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Weight-bearing characteristics during standing in adults with Cerebral Palsy

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And to round off, a quote from Albert Einstein:

If we knew what we were doing, it would not be called research, would it?

ABSTRACT

Aim: The aim of this study was to investigate weight-bearing characteristics in young adults with CP compared to young healthy adults in both quiet and relaxed standing.

Methods: Two standing conditions were tested, one minute quiet standing (QS) and one minute relaxed standing (RS) in both groups. Data were collected with two Kistler force plates and a video camera. Weight-bearing asymmetries, shifts in weight bearing and CoP movements under each foot were calculated in Matlab, and PSAW Statistics was used for statistical analysis.

Results: There were large individual differences in weight bearing characteristics between feet in both CP participants and control participants. In the QS condition, the CP group had equal weight on both feet in average across the trial, a trend towards a higher asymmetrical weight bearing index (p=.08), and larger movements of CoP under each foot than the control participants. In the RS condition, the CP group had no difference in weight bearing between the feet, more shifts in weight bearing in the form of steps, and less asymmetrical weight bearing index than the control group. Also, the CP participants had more CoP movements on their non-affected side than the controls had on their dominant side, and less CoP movements on their affected side than the controls had on their non-dominant side.

Conclusion: CP participants have several different strategies for maintaining upright standing posture, varying from largely relying on their non-affected side for weight support, to standing almost symmetrical, to supporting more weight on their affected leg. Even though CP participants have more asymmetrical weight bearing in quiet standing compared to controls, this is not the case in relaxed standing where controls are more asymmetrical. This study provides more insight into relaxed standing and the strategies CP patients use to maintain an upright standing posture. Future studies should investigate the prevalence of postural asymmetry in a larger sample of patients, for a longer period of time, and how possible findings can be used in treatment of this patient group.

Key words: Cerebral palsy, quiet standing, relaxed standing, weight-bearing asymmetries, shifts in weight-bearing, center of pressure.

CONTENTS

INTRODUCTION

The most common cause of physical disability in children is Cerebral palsy (CP) (Bax et al., 2005). CP results from an injury in the developing central nervous system (CNS), which can occur in utero, during delivery, or during the first two years of life (Cans, 2000; Koman, Smith, & Shilt, 2004). CP is characterized as a group of disorders affecting the development of movement and posture, with characteristic signs like spasticity, muscle weakness, ataxia, and rigidity. The severity ranges from small motor impairments in part of the body to large impairments of the whole body (Bax et al., 2005; Koman et al., 2004). Patients with CP have been found to have increased co-contraction of agonist and antagonist muscles, a proximal to distal muscle response, and decreased trunk muscle activation (Burtner, Qualls, & Woollacott, 1998; Carlberg & Hadders-Algra, 2005; Donker, Ledebt, Roerdink, Savelsbergh, & Beek, 2008; Rose, Wolff, Jones, Bloch, & Gamble, 2002). Furthermore, patients with CP tend to have impaired coordination of movement, reduced between- limb synchronization and less weight bearing on the affected side, which in turn can cause problems with maintaining upright weight-bearing position and gait (Bax et al., 2005; Woollacott & Shumway-Cook, 2005).

Motor control and control of upright weight-bearing position are tightly related. Our capacity to undertake a wide range of activities and perform many voluntary motor skills depends on the quality of upright standing position (Huxham, Goldie, & Patla, 2001). Maintaining an upright standing position is a complex task that requires involvement of both the musculoskeletal system and all levels of CNS to predict disturbances, and produce a sufficient response (Massion, 1994; Winter, 1995). When standing, it is necessary to maintain the projection line of the center of mass (CoM) within the base of support to avoid step responses or, ultimately, falls (Winter, 1995). In the major portion of studies on postural sway, however, the center of pressure (CoP) is measured rather than CoM. The CoP fluctuates around CoM in order to keep the CoM over the base of support, and coincides with the CoM when the horizontal reaction forces are equal to zero (Winter, 1995). Typically, postural sway measurements are done by measuring CoP displacement under both feet combined using one force plate only (Mansfield, Danells, Inness, Mochizuki, & Mcllroy, 2011). In healthy humans, both feet work together in a synchronized way to maintain stability during quiet standing. A symmetric weight bearing distribution between the legs during quiet standing provides optimal biomechanical stability, while weight shifts prevent the progressive build up of fatigue in the legs (Anker et al, 2008). However, patients with postural deficits like CP might have a different weight distribution and CoP movements between the legs, and CoP displacement measured by one force plate only is unable to characterize any asymmetry in the weight distribution between the legs, or individual CoP traces beneath each foot (Anker et al., 2008; Genthon & Rougier, 2005). It has been argued that to capture the relation between motor impairments and the control of upright stance, it is necessary to evaluate each leg separately. By evaluating each separate leg, rather than overall standing control, the ability to control overall posture will not be obscured by the compensations of the non-paretic side (Van Asseldonk et al., 2006). As an example, the postural impairments in stroke patients caused by a paretic leg have been assessed using two force plates to get the CoP trace of each leg (Genthon et al., 2008; Mansfield et al., 2011; Mizrahi, Solzi, Rinf, & Nisell, 1989). This method has found that stroke patients have larger CoP fluctuations, reduced synchronization in CoP between the legs, and more asymmetry in weight distribution (Genthon et al., 2008; Mansfield et al., 2011; Mizrahi et al., 1989). Due to their postural impairments, the same findings might be expected in patients with CP, but such a study has not been conducted to date. Thus, one aim of the present study is to investigate weight bearing and CoP movements under each foot, separately, in young adults with CP.

The literature consists of an enormous body of research that has investigated how we stand (see f.eks Collins & De Luca, 1993; Huxham et al., 2001; Newell, Slobounov, Slobounova & Molenaar, 1997; Pai, 2003; Winter, 1995). There are two common experimental designs used to investigate upright position. These experimental designs includes specific standing tasks like standing as still as possible, with eyes open or closed, with feet side by side, in a Romberg position, or in a tandem position (Collins & De Luca, 1993; Goldie, Bach, & Evans, 1989; Newell et al., 1997; Winter, 1995). Furthermore, the second common designs has been developed to assess reactive adaptations in the postural sway pattern where individuals are asked to stand quietly and respond to a perturbation in a moveable force plate, without taking a step unless they would otherwise fall (Burtner et al., 1998; Nashner et al., 1983; Woollacott & Shumway-Cook, 2005). Still, most studies on postural sway have an experimental design that only includes quiet standing over a short duration of time (Burtner et al., 1998; Carlberg & Hadders-Algra, 2005; Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007; Nashner, Shumway-Cook, & Marin, 1983; Ruhe, Fejer, & Walker, 2010). However, one limitation of studies involving quiet standing is to establish whether the occurrence of a particular CoP pattern indicates a good or bad quality of balance or just a poor performance according to the task instructions (Visser, Carpenter, van der Kooij, & Bloem, 2008). As an example, larger sway amplitude in different patient groups during quiet standing is interpreted as deficiency in balance (Pai, 2003). On the other hand, relaxed standing in everyday life often consists of gross body movements like upper body changes, shifting weight from one foot to the other, and taking steps (Duarte & Zatsiorsky, 2000). These CoM movements will produce larger sway amplitude (i.e. CoP amplitude) without necessarily indicating balance impairments. Even though relaxed standing has been investigated in both healthy humans and a few different patient groups, these studies have focused on standing over a very long period of time, typically 30 minutes, and not the standing characteristics and strategies of relaxed everyday standing over shorter time intervals. Thus, a second aim of this study is to investigate standing characteristics during quiet and relaxed one minute standing.

