Gait & Posture 92 (2022) 110–115

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Evaluation of sitting and standing postural balance in cerebral palsy by center-of-pressure measurement using force plates: comparison with clinical measurements☆

Dain Shim, Dongho Park [1,2], Beomki Yoo [3], Joong-on Choi, Juntaek Hong, Tae Young Choi, Eun Sook Park, Dong-wook Rha [*,4]

Department and Research Institute of Rehabilitation Medicine, Yonsei University College of Medicine, Seoul, South Korea

ARTICLE INFO

Keywords:
Cerebral palsy
Balance
Center-of-Pressure
Assessment

ABSTRACT

Background: Center-of-pressure (CoP) measurements have been studied for assessing balance control. While CoP measurements using force plates have been used to assess standing balance in children with cerebral palsy (CP), it has not been assessed in a sitting position, which specifically reflects trunk postural control.

Research question: The purpose of this study was to compare CoP measurements using force plates during both standing and sitting trials with the Pediatric Balance Scale (PBS) in children with spastic CP.

Methods: We recruited 26 children with spastic CP (7.8 ± 3.4 years, 4–13 years) and used the PBS, a validated evaluation tool that measures static and dynamic balance control. We took CoP measurements using force plates during sitting and standing. For both trials, subjects stayed still for 10 s with their eyes open or closed. We calculated the CoP velocity, mediolateral (ML) and anteroposterior (AP) velocity, and ML and AP displacements of CoP.

Results and Significance: During standing trials, static PBS standing scores negatively correlated with more AP displacement and velocity than ML displacement and velocity ($p < 0.05$). During sitting trials, dynamic PBS sitting scores negatively correlated with ML displacement and velocity ($p < 0.05$). CoP parameters in the ML direction of the sitting position and CoP parameters in the AP direction of the standing position may better reflect the balance control in children with spastic CP.

1. Introduction

Children with cerebral palsy (CP) are impaired in responding to changes in posture and external environment during their daily activities due to weakness, abnormal muscle tone, and lack of motor control [1]. Muscle stiffness due to spasticity and/or shortening makes it more difficult for these children to control balance during standing and walking [2]. Therefore, training balance control is important for enabling children with spastic CP to perform a variety of daily living activities more safely and efficiently [3]. An accurate evaluation of balance control ability is necessary to assess baseline ability and track improvement after training.

The Pediatric Balance Scale (PBS) is widely used as a tool to evaluate balance control in children with CP. The PBS is modified for children from the Berg Balance Scale (BBS) for evaluating balance control in adults. The modifications are minor and include reordering test items, reducing time standards for maintenance of static postures, and clarifying directions [4]. The PBS includes 14 items that items assess

Abbreviations: CP, cerebral palsy; CoP, Center-of-Pressure; PBS, Pediartic Balance Scale; ML, mediolateral; AP, anteroposterior.

☆ Value of center-of-pressure measurement using force plates to assess the balance control in children with spastic cerebral palsy

* Correspondence to: Dept. and Research Institute of Rehabilitation Medicine, Dept. of Medical Device Industry, Yonsei University College of Medicine, Severance Rehabilitation Hospital, Biomechanics and Robotic Rehabilitation Laboratory, 50–1 Yonsei-ro, Seodaemun-gu, Seoul 03722, South Korea.

E-mail address: medicus@yonsei.ac.kr (D.-w. Rha).

[1] Current Affiliation: Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA.

[2] Current Affiliation: Institute for Robotics and Intelligent Machines, Georgia Institute of Technology, Atlanta, GA, USA.

[3] Current Affiliation: Department of R&D, iMediSync, Seoul, Korea.

[4] ORCID ID: 0000-0002-7153-4937

https://doi.org/10.1016/j.gaitpost.2021.11.024
Received 11 April 2021; Received in revised form 10 November 2021; Accepted 16 November 2021
Available online 20 November 2021

functional balance control skills related to everyday tasks [5].

