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ORIGINAL PAPER

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Assessment of relation between gait and static balance in children with cerebral palsy

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ABSTRACT

Introduction. Cancer, after cardiovascular disease, is the second most common cause of death both in Poland anIntroduction. In children with cerebral palsy, gait and balance assessment allows for an objective gait pattern evaluation as well as for therapy planning and assessment. It was hypothesised that asymmetry of the lower limbs load in a standing position causes asymmetry of spatiotemporal gait parameters.

Material and methods. 19 children with spastic diplegia and 20 healthy children participated in this study. 3D gait analysis was performed using the BTS Smart optoelectronic system. Stabilometric evaluation was performed using the Zebris Force Plate. Additionally, the Symmetry Index for selected gait and balance parameters was calculated.

Results and conclusion. It was shown that symmetry of gait parameters and lower limb load in standing position differs significantly between the study and control groups. There was no correlation confirmed between lower limbs symmetry in standing position and symmetry of gait parameters. It was shown that 80% of children with cerebral palsy had asymmetrical gait patterns. It has also been shown that asymmetry of lower limbs load in a standing position correlates with an asymmetry of spatiotemporal gait parameters. The majority of children with spastic diplegia present asymmetrical gait patterns and asymmetrical balance parameters, but it has no influence on gait symmetry.

Keywords. spatiotemporal gait parameters, postural stability, asymmetry

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Introduction

Human gait involves complex movement and requires coordination between successions of the swing phase and the stance phase that induce oscillations of the head and trunk observable in the sagittal and frontal planes.[1] The subject must constantly maintain postural balance while propelling himself forward to move in space.

An important gait feature that is recently often investigated and reported, particularly in hemiplegic patients and single leg amputees where one limb is predominantly affected, is symmetry. However, asymmetrical behavior of the lower limbs is not limited only to hemiplegic population and moreover is also present in healthy subjects.[2] Clinically, gait asymmetry is important since it may be associated with a number of negative consequences. These are challenges to control balance.[3]

It is well known that the children with cerebral palsy (CP) have varying levels of deficits in balance and postural control, which is a major component of the gait disorder.[4]

Postural control, specifically postural stability, is a fundamental prerequisite for motor development in children. It is the complex ability of an individual to maintain the center of the gravity of the body over the support base when we are standing still (static balance), in motion (dynamic, functional balance), preparing to perform a movement or preparing to end a movement.[5] Postural control depends on the delicate integration of vision, vestibular and proprioceptive sensations, commands from the central nervous system and neuromuscular responses. In patients with cerebral palsy, these interactions are known to be affected, which may be a reason why postural control is impaired and the maintenance of stability is critical.[6]

Postural control often plays a major role in contributing to motor disorders in children with CP. Postural stability is crucial for purposeful movement and functional activities. Poor postural control limits gross motor functions, ability to explore and interact with the environment, affecting the quality of life for children with CP. Among various measures used to assess stance stability, the motion of the center of pressure (COP) is one of the most common parameters.[7]

In children with cerebral palsy analysis of gait and postural stability parameters asymmetry can provide information on the control of walking and balance and may help clinicians in making treatment decisions. Human gait can be considered as a continual state of imbalance caused by the relationship between the center of mass (COM) and the COP. Every individual must constantly maintain postural balance while propelling himself forward to move in space.[8]

This led us to the hypothesis that presumed asymmetry of the lower limbs load in a standing position affects the spatiotemporal gait parameters symmetry and according to the clinical perspective balance training might increase gait symmetry in patients with CP.

Although the literature has widely investigated the degree of functional limitation of gait and posture in children with CP using 3D movement analysis there are not many studies analyzing the symmetry of gait and balance simultaneously with the use of the symmetry ratio.[7,9–16]

Aim of the study

Therefore the purpose of this study was to investigate the relation between gait parameters and static balance in CP children.

This study compares spatiotemporal gait parameters and postural stability parameters during quiet standing between non-disabled children and children with CP as well as the level of symmetry of these parameters and relation between the symmetry of static balance and gait characteristics.