To summarize, there are only few studies on asymmetric weight bearing and CoP patterns during standing, and none have focused on CP patients or on relaxed standing. Given the often lateralized nature of CP, it is important to examine not only joint CoP characteristics across both feet, but also the CoP profiles under the affected and non-affected foot separately. Therefore, the aim of this study was to investigate weight-bearing characteristics in young adults with CP compared to young healthy adults in both quiet and relaxed standing. To investigate possible differences between sides, two separate force plates were used. The expectations were that CP patients would have higher overall differences across feet, stronger asymmetries between the feet, and more CoP movements beneath each foot than healthy adults. Specifically, the expectations were less overall weight bearing on the affected foot, and more overall movement in the non-affected foot in CP adults compared to healthy adults in both quiet and relaxed standing.

METHODS

Participants

Twenty-one participants (9 CP and 12 controls), age ranging from 18-31, were recruited for this study (see Table 1A and 1B for participant characteristics). The CP patients were recruited by St. Olav`s Hospital in the region of mid-Norway. Four patients were classified as having hemiplegic CP and five as diplegic CP. Of the four hemiplegic CP participants, one was right-side affected, while three were left-side affected. The most affected foot in the participants with diplegia was used to determine affected side. Of the five diplegic participants, three were characterized as left-side affected and two as right-side affected. All CP participants had a Gross Motor Function Classification System (GMFCS) score between I and II, indicating that they were relatively well-functioning CP patients. The exclusion criteria for CP patients were treatment with Botulinum toxin A in the last six months and/or surgery in the lower extremities in the last two years. A control group of healthy young adults were recruited at the local university, Norwegian University of Science and Technology (NTNU). The participants in the control group had no known balance problems, diseases, or used any medication that could affect balance. One of the participants in the control group was characterized as left footed while the others were right footed according to the Waterloo Footedness Questionnaire – Revised (WFQ-R) (Elias, Bryden, & Bulman-Fleming, 1998) (see Appendix 1 for questionnaire). Prior to testing, all participants received oral and written information about the study and were given the opportunity to ask questions before signing a written consent. The study was approved by the Regional Committee for Medical and Health Research Ethics (REK).

Equipment

Ground reaction forces and moments were registered for each foot separately using two Kistler force plates (40 x 60 cm) (type 9286A, Kistler Group, Switzerland) placed side-by-side so that they were as close together as possible without touching (≈1 mm apart). The sampling rate was 50 Hz for each of the eight analog channels giving three force variables and three moment variables. The plates were calibrated prior to each trial and the noise level was SD<.01 mm for both plates. A video camera (Sony VX) was placed behind the subjects to record each session. The subjects` body mass was registered with a scale and a measuring band was used to measure waist and hip circumference.

Table 1A: Participant characteristics

	CP group			Control group		
Participants	9			12		
	Mean	Range	SE	Mean	Range	SE
Age (yrs)	20.6	18-26	(0.9)	21.8	18-31	(1.02)
Height (cm)	171.9	155-190	(0.04)	175.2	167-185	(0.02)
Weight (kg)	72.7	48-105.1	(6.3)	80.5	62.7-107	(3.4)
BMI*	24.3	19.9-33.6	(1.5)	26.1	22.5-31.3	(0.8)
Waist circ (cm)	84.1	63-108	(4.5)	83	72-106	(2.7)
Hip circ (cm)	100.5	87-118	(3.5)	109.7	95-171.1	(5.9)
WH-ratio**	0.83	0.7-0.9	(0.02)	0.8	0.4-0.9	(0.04)

Abbreviations: BMI = body mass index, Waist circ = waist circumference, Hip circ = hip circumference, WH-ratio = waist-hip ratio

*BMI calculated as: weight (kg)/ (height (m) x height (m))

** Waist-hip ratio calculated as: waist circumference (cm)/hip circumference (cm)

Table 1B: Additional CP characteristics

	Participants
Affected side (number)	
- Right	4
- Left	5
GMFCS (number)	
- I	5
- I-II	3
- II	1
Leg length discrepancy (number)	7
Previous surgery (number)*	
- Hamstring, gracilis, or adductor lengthening	3
- Tendo Achilles lengthening	7
Shoe inserts/splints (number)**	2

*All participants with hamstrings, gracilis, or adductor lengthening, also had tendo Achilles lengthening.
**7 participants had adapted shoe inserts and/or splints, but only 2 used them at a daily basis.

With respect to anthropometric measures, an independent t-test was conducted. No significant differences was found between the groups (all p`s > .208), and this will therefore not be investigated further.

Procedure

All test conditions took place in the movement laboratory at the Department of Human Movement Science at NTNU, Trondheim. Upon arrival the participants were given oral and written information about the project and signed a consent form. They were fitted with four near infrared spectroscopy optodes (Oxymon MKIII, Artinis Medical Systems, the Netherlands) on each calf. Three standing conditions were tested; one minute quiet standing (QS), one minute relaxed standing (RS), and ten minute relaxed standing (RM). In addition, the control group had a 30 minute relaxed standing trial. All conditions were run following the same procedure. First, the two force plates were reset to zero and data collection started before the participants stepped on the plates. Then the start of the trial was indicated with a double tap on one of the force plates. During all trials, one of the researchers took notes regarding visible postural changes. For all conditions, the participants were instructed to have one foot on each force plate. Further instruction for the QS condition was to look straight ahead and stand as quietly as possible for 60 seconds. The instruction for the RS and RM conditions was to stand naturally and relaxed for one minute and ten minutes, respectively. To help participants stand relaxed during the prolonged RM condition, they listened to a fairy tale. The participants had a two minute break between QS, RS, and RM conditions. All participants were able to stand unsupported during all conditions. The participants wore comfortable clothes and shoes during all sessions. Two of the CP patients used shoe inserts and/or splints during all test conditions. After all test conditions, information about age, surgical history, shoe insert and/or splints, and leg length discrepancy were collected. Finally, the participants` weight, height, and hip and waist circumference was measured, and they filled out the WFQ-R (Elias et al., 1998).