In a preliminary PBS study with 40 healthy children aged 5–7 years, high correlation coefficients were reported for inter-rater reliability ($ICC_{3,1}$ =0.997) and test-retest reliability ($ICC_{3,1}$ =0.998) [6]. A study of 24 children with CP reported high test-retest reliability ($ICC_{3,1}$ =0.89–0.93), inter-rater reliability ($ICC_{3,1}$ =0.91–0.93), and intra-rater reliability obtained by four physical therapists ($ICC_{3,1}$ =0.97–0.99). [4]. Therefore, the PBS is a reliable modified measurement of the BBS for measuring balance control in children with CP [6]. In a validation study that analyzed the correlation between the Gross Motor Function Measure (GMFM) and the PBS in children with CP, the total score of the PBS highly correlated with the D (standing) and E (walking, running, jumping) dimension scores of the GMFM [7]. However, the PBS still depends on the subjective judgment of properly trained and qualified inspectors. In addition, scale values are semi-quantitative and not proportional to balance control ability, which makes it difficult to quantify balance.

The center-of-pressure (CoP) movement derived from force plates measuring the ground reaction force is one of the most common parameters for measuring postural stability during quiet standing. The speed and range of the CoP movement is calculated while the subject stands as stably as possible on force plates, allowing the tester to obtain an objective measure of balance control [8].

A previous study analyzed the correlation between BBS scores and parameters of CoP movement in adults with stroke. In that study, BBS was divided into static balance score consisting of items that maintain a certain position and dynamic balance score consisting of items that maintain balance when transitioning from one position to another. The study reported that the mean velocity of CoP displacement in the anteroposterior direction correlated moderately only with static balance score, not with dynamic balance score of BBS [9]. However, no study has analyzed the correlation between PBS and CoP parameters in children with CP. In addition, since sitting instability in CP greatly affects daily life activity [10], it is also important to accurately measure the sitting balance. To our knowledge, CoP measurement during quiet sitting has not been studied before. Therefore, the aim of this study was to investigate the correlation between the clinical measurement of balance control using PBS and CoP parameters obtained during sitting and standing trials in children with CP by incorporating force plates.

2. Method

2.1. Participants

The inclusion criteria were as follows: 1) 3–18-year-old children, 2) sufficient cognitive function to follow instructions given during the PBS and CoP assessments, and 3) sufficient physical function to stand independently without any assistive device for more than 10 s.

The exclusion criteria were as follows: 1) botulinum toxin injection or lower limb plaster fixation within 6 months prior to assessment, 2) neurosurgical or orthopedic surgery within 6 months prior to assessment, 3) dyskinetic and ataxic CP, or 4) diagnosed with any visual impairment, hearing impairment, and/or vestibular dysfunction. Twenty-six ambulatory children and adolescents were diagnosed spastic CP and I-III level of Gross Motor Function Classification System (GMFCS) participated in this study. The general characteristics of the participating children with spastic CP are presented in Table 1.

2.2. Protocol

The subjects undertook the Korean version of the PBS (K-PBS) by an occupational therapist, one of the authors (D. Shim). We measured the CoP movement of participants during sitting and standing on two force plates (AMTI, Watertown, MA, USA).

Table 1
Demographic characteristics.

Demographics	Number (%) or mean ± SD (range)
Age, years (range)	7.8 ± 3.4 (4–13)
Sex, n (%)	
Male	14 (53.8)
Female	12 (46.2)
Affected Limb, n (%)	
Unilateral	10 (38.5)
Bilateral	16 (61.5)
GMFCS, n (%)	
Level I	15 (57.7)
Level II	10 (38.5)
Level III	1 (3.8)

Abbreviation: GMFCS, Gross Motor Functional Classification System

2.3. Pediatric balance scale

The PBS consists of 14 items, each scored on a 5-point scale from 0 to 4, depending on the child's balance ability. The 14 items may be classified into static or dynamic balance measurement groups. The static balance measurement group (6 items) includes tasks maintaining static posture, and the dynamic balance measurement group (8 items) includes tasks maintaining balance during movement [9].

In addition, we classified the 14 items of the PBS into sitting or standing balance measurements. Sitting balance measures the ability to control balance in the sitting posture (4 items). Standing balance measures the ability to control balance in a standing position (10 items).

