Journal of Motor Behavior

ISSN: 0022-2895 (Print) 1940-1027 (Online) Journal homepage: https://www.tandfonline.com/loi/vjmb20

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To cite this article: Asa Bartonek, Cecilia Lidbeck, Kerstin Hellgren & Elena Gutierrez-Farewik (2019) Head and Trunk Movements During Turning Gait in Children with Cerebral Palsy, Journal of Motor Behavior, 51:4, 362-370, DOI: 10.1080/00222895.2018.1485009

To link to this article: https://doi.org/10.1080/00222895.2018.1485009

Published online: 16 Oct 2018.

Journal of Motor Behavior, Vol. 51, No. 4, 2019

RESEARCH ARTICLE

Head and Trunk Movements During Turning Gait in Children with Cerebral Palsy

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ABSTRACT. Thirty children with cerebral palsy (CP) and 22 typical developing (TD) were tested with 3D-gait analysis. At turning, trunk rotation was larger in CP2 (GMFCS II) than in TD and CP1 (GMFCS I), and head flexion was larger in CP3 (GMFCS III) than TD. Maximum head and trunk flexion values during the entire trial were larger in CP3 than in the other groups, and trunk flexion was larger in CP2 than in TD. Trial time increased with GMFCS-level. Less trunk rotation than TD and CP1 reflects spatial insecurity in CP2, which in CP3 is compensated by the walker. The flexed head and trunk in CP3 and trunk in CP2 may reflect deficits in proprioception and sensation requiring visual control of the lower limbs.

Keywords: gait, perception, sensation, proprioception, spatial orientation

In children with cerebral palsy (CP), turning during gait has been proposed to better approximate daily walking tasks than straight walking (Dixon, Stebbins, Theologis, & Zavatsky, 2016). Various turning strategies of the lower limb position with respect to pelvic rotation have been identified in children with spastic diplegic CP (Dixon, Stebbins, Theologis, & Zavatsky, 2013). However, when comparing turning gait between children with CP and typically developing (TD) children, only few overall group differences were found in kinematics of hip, knee, ankle and foot as well as in hip and knee kinetics (Dixon et al., 2016). Furthermore, in the CP group, reduced stability during the approach phase of turning as well as decreased stride length and decreased stride width were found in the latter study. Dixon et al (2016) recommend inclusion of turning protocols to identify motion patterns not evident in straight walking for patients with even minor deviations in gait. In this study, we were interested to objectively register turning movements in children with motor difficulties.

There is a close coordination between the movements of the lower body that sustain bipedal locomotion, and the head and eye motions that direct and orient gaze. While eye, head, and body movements stabilize gaze during straight walking, anticipatory roll head movements during turning are likely to be utilized to overcome inertial forces that would destabilize balance during turning (Imai, Moore, Raphan & Cohen, 2001). Controlling head movement while walking might be one of the key factors in locomotor equilibrium development during childhood (Assaiante & Amblard, 1993). Moreover, during locomotion, information for upright stability and body position relative to the external environment is provided by vision (Logan et al., 2010). In children with CP with oculomotor dysfunction, compensatory strategies such as brusque head movements have been reported (Fazzi et al., 2012). Furthermore, differences have been observed between children with CP and control children in head movements in the frontal plane, as well as in trunk movements in the frontal and sagittal planes. These deviations were considered to enable children with CP to develop "en bloc" compensation strategies in gait production by reducing the number of degrees of freedom that have to be controlled (Wallard, Bril, Dietrich, Kerlirzin, & Bredin, 2012).

According to the definition of CP, motor disorders are often accompanied by disturbances in. sensation, perception and cognition, which at times produce even greater activity limitation than the motor impairments (Rosenbaum et al., 2007). Basing the diagnostic framework mainly on the analysis of motor problems may thus cover a child's genuine movement difficulties and more research has been sought to understand the impact of factors such as vision, cognition and motivation, as well as to explore individual differences in mobility among children within the same gross motor function level (Rosenbaum et al., 2002; Tieman, Palisano, Gracely, & Rosenbaum, 2007). Already in the1980s, authors reported deficits in the strategy to organize sensory inputs and to coordinate activities of leg and arm muscles in children with CP (Nashner, Shumway-Cook, & Marin, 1983). Studies have also reported disturbances in joint proprioception compared to control children. Wingert, Burton, Sinclair, Brunstrom, and Damiano (2009) found a threefold greater error joint-position sense in the hips in children with CP, indicating tactile and proprioception deficits. Furthermore, children with more intact lower extremity proprioception values walked faster and had less postural sway than those with less,