Data analysis

For the present study, only the force plates data and video recordings from the one minute quiet and relaxed standing trials were subjects to further analyses. The data from QS and RS trial were processed and analyzed along the following steps. First, the ground reaction forces in the vertical direction were compared with the video data to classify events during the RS trial. The force data between the double taps in the beginning and the end for each trial were identified and low-pass filtered by a 4^{th}-order two-way Butterworth filter with a cut-off frequency of 10 Hz. The CoP was calculated from the ground reaction forces and moments for each plate. Histograms of the ground reaction force in vertical direction were calculated to analyze weight distribution. The bin size in the histograms was standardized to 5 % of the body weight where the number and placement of modes (i.e., the most frequently occurring value in the array) reflected preferences in weight distribution (see Figure 2). In addition, the CoP area for each foot was calculated by fitting an ellipse to the stabilogram. The directions of the two axes of the ellipse were computed by principal component analyses. Figure 1A shows a stabilogram for one of the participants during the QS condition. In figure 1B the principal axis has been added as calculated by principal component analysis. The direction of the principal axis is the first eigenvector of the covariance matrix and the variance along this axis is the largest eigenvector. The second eigenvector is orthogonal to the first and forms the second axis of the ellipse. The length of each ellipse axis was subsequently set to 1.96 x SD along the principal components (Oliviera, Simpson, & Nadal, 1996). Figure 1C shows the principal axes and the fitted ellipse. The number and placement of modes and CoP area was compared to the video data to check whether these parameters represented visible postural changes. Finally, to quantify foot asymmetry an absolute symmetry index, expressed in percentage, was calculated by dividing the absolute difference between overall vertical forces of the right and left plate by the sum of the right and left vertical forces:

$$\text{Symmetry index (SI) \%} = \left|\frac{L-R}{L+R}\right| \times 100$$

Higher values of SI indicate more asymmetry, while values close to 0% indicate a symmetrical standing posture. All analyses and signal processing were done in Matlab version 7.11 .0 R2010b (The Mathworks Inc., MA, US). All measures were normally distributed and statistical analyses for comparison of the CP participants and control group consisted of t-tests and repeated measures ANOVAs. Significance level was set at $p < .05$, while p-values between .05 - .1 are reported as trends. All statistical processing was done in PASW (Predictive Analytics SoftWare) Statistics version 18.0.

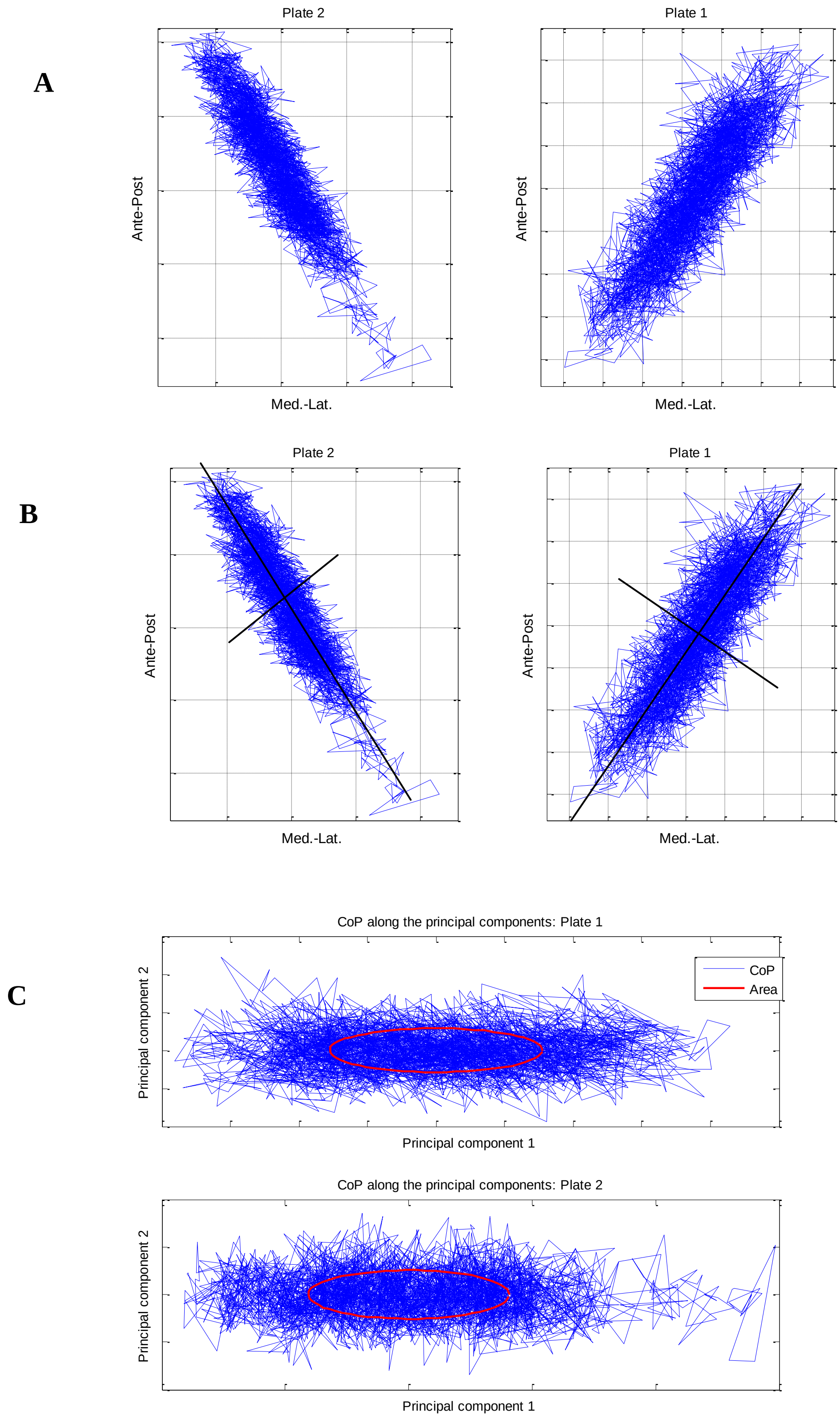

Figure 1: Stabilogram for one participant during a quiet standing (QS) trial. A) Original stabilogram within anterior-posterior and medio-lateral direction. B) Stabilogram with axes according to principal components. C) CoP along the principal component axes with the x 1.96 SD fitted ellipse.

RESULTS

The results are presented in four parts. First, qualitative postural changes are described based on visible postural changes and number of steps taken by the participants as seen on the video recordings. Second, weight bearing asymmetry is presented with respect to overall weight distribution between affected/non-dominant and non-affected/dominant side based on the mean vertical force (Fz), and an absolute symmetry index (SI). Third, shifts in weight distribution are described based on the modes from the histograms. Finally, CoP area and the amount of movements in CoP between feet in both groups and conditions are presented. For all analyses, foot 1 refers to the affected side for CP and the non-dominant side for control participants (as determined by WFQ-R`s). Foot 2 refers to the non-affected side for CP and the dominant side for control participants. These definitions are consistent with recommendations in the literature (e.g., Mansfield et al., 2011).

Qualitative postural changes

The video and the testers notes where used to discern body posture and visible postural changes during all conditions. During the QS conditions, none of the participants made any larger, visible body movements or postural changes. All participants held their arms in one position, either having their arms hanging down along the side of their body, having their hands in their pockets, or arms crossed in front of the chest, during the entire trial. During the RS conditions, there were large individual differences with respect to the frequency and type of postural change in both groups. In these trials, all participants changed arm positions, some more frequently than others. One participant in the control group constantly moved her upper body during the RS condition, swaying her arms back and forth and changing her arm positions every few seconds. Participants in both groups made postural changes in the form of weight shifts from one foot to another, adjustments in feet placement, and steps. For several of the CP participants, shifts in weight distribution took the form of one or more steps (see Table 2). Of these three participants took more steps on their affected side than on their non-affected side whereas only one control participant took steps. Only one of the control participants took steps. Instead of taking steps, control participants had more weight shifts and movements of the lower extremities without lifting their feet from the force plates, but instead sliding their feet along the surface of the plates.