Ultimately, the PBS items were classified as static or dynamic balance in a sitting posture or as static and dynamic balance in a standing posture to analyze the correlation with CoP parameters (Table 2).

2.4. CoP measurement

When sitting or standing on two force plates, the ground reaction force was measured at a sampling rate of 100 Hz (Fig. 1).

To measure CoP movement during sitting, a bench was placed on the force plates, symmetrically spaced with one leg on each force plate. The bench had two support legs, and the middle of one leg was recessed so the bench rested on the force plates in a total of 4 points. The contact points were marked so that the location of bench was always the same, and the children were instructed to sit in the middle of the bench. When the children sat on the bench, the height of the bench was adjusted so that their legs flexed to about 90° and the soles of their feet were in full contact with the space outside the force plates. During CoP measurement, the children placed their hands on both knees and sat as still as possible with eyes opened or closed for 10 s each. CoP measurement was performed three times for each trial. To measure CoP movement during standing, the children stood on two force plates, each foot on one force plate. During the standing trial, the children were instructed to stand upright facing the front, to keep the soles of their feet in continuous contact with the force plates, and to not move intentionally.

Table 2
Classified items of PBS into 4 categories.

	Sitting	Standing
Static	Item 4. sitting unsupported	Item 5. standing unsupported Item 6. standing with eyes closed Item 7. standing with feet together Item 8. standing with one foot in front Item 9. standing on one foot
Dynamic	Item 1. sitting to standing Item 2. standing to sitting Item 3. transfers	Item 10. turning 360 degrees Item 11. turning to look behind Item 12. retrieving object from floor Item 13. placing alternate feet on a stool Item 14. reaching forward with an outstretched arm