Material and methods

The research was single, cross-section examination conducted on homogenous group of both healthy children and children diagnosed with CP. The purpose and process of the research was presented and explained to the parents of all participants. All parents gave their written consent to participation of their children in the examination. The project of the research was approved by Bioethics Board. The research was conducted among children consecutively admitted to rehabilitation or orthopedic clinics for CP children.

19 children with cerebral palsy and 20 age-matched healthy children were qualified and participated in this study (age 8–13 years). The qualifying criteria to the control group were as follows: children with spastic diplegia; the ability to stand independently without support for more than 30 seconds; the ability to walk independently; a classification to level II–III in the Gross Motor Function Classification System (GMFCS); and no disorders of higher mental functions. Disqualifying criteria included: children treated with botulinum toxin within the preceding 6 months; children treated surgically within a 1-year period prior to the examination; active drug-resistant epilepsy; baclofen therapy with the use of an implanted infusion pump; inhibiting casts worn during the preceding 6 months; significant amblyopia and hearing loss and lack of patient cooperation. Children being able to stand barefoot without support for more than 30 seconds and with no history of any orthopedic or neurological disorders were included in the control group. The demographic characteristics of the participants of both groups are presented in Table 1.

Ten children with cerebral palsy (52%) were classified as Gross Motor Function Classification System (GMFCS) level II, whereas nine (48%) were classified as GMFCS level III.

Gait analysis was performed by means of the BTS Smart motion analysis system (BTS Bioengineering, Italy).

Table 1. Participants' characteristics

	Study group (n = 19)	Control group (n = 20)
Age, years, mean, [median]	10.1 [10.5]	10.6 [11.1]
(sd)	(2.2)	(2.4)
Gender: males/females, n (%)	10/9 (52/48)	8/12 (40/60)

sd: standard deviation;

This system contains 6 digital infrared cameras with 120 Hz sampling frequency and two visible range NetworkCam AXIS 210A cameras with 20 Hz frequency. All those devices make the measurements simultaneously. Cameras were calibrated each day before the first gait assessment. The scheme of their location in the laboratory of movement analysis is presented in Figure 1. Motion analysis were used to capture 22 photo-reflective markers placed at the bony landmarks of the participant in accordance with the modified Davis model.[17] Each marker must be seen by at least two cameras. The participants walked barefoot at their preferred speed in a minimum of six trials on a 7 m x 0.90 m gait track. The data was collected by the USB/PC controller and analyzed by BTS Smart Analyzer. The research stages included: BTS Smart Capture – data collection, Smart Tracker – markers' tracking and Smart Analyzer – analysis and data processing. The following spatiotemporal gait parameters such as the percentage share of the stance-, swing- and double-stance phase, step length, mean gait velocity and step width were analyzed. Then, spatiotemporal parameters from the BTS Smart were averaged from the six gait cycles for each lower limb trial for each participant.