Table 2: Number of steps taken during the RS conditions for the participants that took steps.

Participant taking steps	Number of steps taken		
	Left	Right	Total
CP02	1	1*	2
CP03	3*	6	9
CP04	3*	1	4
CP08	0	3*	3
CP09	1	3*	4
KT11	3	4*	7

*=affected foot in CP participants, and dominant foot in control participants.

Weight-bearing asymmetry

In order to express weight-bearing asymmetry the mean Fz per foot and the absolute symmetry index based on the Fz signals have been used. The mean Fz values refer to the amount of weight taken my each foot during a trial. The absolute symmetry index gives an implication of how much asymmetry, in total, the participants had during a trial. In general, overall weight bearing varied between the participants and between the conditions.

Several of the participants had an uneven percentage of overall weight bearing between the two feet during the QS condition. Also, which foot having more weight bearing during the trial varied greatly. Of the nine CP participants, three had a symmetrical distribution of weight, three had more weight on the affected side, and three had more weight on the non-affected side. In the controls, six had a symmetrical distribution of weight, while four had more weight on their non-dominant foot, and two had most weight on their dominant foot. Because of these individual differences going in either direction, the means in the two groups were equal (CP=50% on both feet on average across the group, control=50% on both feet on average across the group) (see Appendix 2 for individual Fz data).

During the RS condition, the weight distribution between the two feet varied greatly from participant to participant, both within and between groups. Of the CP participants, two had a symmetrical distribution of weight, three had most weight on their affected side, and four had most weight on their non-affected side. In the controls, five had a symmetrical stance distribution, five preferred having most weight on their dominant foot, and two had more weight on their non-dominant foot. Two CP participants and four control participants had more than 10 % weight difference between the feet, while the rest had less than 10 % difference in weight bearing between feet. Surprisingly, also in this condition, the average mean in the CP group was 50 % on both feet. The control group on the other hand, had a higher average Fz on the dominant foot (M=55.52%) than on the non-dominant foot (M=46.04%) (see Appendix 2 for individual Fz data). An independent samples t-test on the Fz values in foot 1 and foot 2 were conducted to assess possible weight bearing differences for the two feet between the groups. This showed no significant difference between affected and non-dominant foot ($t(19)=.781$, p=.444), nor between the non-affected and dominant foot ($t(19)= -.742$, p=.467).

Using the absolute SI score, the amount of asymmetry between the feet for each participant is quantified without taking the direction of asymmetry into account. As a group, the CP participants had a higher mean SI (M=10.1% ±7.6) than the control group (M=4.7% ± 4.1) in quiet standing. During the QS condition four of the CP participants had a SI > 16 %, and five had a SI < 7 %. Of the four CP participants that had a high SI, two had more weight on their affected side, and two had more weight on their non-affected side. Not surprisingly, the participants having high SI scores also had high mean vertical force differences between the two legs. The control participants had on average a more symmetrical stance with 11 participants having SI < 8 %, and the last participant had SI=14%. In the relaxed standing condition the control group had a higher mean SI (M=24.8% ± 29.9) than the CP group (M=15.9% ± 13.8). Here four of the control participants had a SI from 36 % to 82 %, while only two CP participants had a SI score >29% (see Appendix 2 for individual SI scores). To assess possible weight bearing asymmetry between the two groups, an independent-samples t-test on the SI scores was conducted. This showed no significant difference between the two groups in the RS conditions ($t(16.32)=.904$, p=.379), but there was a trend towards asymmetry differences in the QS condition ($t(11.5)=1.92$, p=.08), with the CP group having a more asymmetric posture than the control group.

Shifts in weight bearing

In order to express shifts in weight distribution during a trial, histograms were calculated on the Fz signals. From the histograms, number and position of modes reflected changes of weight distribution and defines preferred areas to stand in (see Figure 2).

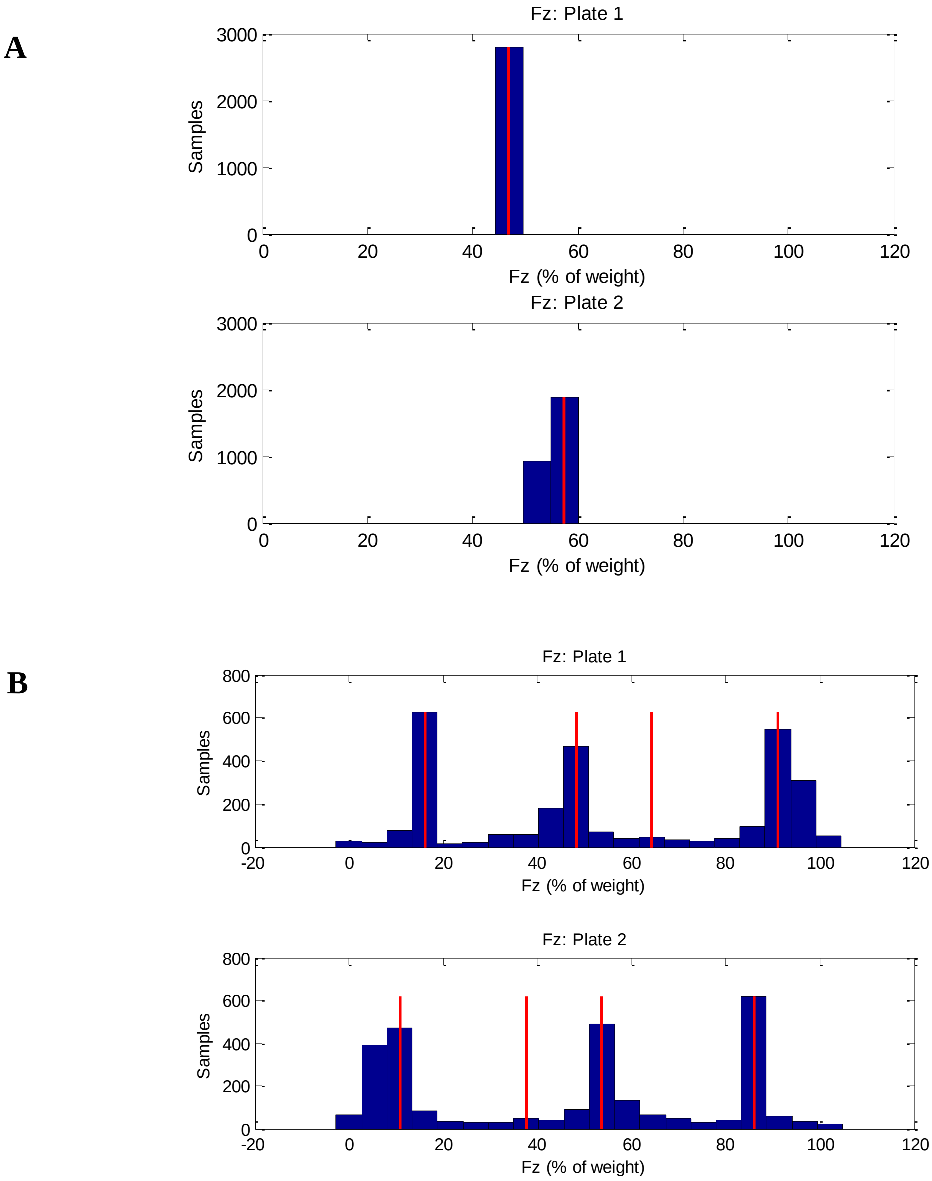

Figure 2: Examples of histograms showing weight distribution in percentage for one of the control participants during A) quiet standing condition (QS), and B) relaxed standing condition (RS). For this participant plate 1 is the non-dominant foot and plate 2 is the dominant foot. Modes are represented with red lines.