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indicating a link between sensory and motor performance (Damiano, Wingert, Stanley, & Curatalo, 2013). A recent theory suggests that visuospatial deficits involving the manipulation of multiple spatial reference frames are crucial components in CP and that "motor" or "sensorimotor" deficits can be observed either in manipulation, in locomotion, navigation or in spatial orientation (Berthoz & Zaoui, 2015). In an attempt to identify perceptual disorders in children with CP, specific signs have been suggested (Ferrari, Sghedoni, Alboresi, Pedroni, & Lombardi, 2014). One of these signs is a static posture of upper limbs in startle reaction position which is characterized as flexed and abducted shoulders, opened hands and flexed wrists. Another sign is postural freezing with trunk and head in a rigid and fixed position inhibiting the child from using its motor repertoire during activities. Both signs are usually proportional to depth perception and are often observable when the child's awareness of exposure to the surrounding space increases. In the study of Ferrari et al. (2014), interrater reliability was moderate for startle position in upper limbs, and fair for posture freezing, nevertheless we consider the signs useful to characterize postural responses in children with disturbances in movement and posture as mentioned in the definition of CP. The impact of perceptual disorder in children with CP has also been investigated during a functional reach and touch experiment from a sitting posture (Ferrari, Tersi, Ferrari, Sghedoni, & Chiari, 2010). Their results showed that children diagnosed with CP and perceptual disorder had major difficulty in accomplishing the reaching tasks, and rarely recruited anticipatory postural adjustments, each of which was characterized by small amplitude and inaccuracy in direction.

In a previous study, we have reported about head and trunk movements in children with bilateral spastic CP (BSCP) during straight walking towards an external target at the end of the walkway (Bartonek, Lidbeck, & Gutierrez-Farewik, 2016). In that study, the children were instructed that they should look at a 15-cm diameter lamp covered with red translucent tissue placed at eye level at end of the walkway. Towards the target, children with TD reduced head, neck and trunk movements in the sagittal and transverse planes as well as temporal-spatial parameters. Children in GMFCS I reduced movements similar to children with TD, children in GMFCS II behaved nearly unchanged, whereas children in GMFCS III reduced movements and temporal-spatial parameters, potentially as a consequence of lack of sensory information from lower limbs with the need of compensatory visual control. Furthermore, in children in GMFCS III, the walker was considered to serve as an external reference frame, which enabled functional ambulation in the presence of difficulties in spatial perception.

In clinic, we have observed the phenomenon with "en bloc" turning in children with CP as described by Wallard et al. (2012). The aim of this study was to explore head and trunk movements during turning based on the hypothesis that movements would increasingly deviate with greater motor impairment.

Methods

Participants

Thirty-five children with BSCP and with independent walking with or without a walking aid and ability to follow verbal instructions were consecutively included in this observational study between August 2012 and September 2013. Five children were excluded – three who could not steer their walkers and two who used canes – thus 30 children (14 females; median age 11.7 years) participated in the study. The children were divided in groups with respect to their motor function; 8 children were functioning at GMFCS level I (CP1), 12 children at GMFCS level II (CP2), and 10 children were at GMFCS level III, requiring a walker (CP3). All children were recruited through the neuro-orthopedic unit of Karolinska University Hospital, Stockholm, receiving their rehabilitation from the community outclinic service. Twenty-two TD children (11 females; median age

TABLE 1. Age, Weight and Height in Children with Typical Development (TD) and in Three Groups of Children with Bilateral Spastic Cerebral Palsy (CP).

	TD, $n = 22$	CP1, $n = 8$	CP2, $n = 12$	CP3, $n = 10$	p-value
GMFCS level		I	II	III	
Age, years, median (range)	9.9 (6.6–14.9)	11.5 (8.4–16.2)	11.5 (7.9–16.1)	12.3 (7.8–17.4)	ns
Weight, kg, median (range)	38.8 (22.3–81.8)	41.8 (31.6–52.7)	40.3 (26.4–99.7)	40.9 (18.5–56.2)	ns
Height, cm, median (range)	140 (121–179)	151 (131–164)	147 (124–166)	142 (110–170)	ns

ns indicates non-significant statistical difference.