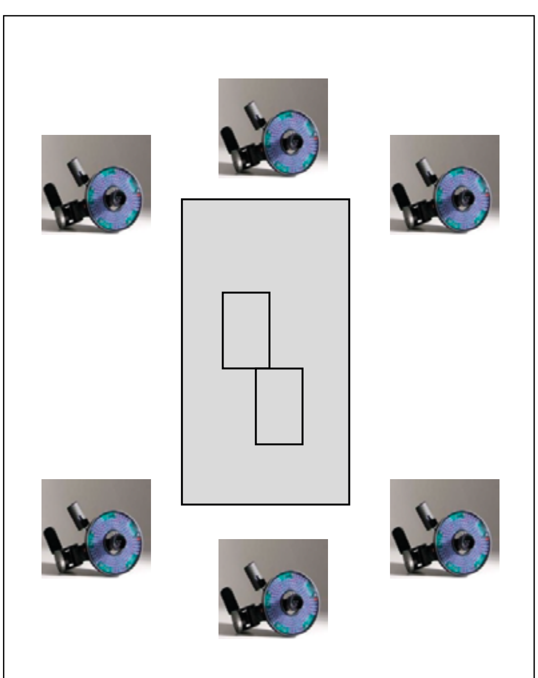

Figure 1. Scheme of cameras location

Stabilometric evaluation was performed with the use of the Zebris WinPDMS Force Plate (Zebris Medical GmbH, Germany), which measures the pressure distribution of static forces. The WinPDMS system analyzes the statical pressure distribution in real-time. The platform dimensions are: 600 mm x 380 mm x 20.1 mm (B x H x T) and it is equipped with 1536 pressure sensors with pressure measurement ranges of 1–120 N/cm^2 and a resolution of 1 sensor/cm^2 and sensor area 320 mm x 480 mm. The sensors respond to the lower limbs load changes. The testing was performed and data was recorded at the recommended sampling frequency of 20 Hz. Afterward the system automatically performed basic analysis of the captured signals for stabilometric assessment. Multiple COP deflection during the test were marked by lines creating the ellipse of different size. The ellipse includes 95% of the COP. Characteristics of the ellipse are presented in a chart.

Balance ability was evaluated during 2 quiet standing tasks: eyes open on a firm surface (EO) and eyes closed on a firm surface (EC). Each child was shown how to stand on the platform. The children were asked to stand barefoot on the platform, with their feet at pelvic width, parallel to the anterior-posterior axis of the platform and with arms at their sides. Children were allowed to stabilize their position for 30 seconds, and then the balance evaluation began with the participants trying to balance themselves while standing in the EO and EC test positions. Each balanced standing position had to be kept for 30 seconds. Subsequently, there was a 30 second long rest between each trial and the child was allowed to sit during that period. Before the EO test, barefoot children standing on the platform had been instructed to fix their eyes on a black point located 1.5 meters away. The position of the black point was adjusted according to the heights and eye level of the participant.

COP sway area, COP length, average value of COP anterior-posterior and medio-lateral sway, as well as the percentage share of right and left lower limb load, were analyzed.

All calculations and statistical analyses were performed with the use of STATISTICA ver. 10.0 (StatSoft, Poland).

Both the normalities of the gait and stabilometric parameters distributions were examined with the Shapiro-Wilk test while the homogeneity of variance was assessed with the use of Levene's test. The analysis revealed that some data were not normally distributed; therefore the authors decided to apply parametric and nonparametric tests. Comparisons between groups were performed with the use of the t-student test for independent variables and the U Mann–Whitney test. The results of parametric tests were marked in bold. Not only mean values but also the standard deviations, medians and 95% confidence interval were used for a better statistical description. To identify and test the strength of a relation between two sets of data, Pearson correlation and Spearman's rank correlation tests were used. A value of $P < 0.05$ was considered to be statistically significant.

To determine the symmetry of selected balance and gait measures the symmetry ratio was applied and calculated according to the following formula: the value of the specified parameter for the one limb/ the value of the specified parameter for the opposite limb (the greater value was divided by the lower value). For calculation of the different parameters of gait and balance symmetry average data were used. A symmetry ratio of 1 indicates that the values for both limbs are equal (i.e. perfect symmetry).[3]

Results

Analysis of the spatiotemporal gait parameters demonstrated that all differences in the spatiotemporal gait parameters between the study- and the control group were statistically significant. The stance phase and double stance phase for the study group were longer. The step length was shorter in the study group than in the control group. Both the step width and the mean gait speed were lower for the study group than for the control group (Table 2).

The symmetry of gait parameters in the study and the control group also significantly differed statistically. Better results of symmetry were observed in the control group in which values of analyzed parameters were more similar to 1.0 (Table 3).