During the QS conditions, both groups followed the instructions - and stood quietly, as indicated by one mode only for all participants (see Figure 2A for an example).

The amount of modes in RS differed between participants. On average, the CP group had slightly more modes (M=2.11) than the control group (M=1.88). Six CP participants and six control participants had two or more modes on one or both of the feet, while the remaining participants had only one mode on each foot. The CP participants who had more than two modes in total on both feet, had an unequal number of modes, while all except one of the control participants had in total an equal number of modes. Of the CP participants with several modes, only one had a higher number of modes on his affected foot. In total, the affected/non-dominant foot had a smaller number of modes (M=1.86) than the non-affected/dominant foot (M=2.13) (see Appendix 2 for individual data on number of modes).

CoP movements

The amount of CoP movements under left and right foot is reflected in the sway area, which was calculated by fitting an ellipse on the stabilograms (see Figure 1 for an example).

As expected, the difference between the groups in sway area is larger in the relaxed standing condition than in the quiet standing condition (see Figure 3). A 2-way repeated measures Group (2) x Condition (2) ANOVA on the average movement area for QS and RS conditions showed an expected significant effect for Conditions, F (1,19)=15.36, p=.001. There was no significant interaction between Condition and Group (p=.732), nor an effect of Group (p=.643).

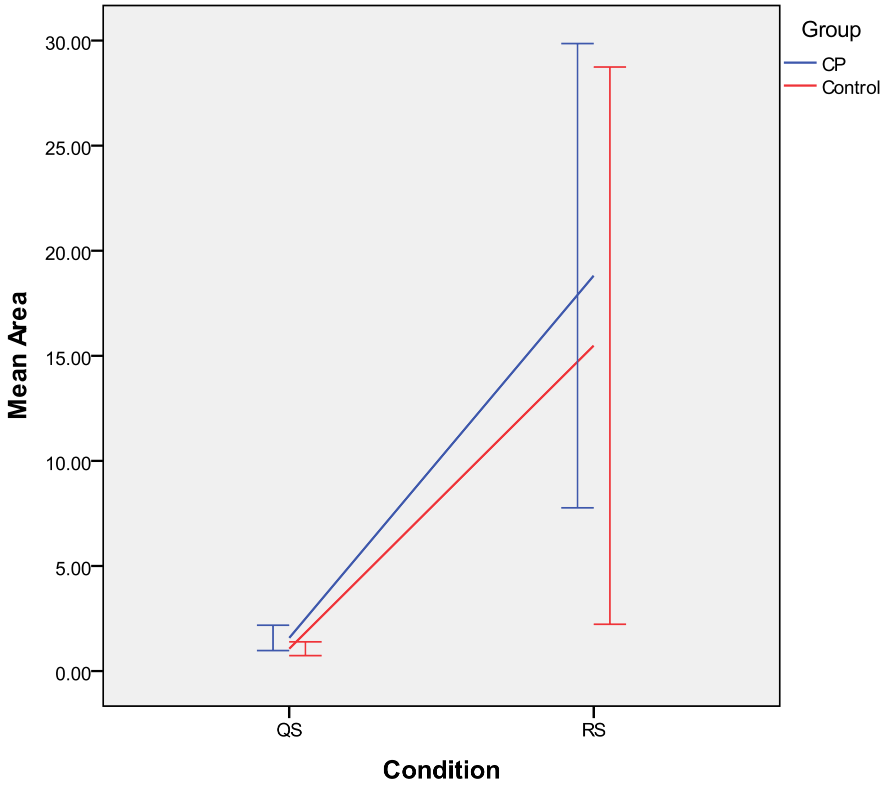

Figure 3: Mean area and standard error for CP participants (blue) and control participants (red) in quiet (QS) and relaxed (RS) standing.

To asses possible differences in CoP movements between the two feet, three separate paired samples t-test on CP (affected versus non-affected side) and control participants (dominant versus non-dominant, and left versus right foot) were preformed. During the QS conditions, all CP participants except one had larger movements on the non-affected side than on the affected side. A paired samples t-test revealed a significant difference between the CoP movements between the affected side (M=.602 cm^2) and the non-affected side (M=.976 cm^2), $t(8)=-3.267$, $p=.011$. Surprisingly, also during the RS conditions all CP participants except one had larger movements on the non-affected side (see Appendix 1 for individual data on CoP movements). A paired samples t-test revealed a significant difference between the CoP movements on the affected side (M=6.823 cm^2) and the non-affected side (M=11.991 cm^2), $t(8)=-2.613$, $p=.031$.

For the control participants, there was a smaller difference in the CoP movements between the two feet during the QS condition, and which foot had the larger movements differed from participant to participant. Also in the RS condition, the control participants had large individual differences in CoP movements between the two feet (see Appendix 1 for individual data on CoP movements). Neither left-right nor dominant-non dominant comparisons showed significant differences in CoP movements in the control group for the QS condition (all p`s>.59), nor the RS condition (all p`s>.46).

DISCUSSION

The aim of this study was to investigate weight-bearing characteristics in young adults with CP compared to healthy young adults. This was studied in both quiet and relaxed standing using two force plates to analyze possible differences between body sides. The results showed large individual differences for all participants in weight-bearing characteristics. There were no differences in the overall distribution of weight between the two sides across a trial for either of the groups in quiet standing. However, the absolute symmetry index showed that the CP group had more asymmetrical weight bearing compared to the controls. Furthermore, the CP participants had more CoP movements under both feet than the control participants. Surprisingly, in the relaxed standing condition there were no differences in overall weight bearing between the two feet for the CP participants, while the control group had a larger, but not significant, difference between dominant and non-dominant foot. The absolute symmetry index showed that the CP participants had less asymmetry in the relaxed standing condition than the controls. Also, the CP group had a slightly higher number of weight shifts and took more steps than the control group. The CP group had a significant difference in CoP movement under each foot, and had more CoP movements on their non-affected side than the controls had on their dominant side, and less CoP movements on their affected side than the controls had on their non-dominant side.

The discussion below consists of three parts. First, the weight-bearing findings from the results will be presented and discussed with respect to CoP movements, qualitative postural changes, shifts in weight bearing, and weight-bearing asymmetry, respectively. Thereafter, strategies in standing and suggestions for possible future directions will be presented.