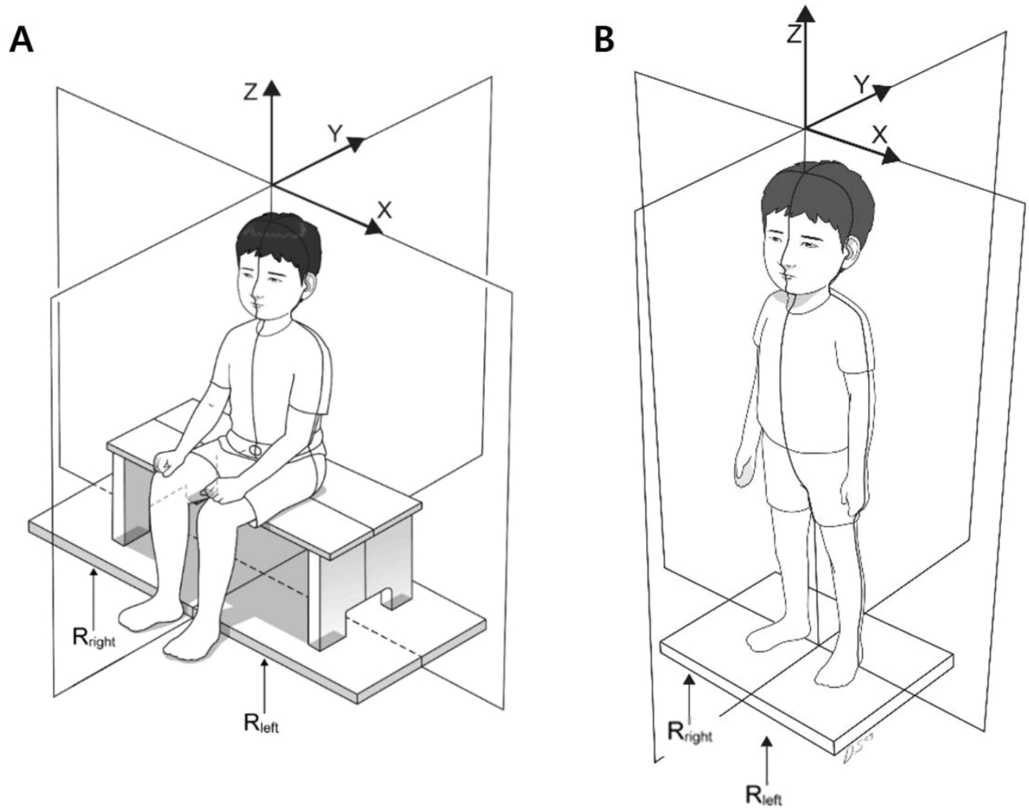

Fig. 1. : A. Center-of-Pressure (CoP) measurement on force plates during sitting. B. Center-of-Pressure (CoP) measurement on force plates during standing. The CoP components (x, y) corresponded respectively to mediolateral and anteroposterior signals in the measurement system using dual force platforms. R_{right} and R_{left} are the magnitudes of vertical round reaction forces under the right and left legs of bench or children, respectively.

In both trials, the net CoP was calculated from CoP coordinates from each force plate. The CoP parameters, including CoP velocity, anteroposterior (AP) velocity, mediolateral (ML) velocity, AP displacement, and ML displacement, were calculated using the net CoP [8]. Velocity parameters (CoP velocity, AP velocity, and ML velocity) were calculated by dividing the total CoP length by 10 s, the duration of quiet sitting or standing. CoP velocity reflects total movement distance of the CoP during sitting and standing for 10 s. The total movement distance of the CoP was approximated by the sum of the distances between consecutive points on the CoP path; this calculation was also applied to ML and AP parameters (Fig. 2). AP displacement is the range of CoP movement in the AP direction, and ML displacement is the range of CoP movement in the ML direction during sitting and standing. CoP measurement on force plates during sitting with eyes open and eyes closed and standing with eyes open and eyes closed were conducted three times for each person, and the average value of three trials was analyzed.

2.5. Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences for Windows (SPSS version 23.0, IBM SPSS Incorporated, Chicago, IL, USA). Spearman's rank correlation coefficients were calculated to estimate associations between PBS static and dynamic scores and CoP parameters.

Correlation coefficients were interpreted as follows: 0.00–0.10 (0.00 to −0.10): negligible correlation; 0.10–0.39 (−0.10 to −0.39): weak positive (negative) correlation; 0.40–0.69 (−0.40 to −0.69): moderate positive (negative) correlation; 0.70–0.89 (−0.70 to −0.89): strong positive (negative) correlation; 0.90–1.00 (−0.90 to −1.00): very strong positive (negative) correlation [11].

Intraclass correlation coefficients ($ICC_{2,\ 1}$) with 95% confidence intervals were used to evaluate the inter-test reliability of 3 trials of CoP measurement during sitting and standing.

3. Results

3.1. Sitting trials

Correlations between balance parameters of CoP measurement in sitting trials and PBS scores are summarized in Table 3.

During sitting trials with eyes opened, static PBS scores moderately negatively correlated with AP displacement ($p < 0.05$). Dynamic PBS scores moderately negatively correlated with ML displacement ($p < 0.05$) and ML velocity ($p < 0.01$).

Dynamic PBS sitting scores analyzed separately from standing scores moderately negatively correlated with ML displacement ($p < 0.05$) and ML velocity ($p < 0.01$) (Fig. 3A).

During sitting trials with eyes closed, dynamic PBS scores moderately negatively correlated with ML displacement ($p < 0.05$).

Dynamic PBS sitting scores analyzed separately from standing scores moderately negatively correlated with ML displacement and ML velocity ($p < 0.05$).

The inter-test reliabilities of the CoP parameters were good to excellent (ICC 0.87, 0.84, 0.926, 0.764, 0.682; COP velocity, AP velocity, ML velocity, AP displacement, ML displacement) during sitting trials with eyes opened. And the inter-test reliabilities of the CoP parameters were fair to excellent (ICC 0.723, 0.534, 0.947, 0.754, 0.903; COP velocity, AP velocity, ML velocity, AP displacement, ML displacement) during sitting trials with eyes closed.