Table 2. Spatiotemporal gait parameters

	Study group n = 19		Control group n = 20		p
	x (s)	95% CI	x (s)	95% CI	
Stance phase r	65.9 (6.2)	62.9–68.9	59.4 (1.9)	58.6–60.3	0.0001
Stance phase L	66.0 (6.8)	62.8–69.3	58.9 (2.2)	57.9–59.9	0.0001
Swing phase r	34.1 (6.1)	31.1–37.0	40.6 (1.9)	39.7–41.4	0.0001
Swing phase L	33.8 (7.0)	30.4–37.1	41.1 (2.2)	40.1–42.1	0.0001
Double stance r	15.8 (7.3)	12.3–19.3	9.3 (2.0)	8.4–10.2	0.0005
Double stance L	16.8 (6.5)	13.7–19.9	9.3 (2.1)	8.3–10.3	0.0000
Step lenght r	0.3 (0.1)	0.2–0.3	0.5 (0.1)	0.5–0.5	0.0000
Step length L	0.3 (0.1)	0.2–0.3	0.5 (0.1)	0.5–0.5	0.0000
Step width	0.2 (0.0)	0.2–0.2	0.1 (0.0)	0.1–0.1	0.0000
V (m/s)	0.4 (0.1)	0.3–0.4	1.1 (0.2)	1.1–1.2	0.0000

x – average, s – standard deviation, 95% CI – 95% confidence interwal, p – p-value, V – gait velocity (m/s), r/l – right/left lower limb

Table 3. Symmetry ratio of gait parameters

	Study group n = 19		Control group n = 20		p
	x (s)	95% CI	x (s)	95% CI	
Stance phase ratio	1.06 (0.05)	1.04–1.08	1.01 (0.01)	1.01–1.02	0.0001
Swing phase ratio	1.13 (0.13)	1.06–1.19	1.02 (0.01)	1.01–1.03	0.0001
Double stance ratio	1.76 (1.55)	1.01–2.50	1.09 (0.09)	1.05–1.13	0.0036
Step lenght ratio	1.21 (0.19)	1.12–1.31	1.04 (0.03)	1.03–1.06	0.0003

x – average, s – standard deviation, 95% CI– 95% confidence interval, p – p-value;

Table 4. Stabilometric parameters (open eyes)

	Study group n = 19		Control group n = 20		p
	x (s)	95% CI	x (s)	95% CI	
Sway Area (mm2)	654.3 (616.5)	357.2–951.5	110.5 (136.0)	46.9–174.2	0.0000
COP Length (mm)	1450.9 (468.5)	1225.1–1676.8	1358.9 (263.3)	1235.7–1482.2	0.7045
Hd (mm)	12.3 (9.3)	7.8–16.8	3.5 (1.8)	2.6–4.4	0.0000
Vd (mm)	10.5 (4.8)	8.2–12.8	6.0 (2.8)	4.7–7.3	0.0003
F L (%)	51.0 (16.3)	43.2–58.8	50.3 (4.3)	48.3–52.3	0.8534
F R (%)	49.0 (16.3)	41.1–56.8	49.7 (4.3)	47.7–51.7	0.8513
F ratio	1.9 (0.8)	1.5–2.3	1.1 (0.1)	1.1–1.2	0.0018

COP – center of pressure, Hd (mm) – horizontal deviation (mm), Vd (mm) – Vertical deviation (mm), F L (%) – Left Average forces, total (%) F R (%) - Right Average forces, total (%), F ratio (F L/F R)

Table 5. Relationships between spatiotemporal gait parameters symmetry and symmetry of the lower limbs load

*R significant at $p < 0.05$	F ratio			
	Study group n=19		Control group n=20	
	EO	EC	EO	EC
Stance phase ratio	-0.05	-0.01	0.17	-0.12
Swing phase ratio	0.01	0.10	0.19	-0.12
Double stance ratio	0.26	-0.06	0.15	0.01
Step lenght ratio	-0.09	-0.21	-0.04	-0.05

EO – eyes open, EC – eyes closed, F ratio – (Left Average forces, total (%) / Right Average forces, total (%))

In terms of stabilometric parameters statistically significant differences between the study and the control group in both EO and EC trials were related to the confidence ellipse area, as well as to the horizontal and vertical COP deviation. The results of the CP children were higher, (i.e., worse) than children from the control group. When compared with the control group, the symmetry ratio of average forces during quiet standing was higher in the study group and was also statistically significantly different. Due to similar results in both trials in terms of statistically significant differences, Table 4 presents the results only of the EO test.