Weight-bearing characteristics

CoP movements

The present study found that during quiet standing, CP participants have in general more CoP movements under each foot than the control participants. Two force plates have not previously been used to study control of upright stance in CP patients. However, previous studies on CP patients have found that they exhibit a larger amount of sway than healthy individuals (Donker et al., 2008; Ferdjallah, Harris, Smith, & Wertsch, 2002; Rose et al., 2002). However, these studies focused on quiet standing using one force plate only. In addition, using one plate only one studies the total CoP excursion, while the use of two force plates allows studying the amount of CoP movement under each foot (Winter, 1995). In the current study net CoP was not the focus of study and therefore not calculated, and hence findings in previous studies on net CoP can not directly be compared with the results in the current study.

In the relaxed one minute standing condition the CP group had larger difference in CoP movements between feet than the control group. In addition, CP participants had more CoP excursions on their non-affected side than the controls had on their dominant side, and less CoP excursions on their affected side than the controls had on their non-dominant side. This might imply that CP patients prefer to use their non-affected leg to alter standing posture and adjust position. It might be that this limb has more flexibility and more fine-grained control than the affected leg. These findings are in agreement with previous findings in stroke patients who tend to use their non-paretic lower limb more than the paretic limb to control upright stance (Genthon et al, 2008). However, the study on stroke patients investigated movements in quiet standing only. Relaxed standing on two force plates has not previously been investigated, and is an interesting design that might yield more insight into the strategies used to maintain upright standing in everyday life.

CoP movements have typically been subjected for research in studies of balance on patient groups with several deficits that might have decreased control of upright posture. However, there is no consensus as to whether increased CoP movements are beneficial or sign on disorders, and no agreement on what kind of changes in movement characteristics represent a balance deficiency (Visser et al., 2008; Pai, 2003). Diverging results in studies of postural sway are partly caused by the use of one versus two force plates to look at total sway pattern or CoP movement under each foot, respectively, but also by different methods used to calculate sway magnitude. As an example, Mansfield et al. (2011) calculated the root mean square (RMS) of the anterior-posterior and medio-lateral CoP time series to investigate the amplitude of postural sway, and the synchronization of CoP motion between both feet by cross-correlating CoP movements under left and right foot. The current study used principal component analysis in order to find axes related to the actual sway directions and fit an ellipse around these axes to calculate the area of CoP movements under each foot (Oliviera et al., 1996). This method calculates the area that covers the densest region of the pattern, thereby not over-estimating CoP area as earlier methods were prone to do. However, this method does not take into account CoP data falling outside this region. Thus, it is less sensitive to multi-region patterns, when movement of CoP falls across several smaller preferred areas. In these cases, the rounded shape ellipse will fail to cover the participants' entire area of CoP movement (Oliviera et al., 1996), and hence, give an erroneous calculation of area in some of the participants with a multi-region CoP pattern.

Qualitative postural changes

During any day, humans spend a considerably amount of time standing in many different situations. When standing relaxed, humans usually change their positions effortless from one foot to the other, wiggle their toes, bending their knees, or sliding their feet along the ground as they please. However, in this study CP patients seemed to have a different strategy when changing their relaxed standing position. In contrast to controls, CP patients appeared more restrained in their movements and did not move around as much as the controls. Instead of sliding their feet along the surface, the CP participants took visible steps to alter their foot placement and adjust weight bearing. Several possible explanations might explain these findings. It might be that changes in mechanical properties and impaired muscle activation leads to decreased ankle and hip control synergies that again alter control of standing (Burtner et al., 1998; Ferdjallah et al, 2002). Another possibility is that the small base of support when standing leads to larger demands in control of upright posture (Carlberg & Hadders-Algra, 2005), and hence the need to change foot placement. However, since this strategy is not apparent in all CP patients, it is difficult to state whether taking steps is a choice or a necessity due to lack of finer movement ability, or even due to failure to increase firing rates sufficiently in the proper muscles during contraction as a result of muscle weakness (Rose & McGill, 2005).

Using video recordings as a supplement to force plate data gives opportunities to match quantitative findings with visible movements. In this study, only one camera was used. This was placed straight behind the participants. Even though this camera position gives sufficient information about gross movements made, it did not provide information about the type of step taken, e.g. sideways with one foot or both feet, or one foot backwards and the other foot forwards. To determine this, additional camera angles would be necessary. Several angles might give more information about what kind of strategy different people prefer to use to maintain an upright, relaxed standing position. Furthermore, control of upright standing in the frontal plane seems to be a larger problem in central lateralized disorders (such as stroke), than peripheral lateralized disorders (such as amputation) (de Haart, Geurts, Huidekoper, Fasotti, & van Limbeek, 2004). Having cameras in several positions could give more insight into which plane CP patients prefer to move to maintain balance when standing relaxed, and hence give more information about the strategies used in relaxed standing.

Shifts in weight bearing

In the present study, shifts in weight bearing were studied explicitly to be able to address different standing strategies. The way one changes position and the type of strategy one uses, might give an indication about how free a person is to move around as he pleases, and how different impairments might limit the amount and quality of movements. When standing relaxed, the number of modes in the histogram has to be equal, or maximally differ by one, between feet. The single mode in quiet standing indicated that people, when asked to stand as quietly as possible, indeed manage to stand quiet without changing position. However, when standing for the same amount of time but with the instruction to stand relaxed, the amount of shifts in the weight distribution increased. This indicates that in everyday standing, some people have numerous preferred areas to stand in and changes frequently between these areas. Interestingly, the CP participants that had multiple modes while standing relaxed had odd numbers in total, meaning that they had one more shift on one of the sides, while this was not the case in the control group. Of the six participants having more than one mode on each foot, five had fewer modes on their affected side. This might be a further indication that CP patients prefer to use their non-affected foot to change standing position. One interesting aspect is that having several modes does not necessarily mean an unequal overall weight bearing. For example, one can shift repeatedly from having most weight on the left foot to having most on the right foot, while on average having approximately equal weight bearing on each side.

Most studies investigating asymmetric weight bearing have focused on quiet standing where weight shifts do not occur, and hence shifts in weight bearing has not been a typical subject of research. Usually, the focus has been on the amount, velocity, and patterns of CoP movements a subject produces. Nevertheless, how people shift their weight from one side to the other is used on a daily basis in clinical contexts, as in balance training and assessment of walking ability. Knowing the limitations of the patients is important in planning of treatment (Damiano, 2009). Perhaps the traditional focus on CoP excursions and the amount of sway one produces should not be the main or only focus in the assessment of quality of standing posture, but the latter should also take into account the strategies used in different patients groups to maintain an upright, relaxed standing position.