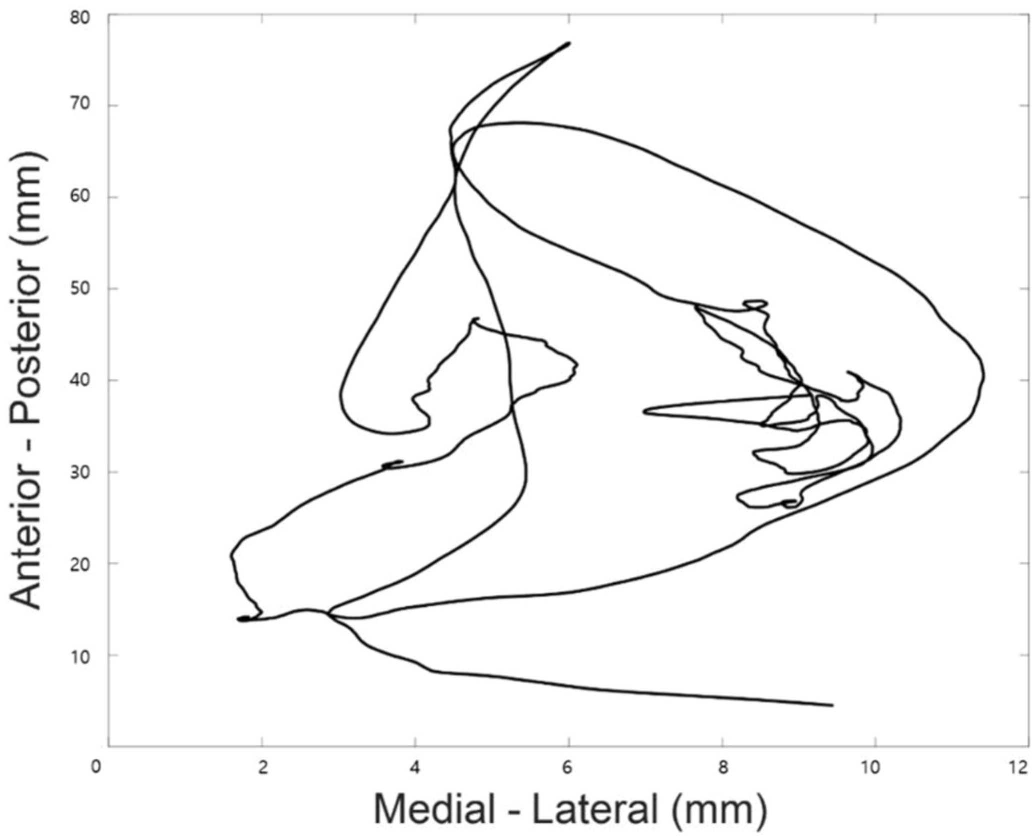

Fig. 2. **:** Center-of-Pressure Trajectory. This graph shows one example of the movement of CoP calculated from dual force plates in a child with cerebral palsy. The length of the line on the graph in a straight line is the total length, the trajectory range in the mediolateral direction is mediolateral displacement, and the trajectory range in the anteroposterior direction is anteroposterior displacement.

Table 3
Correlation between PBS scores and CoP parameters in sitting trials (n = 26).

		PBS sitting		PBS		
		static score	dynamic score	static score	dynamic score	total score
Eyes Opened	ML displacement	–	-0.478 *	-0.309	-0.452 *	-0.366
	AP displacement	–	-0.249	-0.449 *	-0.271	-0.355
	ML velocity	–	-0.536†	-0.308	-0.499†	-0.385
	AP velocity	–	-0.243	-0.370	-0.238	-0.283
	CoP velocity	–	-0.316	-0.365	-0.334	-0.331
	ML displacement	–	-0.399 *	-0.238	-0.414 *	-0.308
	AP displacement	–	-0.304	-0.371	-0.366	-0.372
Eyes Closed	ML velocity	–	-0.425 *	-0.176	-0.377	-0.268
	AP velocity	–	-0.201	-0.247	-0.234	-0.198
	CoP velocity	–	-0.281	-0.216	-0.329	-0.234

Abbreviation: PBS, Pediatric Balance Scale; CoP, Center-of-Pressure; ML, Mediolateral displacement; AP, Anteroposterior
* $p < 0.05$ by Spearman's rank correlation test
†$p < 0.01$ by Spearman's rank correlation test

3.2. Standing trials

Correlations between balance parameters of CoP measurement in standing trials and PBS scores are summarized in Table 4.