9.1 years) constituted a control group. There were no significant differences in age, weight and height between the TD and CP groups (Table 1).

The study was approved by the Regional Ethical Review Board in Stockholm. All parents of the children gave their informed consent for participation in this observational study. Oculomotor function was assessed as present or absent visual fixation, smooth pursuit eye movements, saccadic movements and strabismus. Visual acuity was assessed as sufficient at $\geq$0.3 and visual field as normal versus deviant. Twelve children had corrected vision, wearing glasses, of which seven were in CP2 and five in CP3. Data from an ophthalmological examination were available in 27/30 children. Visual fixation data was available in 24 children of which disturbed in five, smooth pursuit eye movements were discontinuous in 16/27, examination of saccadic movements were available in 26, of which dysmetric in 18, examination of strabismus was available in 26 of which present in 16, examination of acuity was available in 26, of reduced in 2, and visual field was deficient in 10/27 children. There were no significant differences between the CP groups in any ophthalmological symptom.

Movement Analysis

All children were tested with a three-dimensional, eight camera, motion analysis system (Vicon MX40®, Oxford, UK) with a sampling rate of 100 Hz. A conventional full-body biomechanical model with 34 retroreflective markers attached to anatomical landmarks on the head, trunk, pelvis and lower limbs (Plug-In-Gait model Vicon®) was used, based on the Newington model (Davis, Õunpuu, Tyburski, & Gage, 1991). The children were tested barefoot to ensure not to having influenced the conditions of foot sensation and proprioception from the ankle. Positions and movements of the head were registered through four head markers, and of the trunk by virtual markers on midpoints of the suprasternal notch and 7th cervical vertebra, and of the xiphoid process and 10th thoracic vertebra. Digital video recordings were performed simultaneously. The children were instructed to walk towards a red and white target, 20-cm tall of 10 cm diameter, placed approximately 3 m away on the floor, walk around the target, and return to the starting point. Six trials were recorded, three trials walking to the left of the target (TurnR) and three trials to the right of the target (TurnL) in a randomized order at self-selected speeds. In one child, only one trial to each side of the target was available because of physical exertion. One full turning trial was defined between the instant that an ankle marker was 60 cm from the target, and the instant when the same ankle marker had receded 60 cm past the target after turning in an arc motion. No child hit the target. Since there is no standard definition of a turning trial, we chose a virtual threshold of 60 cm, which was easily identifiable as the edge of the force plate in the floor of the gait laboratory. The path the children were instructed to walk is illustrated in Figure 1.

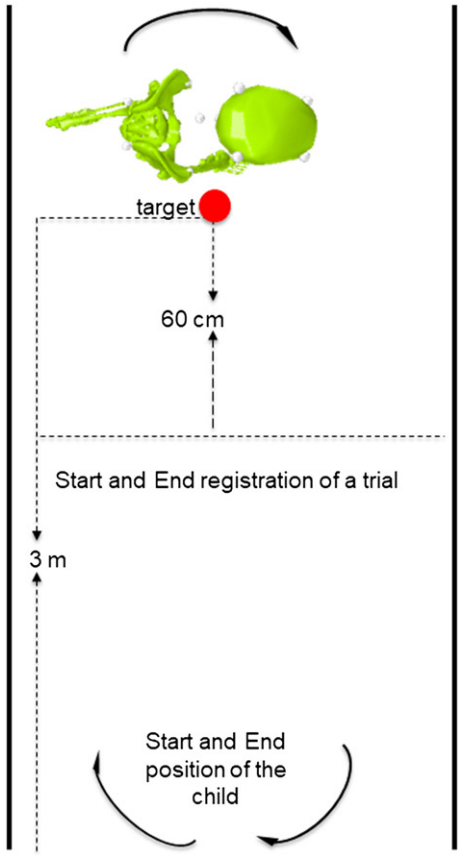

FIGURE 1. Illustration of a Turn Right trial around the target in the direction of the arrows. The figure shows one full turning trial, which was registered between the instant that an ankle marker was 60 cm from the target, and the instant when the same ankle marker had receded 60 cm past the target after turning. The threshold of 60 cm was identifiable as the edge of the force plate in the floor of the gait laboratory. The trial started at a distance of 3 meter from the target.