Weight-bearing asymmetry

In this study, CP patients seemed to have a broad range in their preferred weight distribution, from largely relying on their non-affected side for weight support, to standing almost symmetrical, or even supporting more weight on their affected leg. Due to these large individual differences, there were no overall weight-bearing differences between the CP group and the control group in either of the standing conditions. However, more than two thirds of the CP participants had an asymmetrical weight bearing in either direction, giving an overall asymmetrical result as indicated by the absolute symmetry index in both quiet and relaxed standing. However, in the relaxed standing condition, the controls had a more asymmetrical weight bearing than the controls. This result may not be that surprising as healthy adults, and especially women, tend to laterally shift out their hip and stand with all their weight on one side. Over a short duration of time one is able to maintain this position, and hence you will get a high symmetry score, indicating an asymmetrical standing posture.

Other studies have also used a symmetry index to assess postural asymmetry in patients with a lateralized disorder, such as Parkinson`s disease and stroke. In both these patient groups it has been found that they have less weight bearing on their paretic side when standing quiet for a duration of 30 seconds up to one minute (Genthon et al, 2008, Geurts et al., 2011; Rocchi, Chiari, & Horak, 2002). However, when looking at the CP participants as a whole group, the results in the current study is not in total agreement with the results found for Parkinson`s and stroke patients. Where Parkinson`s and stroke patients seem to prefer having less weight on their paretic side, CP patients have several strategies, and based on the results in this study, it is not possible to state which side have less weight bearing.

In the current study, group results of both healthy young adults and young CP patients were often obscured by large between-subject differences. Although the CP patients were rather similar with respect to their severity of the disease and their Gross Motor Function score, the results in this study illustrate the complexity and heterogeneity of the CP diagnosis. By investigating these patients at the group level only, one misses out on the individual differences that are a major part of this disease. Obviously, the surgical history, leg length discrepancy and shoe inserts/splints in CP patients might play a role in weight bearing and might influence standing characteristics. However, these latter effects could not be disentangled in the current study because most (seven out of nine) CP participants had a leg length discrepancy and previous surgery including tendon Achilles lengthening, and/or hamstrings, m.gracilies or adductor muscles lengthening. Nevertheless, this would be an interesting topic for further research.

In this study, the affected/non-affected foot in CP participants was compared to the dominant/non-dominant foot for control participants in analyses. To divide the control participants` feet into dominant and non-dominant, a questionnaire was used. This questionnaire assesses which foot one prefers to manipulate an object (such as kicking a ball, picking up a marble, etc.) and which foot provides support during an activity (such as standing on one foot balancing on a railway track, etc.) (Elias et al., 1997). However, several of the control participants in this study had large dispersion in their answers on which foot they preferred to use in different situations, and some reported that they used the same foot for both manipulating tasks and stabilizing tasks. These dispersions in the answers might have resulted in classifying the dominant foot wrongly in some of the control participants', and might have affected the results that gave no significant differences in weight-bearing asymmetries between groups, or between feet for the control participants.

Strategies in standing

The expectations in this study were that CP participants would have larger differences between feet, stronger asymmetries with less weight bearing on the affected side, and more CoP movements compared to healthy adults. Surprisingly, the CP group showed three different strategies in weight bearing in both quiet and relaxed standing. Of the six participants having an asymmetrical weight bearing, three participants were found to have the expected distribution of weight. The expectations were based on CP patients often having muscle weakness, excessive co-activation of antagonist muscles, and increased stiffness around joints which can lead to a poor posture and possible gait disturbances (Burtner et al., 1998). The results imply that some of the CP participants might have these motor problems and are not able, or willing, to put half their weight on their impaired side. However, the same number of CP participants had more weight on their affected side. Having more weight on their affected side might indicate that they have fewer degrees of freedom and decreased mobility on their affected foot, and hence lock it in one position to be able to maintain an upright standing posture. Earlier studies have indicated that CP patients have a high level of co-activation which can provide stability, but may reduce flexibility (Carlberg & Hadders-Algra, 2005). Hence, more weight on the affected side might imply that they are able to stabilize when standing, but have a reduced ability to change positions as often or as subtly as healthy persons.

As expected, the results showed that CP participants have more CoP movements in their non-affected foot than in their affected foot. Looking at CoP movements and weight bearing together, it is natural that those with more weight on their affected side use their non-affected side to adjust their position, and hence have more CoP movements on this side. Also, the finding that several of the CP participants have more shifts in weight on their non-affected side lends support to the suggestion that they use their non-affected foot to adjust position. However, for those participants with more weight and more CoP movements on the non-affected side, the implications are not that clear. A possible explanation is that these participants mainly stand on their non-affected side and only switch their weight over to the affected foot for brief moments to be able to adjust position with their non-affected foot.

Even though this study pointed out that CP patients` in general seem to have asymmetric weight bearing, there were some participants that managed to stand symmetrical in the quiet standing condition, and some also seemed to prefer to stand symmetrical in the relaxed standing condition. The symmetrical weight bearing in relaxed standing might point to lack of movement opportunities, or that one minute is too short to have the need to change position to stand comfortable.

Future directions

Even though asymmetrical weight bearing was not apparent in all CP participants, it is a characteristic that is often present in physical disability, and knowledge of weight distribution might be an important step towards improving rehabilitation strategies. More than half of the adults with CP reported reduced ability to walk, due to reduced balance and increased musculoskeletal pain caused by overexertion on one side and inactivity on the other side, respectively (Jahnsen, Villien, Aamodt, Stanghelle, & Holm, 2004). In Norway, having a lifelong physical disability does not mean a systematic lifelong follow-up. After the age of 18, it is up to the individual to state their needs for e.g. physiotherapy, even though maintaining activity also after the age of 18 is important for patients with CP. Physical activity has been shown to reduce chronic pain and slow down deterioration of walking ability (Dodd, Taylor, & Graham, 2003). On the other hand, therapy traditionally has focused on stretching, floor exercises, and walking ability (Damiano, 2009). When deciding on a rehabilitation training program for patients with postural asymmetry, it is essential to consider the biomechanical constraints in addition to the postural deficits that originate from the neurological disease (Genthon & Rougier, 2005). It has been documented that strength training increases muscle strength and functional ability, without increasing spasticity (Dodd, Taylor, & Damiano, 2002). More strength training on the affected side might result in better control of movement and decrease the compensatory role of the stronger limb. This again might provide more freedom to adjust position when standing and have beneficial effects on walking ability (Dodd et al., 2003). Also, it might be important to include more weight-shifting activities that challenge the limits of stability and require accuracy and speed to achieve functional improvement. Assessment of postural asymmetry - rather than “overall” postural control – might prove useful for monitoring disease progression, or as an outcome measure for interventions aimed at improving balance control in CP.