During standing trials with eyes opened, static PBS scores had moderate to strong correlation with all CoP parameters ($p < 0.01$). Dynamic scores of PBS had weak to moderate correlation with all CoP parameters ($p < 0.05$). Total PBS scores moderately negatively correlated with all CoP parameters ($p < 0.01$).

Static PBS standing scores alone had moderate to strong negative correlation with all CoP parameters ($p < 0.05$) (Fig. 3B). Dynamic PBS standing scores moderately negatively correlated with all CoP parameters ($p < 0.05$).

During standing trials with eyes closed, static PBS scores moderately negatively correlated with AP displacement ($p < 0.01$), AP velocity ($p < 0.01$), and CoP velocity ($p < 0.05$). Dynamic PBS scores moderately negatively correlated with AP velocity ($p < 0.01$) and CoP velocity ($p < 0.01$). Total PBS scores moderately negatively correlated with AP displacement ($p < 0.01$), AP velocity ($p < 0.05$), and CoP velocity ($p < 0.05$).

Analyzed separately, static PBS standing scores moderately negatively correlated with AP displacement ($p < 0.01$), AP velocity ($p < 0.05$), and CoP velocity ($p < 0.05$). Dynamic standing scores of PBS moderately negatively correlated with AP velocity ($p < 0.05$) and CoP velocity ($p < 0.01$).

The inter-test reliabilities of the CoP parameters were fair to

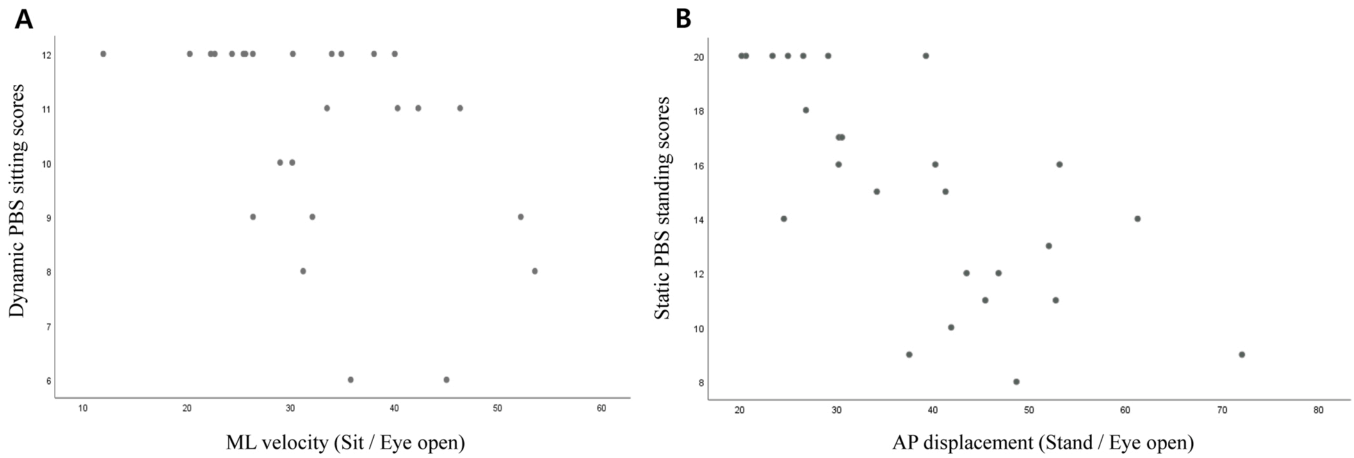

Fig. 3. **:** A. Scatter plot between dynamic PBS sitting scores and mediolateral velocity during sitting with eye-opened. B. Scatter plot between static PBS standing scores and anteroposterior displacement during standing with eye-opened.

Table 4
Correlation between PBS scores and CoP parameters in standing trials (n = 24).

