Parkinson's disease

It was concluded that treadmill training with or without the use of concurrent visual feedback improved the aerobic efficiency of our participants. Improved aerobic efficiency was found by lowered relative heart rates and the less oxygen was required at the treadmill workloads across our assessment periods. Further, trends observed for lowered respiratory exchange ratio, subjective perceived exertion ratings and the mean arterial pressure were also found immediately after our program when compared to pre-test indicated these alternative improvements may also be attained from treadmill training. It was observed that the incorporation of concurrent visual feedback provided participants with greater relative improvements for the physiological variables measured when compared to the control group however, only immediately after training. Therefore it was concluded that concurrent visual feedback during treadmill training provided the greatest aerobic efficiency change that was demonstrated in the short-term. Alternatively, the regular, non-cued treadmill training also improved aerobic efficiency responses in PD however, primarily in the comparison from six weeks post training to pre-test. Therefore to conclude treadmill training can provide improved aerobic efficiency responses in PD.

### 5.5.2 Treadmill Training Improves Spatio-temporal characteristics of gait in Parkinson's disease

It was determined that treadmill training improved the gait of our PD participants. Greater improvements in were achieved by both the step length and velocity immediately after our program relative to the pre-test evaluations after concurrent visual feedback was provided. It was also observed that treadmill training improved the long-term functional gait performance, measured through the TUG test. Our study suggests that the utilization of concurrent visual feedback enhanced the visual groups' gait, possibly because of the demonstrated aerobic efficiency improvements immediately after training was completed. It was therefore concluded that treadmill training with concurrent visual feedback in the form of step cues will benefit the PD gait in both the short and long term and the observed improvements were sustained at six weeks follow up. Alternatively, the participants that treadmill trained without the utilization of concurrent visual feedback responded with improved gait however our study compared the differences from six weeks after the completion of our program relative to the post-test evaluation. Therefore it was concluded that sustained improvements can be attained with regular, non-cued treadmill training in PD.

### 5.5.3 Treadmill Training does not benefit motor symptom severity in PD

It was determined that PD motor symptom severity was not lowered thus did not positively respond to treadmill training with or without the influence of concurrent visual feedback. It was therefore concluded that treadmill training is not a sufficient rehabilitative tool to provide reductions or maintained motor symptom severity scores in PD. It was therefore concluded that treadmill training is an inadequate training tool to provide benefits in motor symptom severity.

It is recommended that future work carefully consider the study design utilized. It is suggested that a crossover design incorporates concurrent visual feedback training for one component with non-cued treadmill training for the other. With such a study design, it can be concluded the effect of concurrent visual feedback with greater assurance, because the particular effect would be more clearly evident. Alternatively, an additional study design to be considered includes the intermittent use of concurrent visual feedback while training. Since the practicality of visual cues is limited in everyday life for those with PD, it is therefore recommended that a practical walking component be used in conjunction with concurrent visual feedback training on the treadmill for greater training feasibility to be achieved.

### 5.5.4 Take Home Messages

1. Treadmills have aerobic benefits to offer!
    a. Improvements to be attained after training:
        i. Lowered heart rate and less oxygen needed
        ii. Burn off fat
        iii. Potential to lower blood pressure
2. Treadmills can benefit your ability to walk!
    a. Capable of walking faster
    b. Take larger steps
    c. Potential to make activities of daily living easier
3. Treadmills may not change your PD symptoms!
    a. Limited in terms of helping/improving the severity of PD

# Appendix A Treadmill Testing Protocol

**PARTICIPANT INFORMATION:**
CODE: ________________DOB: _______________
HR MAXIMUM: 208 – (AGE * 0.7) = _____85% MAXIMUM HR: _____
65% MAXIMUM HR: _____
HEIGHT: ______WEIGHT: ______
COMFORTABLE WALKING PACE FROM GAITRITE = ______
NOTE: 1 mph= 1.61 km/h, 1.5 mph=2.41 km/h, 2 mph=3.22 km/h, 2.5 mph= 4.02 km/h, 3 mph = 4.83 km/h, 3.5 mph = 5.63 km/h, 4 mph = 6.43 km/h, 4.5 mph = 7.24 km/h

| | Time (min) | KPH | Grade (incline) | HR (last 30 sec) | BP (last 30 sec) | RPE (last 30 sec) | METS |
|---|---|---|---|---|---|---|---|
| Baseline | | | | Rest = | Rest = | | |
| Warm Up | 0 to 1 | 1.61 | 0 | | | | |
| Warm Up | 1 to 2 | 2.41 | 0 | | | | |
| Warm Up | 2 to 5 | SSP | 0 | | | | |
| Stage 1 | 0 to 3 | SSP | 1 | | | | |
| Stage 2 | 4 to 7 | SSP | 3 | | | | |
| Stage 3 | 8 to 11 | SSP | 5 | | | | |
| Stage 4 | 12 to 15 | SSP | 6 | | | | |
| Stage 5 | 16 to 19 | SSP | 7 | | | | |
| Stage 6 | 20 to 23 | SSP | 8 | | | | |
| Stage 7 | 24 to 27 | SSP | 9 | | | | |
| Cool Down | 0 to 5 | 2.41 | 0 | | | | |
| Recovery | | | | Rest = | Rest = | | |
| CONTINUE UNTIL REACH 85% MAX HR. BEGIN COOL DOWN ONCE REACHED | | | | | | | |

# Appendix B Treadmill Training Protocol

**PARTICIPANT INFORMATION:**

CODE*: ____________DOB: ___________

HR MAX: 208 – (AGE * 0.7) = _________85% MAX: _______65% MAX: _______

HEIGHT: _______WEIGHT: _______

COMFORTABLE WALKING PACE FROM GAITRITE* = _______

*SPREADSHEET OF VELOCITIES PROVIDED AFTER PRE ASSESSMENT

| | Time (min) | KPH | HR (last minute) | BP (last 30 sec) | RPE (last 30 sec) | METS |
|---|---|---|---|---|---|---|
| | | | | | | |
| Baseline | | | Rest: | Rest: | | |
| Warm Up | 0 to 5 | CWP | | | | |
| | | | | | | |
| Stage 1 | 0 to 4 | | | | | |
| | | | | | | |
| Stage 2 | 5 to 8 | | | | | |
| | | | | | | |
| Stage 3 | 9 to 12 | | | | | |
| | | | | | | |
| Stage 4 | 13 to 16 | | | | | |
| | | | | | | |
| Cool Down | 0 to 5 | CWP | | | | |