Although it was shown that gait parameters of symmetry and symmetry of lower limbs loading in standing position differs significantly between the study and the control group there were no statistically significant correlations between symmetry of the lower limbs loading during standing and symmetry of spatiotemporal gait parameters (Table 5).

Discussion

Spastic diplegia is the most prevalent type of CP. It is characterized by a wide range of ambulatory outcomes.[18] Children with diplegic-type CP have impaired motor control, which frequently leads to limitations in their mobility. As a result, the balance control and the corresponding walking functions are affected.[19]

The ability to control posture during standing is being developed early in life. At the same time the child's walking performance is also developing. With increasing age children tend to walk faster with smaller physiological cost and with a more mature gait. It seems that balance functions are tightly correlated with walking performance in non-disabled children. In children with spastic CP stepping reactions can only be observed in the case of independent walkers, not non-walkers. Therefore it can be assumed that in children with CP balance function is also correlated with independent walking performance. Balance and locomotor abilities are also positively correlated in children with spastic diplegia. The latter ones have a decreased rhythmic shifting ability when compared with children without CP, and this ability is correlated with walking function.[20]

Additionally, Katz-Leurer et al. found a significant linear inverse correlation between balance performance and step length variability among children with traumatic brain injury.[21] Ambulatory children after severe traumatic brain injury had decreased gait speed when compared with age – matched typically developed (TD) ones.

Our study researched differences in stabilometric parameters, as well as in spatiotemporal characteristics of gait in children with CP compared with TD children.

The aim of this study was to evaluate the relation between gait parameters and static balance in CP children. Some researchers believe that asymmetric alignment in posture is especially characteristic in children with unilateral neurological lesions such as unilateral CP (spastic hemiplegia).[22] However, as previously noted, asymmetrical behavior of the lower limbs is not characteristic only for hemiplegic population, so the authors hypothesized that children with CP present asymmetrical patterns of static balance and spatiotemporal gait characteristics and that asymmetry of the lower limbs load in a standing position may cause asymmetry of spatiotemporal gait parameters. To assess the level of symmetry the authors used the symmetry ratio proposed by Patterson et al.[3]

The literature indicates that CP children present a lower postural balance ability when compared with TD children.[23–25] Poor postural control can trigger the delays and deviations in motor skill acquisition and development in CP children. Postural control is often assessed by means of posturography, that is, the quantitative analysis of center-of-pressure (COP) trajectories measured with the use of a force platform.[26] COP data proved to be sensitive in discerning balance performance in healthy adults, patients with post-stroke hemiparesis, cerebellar deficits, Parkinson's disease, healthy adolescents and children with cerebral palsy.[27–34]

Velocity and center of pressure sway, mainly in the medial-lateral direction, exhibit the greatest increases in patients with cerebral palsy.[24,26] Donker at al. found that posturogram characteristics of CP children differed considerably from those of TD children.[26] An interesting and unexpected finding in their study was that the total COP deflation did not differ significantly between CP and TD children. Liao at all reported, that the standing stability of the children with CP was poorer than that of TD children with different sensory conditions.[20]

In this study patients with spastic diplegia presented a significant increase in their COP confidence ellipse area and in both horizontal and vertical COP sway with the EO and EC compared to TD children. Moreover, CP children present asymmetry of average forces during quiet standing.