To get an exact reference point as a basis to relate the head and trunk positions in all participants, we used the instant during turning, at which the two pelvis markers on anterior spinae iliaca superior were parallel oriented to the path with the following outcome variables (Figure 2a):

- Transverse plane movement: mean head rotation (HTPM) and mean trunk rotation (TTPM).
- Sagittal plane movement: mean head flexion (HSPM) and mean trunk flexion (TSPM).

We also registered the maximum flexion values between start and end of the trial with the following outcome variables (Figure 2b):

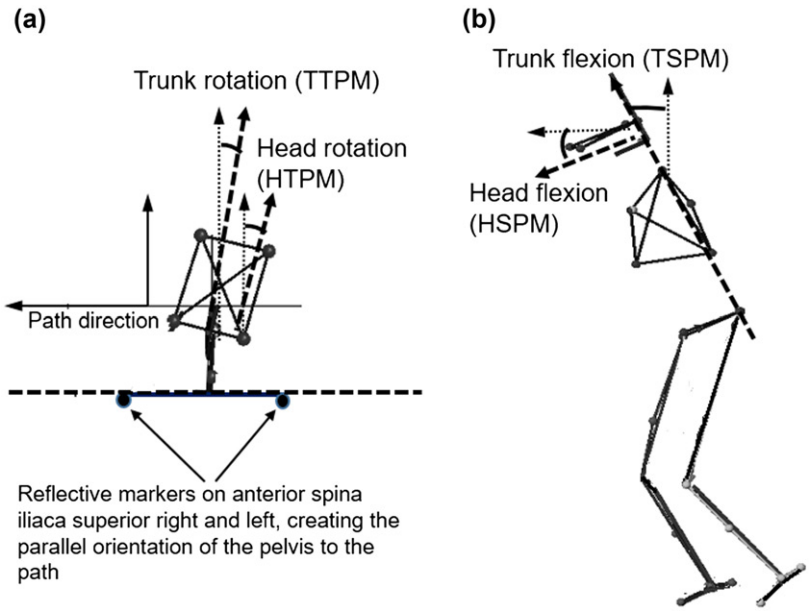

FIGURE 2. Stick figures constructed by the biomechanical marker placement in the gait analysis system. The images illustrate a child with cerebral palsy at the instant of turning, defined as the motion frame when the pelvis was oriented parallel to the path. Positions were measured in a) the transverse plane as head rotation (HTPM) and trunk rotation (TTPM) and in b) the sagittal plane as head flexion (HSPM) and trunk flexion (TSPM). In a) head and trunk rotation were registered as the angles between the perpendicular direction with respect to the path and. In b) head flexion was registered as the angle with respect to the horizontal and trunk flexion with respect to the vertical.

- Sagittal plane movement: maximum head flexion (MaxHSPM) and maximum trunk flexion (MaxTSPM).

Trial time duration during turning was registered as length of a turning trial between the instant that an ankle marker was 60 cm from the target, and the instant when the same ankle marker had receded 60 cm past the target after turning, and presented in seconds. To control for variations in weight and stature of the participants, the following non-dimensionalization was used to define walking velocity during the entire trial: $(v') = v/\sqrt{(g \times \text{leg length})}$ (Hof, 1996).

Statistical Analysis

There was a statistical difference between walking to the left of the target (TurnR) and to the right of the target (TurnL) in only one variable: time duration in TD children, according to a preliminary Wilcoxon Rank test. Since this difference in the TD group was considered non relevant both sides were averaged in the statistical analysis. Movements based on head and trunk positions, trial time durations and non-dimensionalized walking velocity were compared with Kruskal–Wallis tests and post hoc Mann–Whitney *U* tests for the TD and CP groups. Age, height and weight between the TD and CP groups as well as ophthalmological symptoms in the children with CP were compared with Kruskal–Wallis tests. All statistical analyses were carried out using software for statistical analysis (SPSS 20.0, Chicago, IL, USA). Significant differences were determined at the $p < .05$ level.

Results

Transverse Plane Movements at Instant of Turning

There were no differences between the groups in head rotation at instant of turning (HTPM). The trunk was significantly more rotated (TTPM) in the CP2 group than in the TD and CP1 groups (Table 2, Figure 3a). In CP3, the trunk was less rotated than CP2 but not significantly, and similar with TD and CP1.