Based on the results in this study, it is clear that amount of CoP movements and weight-bearing asymmetry varies between the affected and non-affected foot in patients with CP. One interesting direction for further research is to assess what happens when standing relaxed for a longer period of time. Different subject groups may experience the intensity of prolonged standing differently. The activity of relaxed standing for a longer period of time might not be as exhausting for healthy individuals as for persons with a balance disorder. In prolonged standing it is not only maintenance of equilibrium that is important, but also the ability to alter the position of your body in a small space (Duarte & Zatsiorsky, 2000). The crouched posture of individuals with CP may lead to fatigue early on, but it is unknown how long they are able to stand. The period of 30 minutes that have been used in studies on low-back pain (Lafond et al., 2009) and elderly (Freitas, Wieczorek, Marchetti, & Duarte, 2005) might be too straining for CP patients and thus it might be necessary to limit stance time in order to prevent the build-up of too much fatigue and hence, prevent falls. However, standing in an everyday manner for about 10 minutes may tell us more about the ability to maintain upright standing posture than the typically used 30-90 seconds stance. It would be interesting to find out how individuals with CP cope with a prolonged standing task. Will it add new information about standing strategies, or will the results be similar to the present study? Will CP patients frequently change their posture to avoid fatigue, or will they react more like the elderly and move less due to lack of mobility? And will the asymmetric stance characteristics found in this study also be present in a study of longer standing time? Answers to these questions can provide additional insights into both the underlying problems in CP and the remaining abilities that treatment for these individuals could take more advantages of.

Conclusion

This study investigated a small sample of CP patients, all with a mild severity of the disease. Despite being all reasonably well-functioning, the CP participants showed several different strategies in relaxed standing, and more asymmetrical patterns in quiet standing than control participants. These characteristics should be taken into account in future studies of this patient group, and also in the treatment of CP patients. Future studies should investigate the prevalence of postural asymmetry in a larger sample of patients, its relation to disease severity, and its value for therapy evaluation.

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Appendix 1:

The Waterloo Footedness Questionnaire-Revised (WFQ-R)

Instructions: Answer each of the following questions as best you can. If you *always* use one foot to perform the described activity, circle *Ra* or *La* (for *right always* or *left always*). If you *usually* use one foot, circle *Ru* or *Lu*, as appropriate. If you use *both* feet *equally often*, circle *Eq*. Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1.	Which foot would you use to kick a stationary ball at a target straight in front of you?	La	Lu	Eq	Ru	Ra
2.	If you had to stand on one foot, which foot would it be?	La	Lu	Eq	Ru	Ra
3.	Which foot would you use to smooth sand at the beach?	La	Lu	Eq	Ru	Ra
4.	If you had to step up onto a chair, which foot would you place on the chair first?	La	Lu	Eq	Ru	Ra
5.	Which foot would you use to stomp on a fast-moving bug?	La	Lu	Eq	Ru	Ra
6.	If you were to balance on one foot on a railway track, which foot would you use?	La	Lu	Eq	Ru	Ra
7.	If you wanted to pick up a marble with your toes, which foot would you use?	La	Lu	Eq	Ru	Ra
8.	If you had to hop on one foot, which foot would you use?	La	Lu	Eq	Ru	Ra
9.	Which foot would you use to help push a shovel into the ground?	La	Lu	Eq	Ru	Ra
10.	During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?	La	Lu	Eq	Ru	Ra
11.	Is there any reason (i.e., injury) why you have changed your foot preference for any of the above activities?	Yes	No	(Circle one)		
12.	Have you ever been given special training or encouragement to use a particular foot for certain activities?	Yes	No	(Circle one)		
13.	If you have answered yes for either question 11 or 12, please explain:	…				

Appendix 2**: Individual data from all analyses for CP participants (CP01-CP09) and control participants (KT01-KT12) with total group mean and SD.**

	SIQS (%)	SIRS (%)	FzQS1 (%)	FzQS2 (%)	FzRS1 (%)	FzRS2 (%)	ModeRS1 (n)	ModeRS2 (n)	AreaQS1 (cm^2)	AreaQS2 (cm^2)	AreaRS1 (cm^2)	AreaRS2 (cm^2)
CP01	18	45	60,17	41,72	73,64	28,11	1	1	0,62	0,93	0,74	2,48
CP02	3	17	49,03	52,2	42,14	59,19	1	2	0,38	1,19	7,38	12,81
CP03	20	19	60,68	40,44	60,3	40,96	4	3	0,37	0,66	7,39	5,26
CP04	2	4	52,25	50,23	53,44	48,92	2	3	0,29	0,71	17,45	19,92
CP05	17	13	42,07	59,92	44,15	57,88	1	1	1,04	2,03	5,25	8,07
CP06	7	5	47,12	54,7	48,1	53,69	1	2	0,74	0,86	1,12	7,32
CP07	6	9	54,29	48,21	55,89	46,66	1	1	0,54	0,39	0,49	1,55
CP08	16	29	43,17	59,09	36,16	65,68	3	4	0,24	0,6	10,69	27,7
CP09	1	1	50,25	51,48	51,49	50,26	3	4	1,2	1,42	10,88	22,81
Mean	10,1	15,9	51	50,89	51,7	50,15	1,89	2,33	0,602	0,976	6,82	11,99
SD	7,6	13,8	6,622	6,766	11,06	11,06	1,2	1,2	0,34	0,5	5,67	9,42
KT01	1	82	51	50,04	9,17	91,74	1	1	0,49	0,46	9,76	0,62
KT02	1	1	50,88	51,57	50,5	51,9	5	5	0,89	0,99	27,31	23,51
KT03	7	4	54,42	47,03	52,45	48,79	1	1	0,25	0,33	1,15	1,17
KT04	2	7	51,98	49,6	54,42	47,15	1	1	0,32	0,21	1,57	3,1
KT05	8	3	46,63	55	49,08	52,62	1	1	0,38	0,41	0,25	0,22
KT06	14	61	43,84	58,53	19,91	82,19	2	2	0,5	0,34	5,87	1,89
KT07	0	12	50,51	50,6	44,56	56,45	1	1	0,38	0,41	0,94	0,57
KT08	2	36	51,93	49,59	32,37	69	1	2	0,95	0,28	2,86	0,46
KT09	6	5	53,85	47,92	53,52	48,24	1	1	0,58	0,2	3,82	3,36
KT10	7	5	54,1	47,49	53,13	48,44	2	2	0,81	0,75	3,68	5,75
KT11	6	9	53,64	47,57	45,9	55,35	4	4	0,24	0,48	47,13	17,66
KT12	2	72	49,72	51,71	87,31	14,36	2	2	0,85	1,25	2,75	20,4
Mean	4,7	24,8	51,04	50,56	46,04	55,52	1,83	1,92	0,55	0,51	8,92	6,56
SD	4,1	29,9	3,17	3,38	19,5	19,4	1,34	1,31	0,26	0,32	14,11	8,66

Abbreviations: SIQS= symmetry index in quiet standing. SIRS = symmetry index in relaxed standing. FzQS1 = mean Fz in quiet standing in affected/non-dominant side, respectively. FzQS2 = mean Fz in quiet standing in non-affected/dominant side, respectively. FzRS1= mean Fz in relaxed standing in affected/non-dominant side, respectively. FzRS2 = mean Fz in relaxed standing in non-affected/dominant side, respectively. ModeRS1= number of modes in relaxed standing in affected/non-dominant side, respectively. ModeRS2= number of modes in relaxed standing in non-affected/dominant side, respectively. AreaQS1= CoP movement area during quiet standing under affected/non-dominant side, respectively. AreaQS2= CoP movement area during quiet standing under non-affected/dominant side, respectively. AreaRS1= CoP movement area during relaxed standing under affected/non-dominant side, respectively. AreaRS2= CoP movement area during relaxed standing under non-affected/dominant side, respectively.