Regarding spatiotemporal gait parameters Chang et al. proved that children with spastic diplegic CP walk with reduced walking speed and stride length, increased stride time and step width, which indicates reduced gait efficiency.[35]

Our findings showed significantly lower spatiotemporal gait parameters, including walking velocity and step length in children with spastic diplegic CP than in TD children. Step width was larger in children with CP. Moreover, significant differences in proportions of the stance phase (single- and double-limb stance) were observed in children with spastic diplegic CP while compared with TD children. The duration of single- and double-limb support in CP children was longer. Our findings are consistent with those of previous studies reporting deteriorated gait function and altered gait pattern in children with spastic diplegic CP.[36–38] Because of motor weakness and poor voluntary motor control, children with CP use a wider step width than TD children, what indicates that children with CP may choose a wider base of support in order to stabilize the COP.[39]

In addition, in our study the symmetry of gait parameters in the study- and the control group also statistically significantly differed. Better results symmetry were observed in the control group in which values of symmetry ratio were closer to 1.0. However, we didn't find statistically significant correlations between symmetry of the lower limbs_loading during standing and symmetry of spatiotemporal gait parameters.

Kurz et al showed no difference in the walking speeds of the children with CP (aged 7.8 ± 2.8 yrs) and the TD children (CP = 0.79 ± 0.05 m/s; TD = 0.81 ± 0.03 m/s; p = 0.28). During their examination children with CP used a significantly (p = 0.005) wider step width than the TD children (Fig. 3), but had a similar amount of step width variability (CP = 26.0 ± 4.2%; TD = 28.6 ± 4.3%; p = 0.70). Children with CP did not have a longer step length than the TD children (CP = 0.60 ± 0.03; TD = 0.60 ± 0.01; p = 0.78), but their step length was significantly (p = 0.01) more variable [38]. This demonstrates the large variability of gait in CP children. According to Diop et al. due to maturation of gait during growth, gait variability in children is age dependent, being higher in children under eight years old, and inter-stride variability decreases with age.[40] Hausdorff et al. described an inter-stride coefficient of variation as 8.4% at 4 years old, 4.3% at 7 and 1.9% at 11 years old.[41] Prosser et al. reported that children with CP demonstrate slower walking velocity, decreased cadence, shorter step length, and reduced single limb support compared with TD children, which is consistent with our findings.[42]

In our study children with CP spastic diplegia presented a lower standing balance and significant differences in spatiotemporal gait parameters compared with TD children. Although there were no correlations between symmetry of the lower limbs loading during standing and symmetry of spatiotemporal gait parameters measured with the use the symmetry ratio. Rehabilitation therapies for CP patients should focus on improving standing balance and postural stability because postural balance is integral for all motor abilities.

Limitations

The authors acknowledge some limitations of this study. One of the limitations was that the influence of treatments was not taken into account in this hereby analysis. This issue will become the subject of future research concerning further investigation of the influence of both balance treatments and gait profiles as well as observations of the longitudinal evolution of the patients. Another limitation was the lack of standardized, reliable, validated outcome measures of static balance assessment in children.

Additionally, future research should examine the variability and symmetry of other walking characteristics, such as kinematics, kinetics, and muscle activation patterns as well as symmetry of dynamic stability parameters.

Conclusion

There were significant differences in both walking performance and static balance characteristics in spastic diplegic CP children while compared with TD children.

The results of the hereby research revealed that the majority of CP children with spastic diplegia present asymmetrical gait patterns and asymmetrical balance parameters, but asymmetry of the lower limbs load in a standing position does not affect the spatiotemporal gait parameters symmetry. However, the further research of those aspects is needed not only to determine a link between asymmetric control of balance and gait but also to identify other factors that can help to explain gait asymmetry.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflicts of interest.
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References