Sagittal Plane Movements at Instant of Turning

At instant of turning (HSPM), there were no significant differences between the groups, even though greatest head flexion movements were observed in CP3. The trunk position (TSPM) was significantly more anteriorly flexed in CP3 than in the TD group and close to CP1 but not significantly (Table 2, Figure 3b).

TABLE 2. Head and Trunk Movements in Degrees (°) and Trial Time Duration (Seconds) in Children with Typical Development (TD) and in Three Groups of Children with Bilateral Spastic Cerebral Palsy (CP) are Presented as Median and 25th–75th Percentiles.

Median (25th–75th percentiles)	TD ($n = 22$)	CP1 ($n = 8$)	CP2 ($n = 12$)	CP3 ($n = 10$)	p-value	TD–CP1	TD–CP2	TD–CP3	CP1–CP2	CP1–CP3	CP2–CP3
HTPM: Instant of turning (°)	113.47 (104.94; 120.77)	120.97 (104.02; 123.88)	117.46 (110.62; 122.79)	120.47 (95.47; 127.9)	0.751	0.475	0.309	0.589	0.851	0.897	0.974
TTPM: Instant of turning (°)	91.7 (90.5; 94.7)	93.18 (89.11; 96.54)	98.38 (93.62; 100.61)	94.77 (89.85; 97.96)	.005*	0.765	<0.001*	0.204	0.031*	0.515	0.140
HSPM: Instant of turning (°)	−7.03 (−15.46; 0.74)	−6.78 (−14.27; −0.67)	−8.56 (−14.97; −3.78)	−20.52 (−35.55; 3.01)	0.405	0.909	0.466	0.151	0.624	0.173	0.381
TSPM: Instant of turning (°)	−1.71 (−4.78; 1.3)	−4.12 (−4.87; −2.89)	−4.77 (−10.91; −0.29)	−12.10 (−22.97; −3.22)	.019*	0.159	0.118	0.004*	0.678	0.083	0.107
MaxHSPM: Entire trial (°)	−13.23 (−20.98; 0.21)	−15.85 (−21.68; −5.52)	−18.6 (−25.27; −13.1)	−35.75 (−47.77; −25.37)	<.001*	0.511	0.534	<0.001*	0.343	0.002*	0.003*
MaxTSPM: Entire trial (°)	−7.3 (−9.6; −5.57)	−9 (−12.53; −8.13)	−11.57 (−18.16; −8.64)	−23.88 (−30.76; −17.03)	<.001*	0.185	0.003*	<0.001*	0.208	0.001*	0.007*
Entire trial time duration (sec)	2.41 (2.27; 2.78)	2.75 (2.53; 3.58)	4.69 (3.81; 5.38)	8.21 (6.58; 8.93)	<.001*	0.063	<0.001*	<0.001*	0.001*	<0.001*	<0.001*
Non-dimensionalized walking velocity	0.68 (0.6; 0.82)	0.77 (0.7; 0.97)	1.29 (1.11; 1.48)	2.15 (1.86; 2.52)	<.001*	0.063	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*

HTPM: head transverse plane movement; TTPM: trunk transverse plane movement; HSPM: head sagittal plane movement; TSPM: trunk sagittal plane movement; MaxHSPM: maximum value of head sagittal plane movement during the entire trial; MaxTSPM: maximum value of trunk sagittal plane movement during the entire trial. A minus (−) indicates anterior movements. Asterisk (*) indicates significant value.