1. Lamontagne A, De Serres J, Fung S, Paquet JN. Stroke affects the coordination and stabilization of head, thorax and pelvis during voluntary horizontal head motions performed in walking. Clin Neurophysiol. 2005;116:101-11.
2. Böhm H, Döderlein L. Gait asymmetries in children with cerebral palsy: do they deteriorate with running? Gait Posture. 2012;35(2):322-7.
3. Patterson KK, Gage WH, Brooks D, Black SE, McIlroy WE. Evaluation of gait symmetry after stroke: a comparison of

current methods and recommendations for standardization. Gait Posture. 2010;31(2):241-6.
4. Hsue BJ, Miller F, Su FC. The dynamic balance of the children with cerebral palsy and typical developing during gait. Part I: Spatial relationship between COM and COP trajectories. Gait Posture. 2009;29(3):465-70.
5. De Kegel A, Dhooge I, Peersman W, et al. Construct validity of the assessment of balance in children who are developing typically and in children with hearing impairments. Phys Ther. 2010;90(12):1783-94.
6. Woollacott M, Shumway-Cook A. Postural dysfunction during standing and walking in children with cerebral palsy: What are the underlying problems and what new therapies might improve balance? Neur Plast. 2005;12:211-9.
7. Saxena S, Rao BK, Kumaran S. Analysis of postural stability in children with cerebral palsy and children with typical development: An observational study. Pediatr Phys Ther. 2014;26(3):325-30.
8. Wallard L, Dietrich G, Kerlirzin Y, Bredin J. Balance control in gait children with cerebral palsy. Gait Posture. 2014;40(1):43-7.
9. Chang FM, Rhodes JT, Flynn KM, Carollo JJ. The role of gait analysis in treating gait abnormalities in cerebral palsy. Orthop Clin North Am. 2010;41(4):489-506.
10. Cimolin V, Galli M, Tenore N, Albertini G, Crivellini M. Gait strategy of uninvolved limb in children with spastic hemiplegia. Eura Medicophys. 2007;43:303-10.
11. Ferreira LA, Cimolin V, Costici PF, Albertini G, Oliveira CS, Galli M. Effects of gastrocnemius fascia lengthening on gait pattern in children with cerebral palsy using the Gait Profile Score. Res Dev Disabil. 2014;35(5):1137-43.
12. Gage JR. The treatment of gait problems in cerebral palsy. London: Cambridge University Press;2004.
13. Galli M, Cimolin V, Valente EM, Crivellini M, Ialongo T, Albertini G. Computerized gait analysis of botulinum toxin treatment in children with cerebral palsy. Disabil Rehabil. 2007;29(8):659-64.
14. Galli M, Cimolin V, Rigoldi C, Tenore N, Albertini G. Gait patterns in hemiplegic children with cerebral palsy: Comparison of right and left hemiplegia. Res Dev Disabil. 2010;31(6):1340-5.
15. Piccinini L, Cimolin V, Galli M, Berti M, Crivellini M, Turconi AC. Quantification of energy expenditure during gait in children affected by cerebral palsy. Eura Medicophys. 2007;43(1):7-12.
16. Rojas VG, Rebolledo GM, Muňoz EG, Cortés NI, Gaete CB, Delgado CM. Differences in standing balance between patients with diplegic and hemiplegic cerebral palsy. Neural Regen Res. 2013;8(26):2478-83.
17. Davis RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. Hum Mov Science. 1991;10:575-87.
18. Bjornson K, Hays R, Graubert C. Botulinun toxin for spasticity in children with cerebral palsy: A comprehensive evaluation. Pediatrics. 2007;120:49-58.
19. Eek MN, Tranberg R, Beckung E. Muscle strength and kinetic gait pattern in children with bilateral spastic CP. Gait Posture. 2011;33:333-7.
20. Liao HF, Jeng SF, Lai JS, Cheng CK, Hu MH. The relation between standing balance and walking function in children with spastic diplegic cerebral palsy. Dev Med Child Neurol. 1997;39(2):106-12.
21. Katz-Leurer M, Rotem H, Keren O, et al. Balance abilities and gait characteristics in post-traumatic brain injury, cerebral palsy and typically developed children. Dev Neurorehabil. 2009;12:100-5.
22. Bax M, Goldstein M, Rosenbaum P, et al. Proposed definition and classification of cerebral palsy. Dev Med Child Neurol. 2005;47(8):571-6.
23. Liao SF, Yang TF, Hsu TC, et al. Differences in seated postural control in children with spastic cerebral palsy and children who are typically developing. Am J Phys Med Rehabil. 2003;82(8):622-6.
24. Cherng RJ, Lin HC, Ju YH, et al. Effect of seat surface inclination on postural stability and forward reaching efficiency in children with spastic cerebral palsy. Res Dev Disabil. 2009;30(6):1420-7.
25. Kyvelidou A, Harbourne RT, Shostrom VK, et al. Reliability of center of pressure measures for assessing the development of sitting postural control in infants with or at risk of cerebral palsy. Arch Phys Med Rehabil. 2010;91(10):1593-601.
26. Donker SF, Ledebt A, Roerdink M, et al. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. Exp Brain Res. 2008;184(3):363-70.
27. Lin D, Seol H, Nussbaum M, et al. Reliability of COP-based postural sway measures and age-related differences. Gait Posture. 2008;28(2):337-42.
28. Lafond D, Corriveau H, Hébert R, et al. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Arch Phys Med Rehabil. 2004;85(6):896-901.
29. Ioffe ME, Ustinova KI, Chernikova LA, et al. Supervised learning of postural tasks in patients with poststroke hemiparesis, Parkinson's disease or cerebellar ataxia. Exp Brain Res. 2006;168(3):384-94.
30. Rocchi L, Chiari L, Horak FB. Effects of deep brain stimulation and levodopa on postural sway in Parkinson's disease. J Neurol Neurosurg Psychiatry. 2002;73(3):267-74.
31. Rocchi L, Chiari L, Cappello A, et al. Identification of distinct characteristics of postural sway in Parkinson's disease: a feature selection procedure based on principal component analysis. Neurosci Lett. 2006;394(2):140-5.
32. Riach CL, Hayes KC. Maturation of postural sway in young children. Dev Med Child Neurol. 1987;29(5):650-8.
33. Liao HF, Mao PJ, Hwang AW. Test-retest reliability of balance tests in children with cerebral palsy. Dev Med Child Neurol. 2001;43(3):180-6.
34. Cherng RJ, Su FC, Chen JJ, et al. Performance of static standing balance in children with spastic diplegic cerebral palsy

under altered sensory environments. Am J Phys Med Rehabil. 2007;78(4):336-43.
35. Chang CF, Wang TM, Wang WC, et al. Balance control during level walking in children with spastic diplegic cerebral palsy. Biomed Eng. 2011;23:509-17.
36. Kim CJ, Son SM. Comparison of Spatiotemporal Gait Parameters between Children with Normal Development and Children with Diplegic Cerebral Palsy. J Phys Ther Sci. 2014;26(9):1317-9.
37. Johnson DC, Damiano DL, Abel MF. The evolution of gait in childhood and adolescent cerebral palsy. J Pediatr Orthop. 1997;17:392-6.
38. Abel MF, Damiano DL. Strategies for increasing walking speed in diplegic cerebral palsy. J Pediatr Orthop. 1996;16:753-8.
39. Kurz MJ, Arpin DJ, Corr B. Differences in the dynamic gait stability of children with cerebral palsy and typically developing children. Gait Posture. 2012;36:600-4.
40. Diop M, Rahmani A, Calmels P, et al. Influence of speed variation and age on the intrasubject variability of ground reaction forces and spatiotemporal parameters of children's normal gait. Ann Readapt Med Phys. 2004;47(2):72-80.
41. Hausdorff JM, Zemany L, Peng C, Goldberger AL. Maturation of gait dynamics: stride-to-stride variability and its temporal organization in children. J Appl Physiol. 1999;86(3):1040-7.
42. Prosser LA, Lauer RT, VanSant AF, Barbe MF, Lee SC. Variability and symmetry of gait in early walkers with and without bilateral cerebral palsy. Gait Posture. 2010;31(4):522-6.