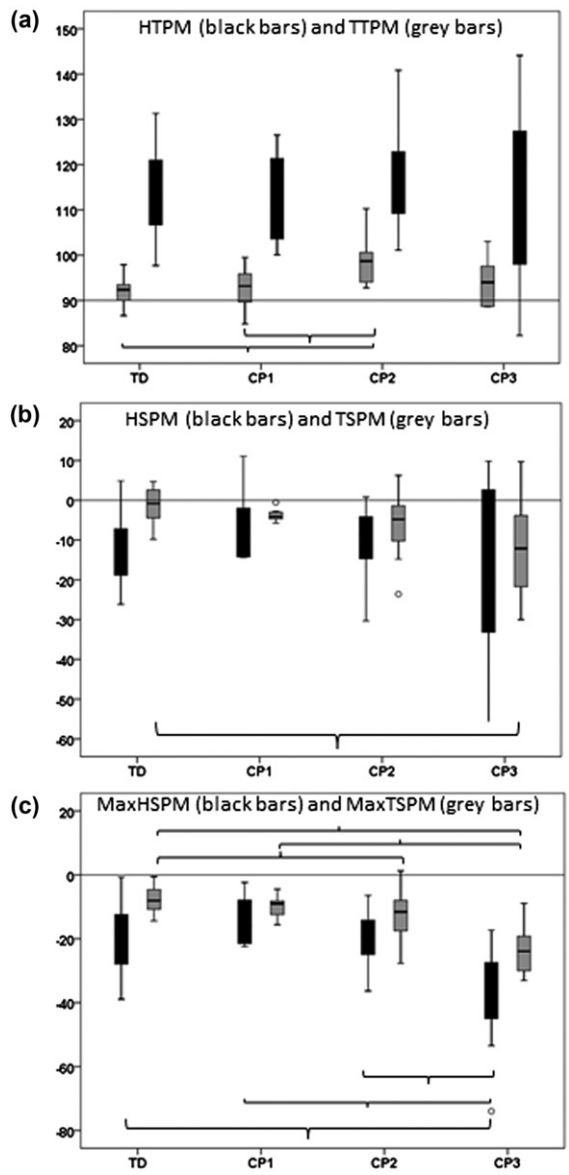

FIGURE 3. Head (HTPM) and trunk (TTPM) movements during the turning task in a) the transverse plane at the instant of turning, in b) head (HSPM) and trunk (TSPM) movements in the sagittal plane at the instant of turning and, in c) the sagittal plane as maximum head flexion (MaxHSPM) and trunk flexion (MaxTSPM) during the entire trial, in children with typical development (TD) and in three groups of children with bilateral spastic cerebral palsy (CP), presented as median and 25th -75th percentiles. In 2a) the horizontal line represents a head position at 90 degrees with respect to the pelvis. In 2b) and 2c) the horizontal lines represent the head and trunk positions respectively with respect to the vertical. "−" (minus) indicates anterior movements. Parentheses indicate statistical significance. Black bars indicate head movements and grey bars indicate trunk movements.

Sagittal Plane Movement; Maximum Value During Entire Trial

Maximum values of head flexion (MaxHSPM) and trunk flexion (MaxTSPM) were significantly greater in CP3 than in TD, CP1 and the CP2 groups. CP2 group had significantly greater maximum value of trunk flexion than the TD group (Table 2, Figure 3c).

Figure 4a–d exemplifies head and trunk movements in in the transverse and sagittal planes during a turning trial in a TD child, and in one individual in groups of CP1, CP2 and CP3.

Trial Time Duration

Durations of the entire trial, as converted to seconds, were increasingly longer with respect to CP groups, significantly between all groups except between the TD and CP1 groups (Table 2).

Nondimensionalized walking velocity during the entire trial was increasingly longer with respect to CP groups, significantly between all groups except between the TD and CP1 groups (Table 2).

Discussion

Contrary to our hypothesis, our findings did not confirm that head and trunk movements increasingly deviate with greater motor impairment. Our main findings were that the CP2 group had rotated the trunk more than TD and CP1 groups but with similar head rotation, whereas the CP3 group with greater motor impairment requiring a walker had similar head and trunk rotation as the other groups. Time durations during the entire trial, however, were increasingly longer with respect to CP groups, significantly between all groups except between the TD and CP1 group, the latter group walking as fast as the TD group.

Dixon et al. (2016) whose aim was mainly to recognize specific kinematic and kinetic adaptations during turning gait in children with CP, found only few group differences in movements and mechanical forces of the lower limb joints and feet. They, however, recommended inclusion of turning protocols for patients with even minor deviations in gait, since turning analysis may identify abnormal motion patterns not evident in straight walking (Dixon et al., 2016). Their results are in accordance with our study, where no significant differences in head rotational movement between any of the groups were found. These findings were unexpected, as deviation in motor functioning and organization to coordinate movement are the core features of CP (Rosenbaum et al., 2007). According to Berthoz and Zaoui (2015), deficits in spatial orientation may occur in children with CP. In this respect, the walker may have offered the children a spatial reference frame, facilitating the use of head

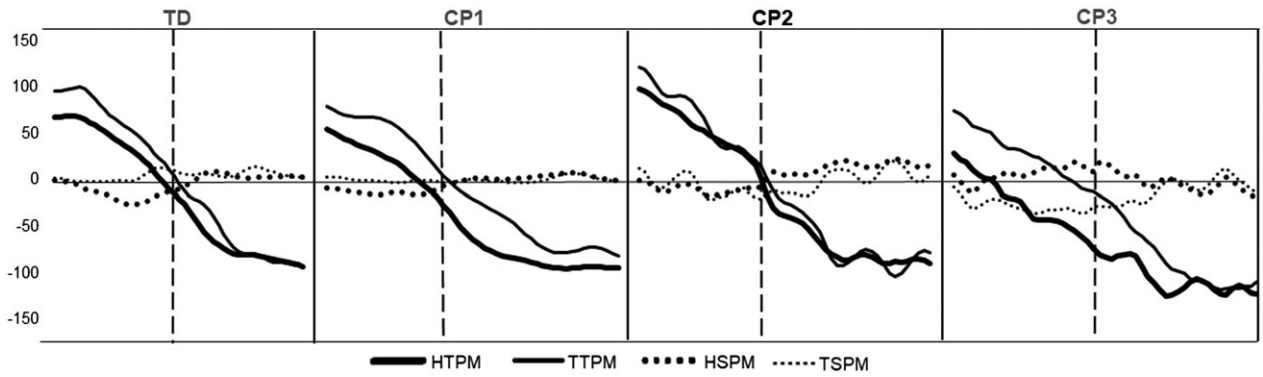

FIGURE 4. Kinematic illustration of head rotation (HTPM) and trunk rotation (TTPM) in the transverse plane and head flexion/extension (HSPM) and trunk flexion/extension (TSPM) movements during a right turning trial in a) a typically developing child (TD), and in one individual in b) cerebral palsy (CP) group CP1, c) in CP2 and 3) in CP3. The vertical line represents instant of turning. Change of direction occurs when the horizontal line is crossed. The curves in the transverse plane express more rotation the nearer to the horizontal line. The curves in the sagittal plane express anterior movements below the horizontal line. All figures have identical scaling proportion in degrees on the y-axis.

movements in the CP3 group, and permitting orientation of gaze during turning. In this group, however, the 25th percentile value was lower than in all other groups, indicating somewhat decreased head rotation movement. In the CP2 group, we observed that some children walked on their toes with their arms extended laterally probably to support balance, while others walked with flexed knee gait. On a group level, however, the difference between trunk and head rotation angles was less than in the other groups. Wallard et al. (2012) found an en bloc organizational strategy during walking in children with CP, in which the head and trunk moved as a single unit. Based on their findings demonstrating difficulty to dissociate rotations of the head from those of the trunk, they proposed that clinical evaluation of posture during gait in children with CP should be reconsidered. Derived from the understanding of CP that motor disorders are accompanied by disturbances in sensation and perception at times generate even greater activity limitation than the motor impairments (Rosenbaum et al., 2007), we consider the decreased rotation between trunk and head in children in the CP2 group as a potential sign of spatial insecurity, similar to freezing of posture, which has been described as a sign of perceptual disorder in children with spastic CP (Ferrari et al., 2014).

Head and trunk anterior flexion at the instant of turning was larger in the CP3 group than in the other groups, though only significant in the trunk, which we attribute to be a more pressing need for the CP3 group to watch their limbs and feet during turning than the other groups. This might be in accordance with the findings of Wingert et al. (2009) who found larger lower limb joint-position sense errors in vision-removed than in vision condition in children with diplegia. We also identified the maximum head and trunk flexion angles during the entire trial, and found that the CP3 group reached larger head and trunk anterior movements than the other groups. This may confirm the assumption that the children in CP3 had more impaired joint proprioception compared to children in the other groups. Impaired sensation from the feet may also influence posture, although since all participants performed the walking test barefoot, this factor was identical for all groups. Wallard et al. (2012) discussed the anterior head flexion in children with CP during straight walking as an attempt to improve postural control, by stabilizing the chin as close to the chest as possible. This may be in accordance with some children in the present CP3 group, whose anterior head and trunk flexion movement may have been a strategy to avoid a startle reaction elicited by neck and trunk extension (Ferrari et al., 2014). Considering all children in CP3 require a walker, imagination of losing the grip by extension of the fingers as a consequence of a startle reaction, may therefore have contributed to the flexion movement of the trunk. The CP1 group performed most similar sagittal trunk motion as the TD children. Since only eight children constituted the CP1 group, this finding must be interpreted with caution, yet, it could be speculated that they, like the TD group, had little or no need to control their feet by vision, as suggested by the similar head movement during turning in these groups. The CP1 group was also the only group that did not walk more slowly than the TD group during the trials. The CP2 group required twice as much time as the TD and CP1 groups to accomplish the trial, whereas the CP3 group used twice as much time as the CP2 group. To avoid for consequences of height differences in the children, we used numbers of non-dimensional quantities.

They may be less familiar and therefore more demanding to interpret, however, they are reported to be most reliable for group comparisons (Hof, 1996). The results of the present study, however, did not indicate any influence of leg length on walking velocity.

The need for the CP3 group to steer their walkers may have led to a slower walking velocity, even though all walkers had a free-wheel function with similar resistance to turn the walkers for all children in this group. In accordance with Damiano et al. (2013) who showed that children with less lower limb proprioception walk more slowly than those with less disturbances, we speculate that the slower walking velocity in children in CP2 and CP3 groups can be an indication of impaired proprioception and sensation in the lower limbs. Similar considerations of disturbances in proprioception were reported in our previous study, wherein we asked the children to focus on a visual target (Bartonek et al., 2016).

According to Fazzi et al. (2012), visual impairment plays a key role in locomotor performance in children with CP, thus the visual deficits in the children in our study must have influenced their movements. Nevertheless, even with visual dysfunction, the children rely strongly on visual information to control movements. In our study group, approximately 90% of the children had some visual or ocular motor dysfunction, such as disturbed visual fixation, strabismus, discontinuous smooth pursuit and dysmetric saccadic movements or deficient visual field. However, since vision did not differ between the CP groups, visual function is not considered to have influenced the findings substantially in the present study. Furthermore, we assume that all children were able to perceive the target on the floor during turning.

Despite no explicit existing data of sensory system deficits, we have some speculations regarding difficulties in sensory and motor organization during the demanding task of turning gait. One indication may be seen in less movement between head and trunk in the CP2 group, possibly due to experienced spatial insecurity. Even if examined in sitting, this appearance may be associated and understood based on reported decreased ability to quickly produce anticipatory postural adjustments in children with perceptual disorder (Ferrari et al., 2010). On the other hand, similar rotational movements in head and trunk in CP3 as in the other groups may reflect that the walker offered a frame for facilitating special perception. Furthermore, the anteriorly flexed head and trunk in the CP3 group and trunk in the CP2 group may reflect deficits in proprioception of the lower limb joints that require visual control of the feet during walking.

Even though we have tried to recognize deficits in perception and sensation that influence movements during turning, there are limitations in this study. First, we have no objective measurement of the children's sensory loss, joint proprioception or vestibular function status. We were furthermore not able to accurately measure the impact of factors such as cognition and motivation, as was suggested by Rosenbaum et al. (2002). Moreover, the low participant number has probably not permitted any significant findings of visual deficits between the groups. Nevertheless, we consider our work an effort towards emphasizing aspects of accompanying impairments of sensation and perception into the motor assessment of the child with CP. The recommendation to assess perceptual impairment in children with CP for long-term prognosis beside the motor and postural disorders (Ferrari et al., 2014), we believe, would also contribute to enhanced understanding of the children's variations in motor control.

Conclusions

Children with BSCP showed variations in head and trunk movements during the turning task while walking. The CP2 group had more trunk rotation than TD and CP1 groups but similar head rotation, resulting in less rotation between head and trunk in CP2. The CP3 group had similar head and trunk rotation as the other groups. Time durations during the entire trial were increasingly longer with respect to CP groups, significantly between all groups except between the TD and CP1 group, the latter group walking as fast as the TD group.

Locomotion is a task that requires processing of multisensory input.

According to the currently most used definition of CP, disturbances in sensation and perception may at times generate even greater activity limitation than the motor impairment. The results of this study indicate some motor difficulties that could be referred to deficits in perception. To enhance understanding of the children's variations in gross motor development, future studies are warranted on the effects of sensory inputs, such as proprioception and sensation of the lower limbs, and their influence on children's motor activity.

ACKNOWLEDGMENTS

We thank the children and their parents who participated in the study. We also thank Mikael Reimeringer for technical support. The study was financially supported through grants from Promobilia Foundation Sweden.

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Received June 20, 2017
Revised May 22, 2018
Accepted May 22, 2018