		PBS standing		PBS		
		static score	dynamic score	static score	dynamic score	total score
Eyes Opened	ML displacement	-0.660†	-0.463 *	-0.690†	-0.485 *	-0.627†
	AP displacement	-0.737†	-0.406 *	-0.733†	-0.390 *	-0.646†
	ML velocity	-0.456 *	-0.410 *	-0.492 *	-0.458 *	-0.465 *
	AP velocity	-0.591†	-0.442 *	-0.628†	-0.489 *	-0.577†
	CoP velocity	-0.646 *	-0.527†	-0.690†	-0.527†	-0.618†
Eyes Closed	ML displacement	-0.32	-0.328	-0.326	-0.38	-0.361
	AP displacement	-0.548†	-0.377	-0.538†	-0.352	-0.501†
	ML velocity	-0.253	-0.319	-0.27	-0.382	-0.303
	AP velocity	-0.454 *	-0.483 *	-0.464 *	-0.534†	-0.478 *
	CoP velocity	-0.468 *	-0.519†	-0.477 *	-0.531†	-0.486 *

Abbreviation: PBS, Pediatric Balance Scale; CoP, Center-of-Pressure; ML, Mediolateral displacement; AP, Anteroposterior
* $p < 0.05$ by Spearman's rank correlation test
†$p < 0.01$ by Spearman's rank correlation test

excellent reliability (ICC 0.86, 0.845, 0.816, 0.459, 0.684; COP velocity, AP velocity, ML velocity, AP displacement, ML displacement) during standing trials with eyes opened. And the inter-test reliabilities of the CoP parameters were good to excellent (ICC 0.842, 0.849, 0.848, 0.774, 0.624; COP velocity, AP velocity, ML velocity, AP displacement, ML displacement) during standing trials with eyes closed.

4. Discussion

In this study, we measured CoP in children during both standing and sitting. In standing trials, static PBS scores generally had moderate to strong correlation with the CoP parameters. Because the CoP measurements using force plates were taken while subjects stood as still as possible, they might have a higher correlation with static PBS scores than with dynamic scores. In addition, CoP parameters in eyes-opened trials correlated more strongly with PBS scores, possibly because the PBS was performed in eyes-opened conditions. This relationship reveals the task specificity of CoP measurement in assessing balance control in children with CP. This finding agrees with a study of adult stroke patients that showed higher correlation between CoP measurement and static BBS scores because of the task specificity of CoP measurement during quiet standing [9]. Using the PBS, static balance can be measured by tasks that evaluate the ability to adjust balance while statically maintaining one posture, and dynamic balance can be measured by tasks that evaluate the ability to adjust balance while moving dynamically.

In this study, we classified PBS items into sitting or standing balance tasks, as well as static or dynamic balance tasks. Therefore, we conducted CoP measurement during both sitting and standing. For test specificity, we analyzed the correlation of CoP measurement during sitting with the sitting PBS score and the correlation of CoP measurement during standing with the standing PBS score.

A previous study reported that CoP measurement during floor sitting was a reliable way of examining the development of sitting postural control in infants with or at risk of CP [12]. However, conducting CoP measurements during bench sitting was more suitable for this study because sitting PBS tasks are assessed while the subject is seated on a bench, rather than on the floor. To our knowledge, this is the first time CoP has been measured during bench sitting in children with CP.

In standing balance trials, the PBS scores showed moderate to strong correlation with more CoP parameters in the AP direction than in the ML direction. This result is similar to that of a previous study showing that displacement and velocity of CoP movement were more correlated in the AP direction than in the ML direction in patients with stroke [9]. Movement of the CoP in the AP direction was related to the degree of ankle control [8]. Because ankle plantarflexion and dorsiflexion movement control dominate in maintaining the balance during standing, the PBS score might have more influence on AP displacement and AP velocity during standing trials of CoP measurement. Soleus, the ankle plantarflexor muscle contained predominantly type I fibers which generates slow, but continuous force in contrast to gastrocnemius predominantly with type II fibers [13]. This muscle composition predominant of type I fibers in soleus is advantageous for maintaining continuous stability. Therefore, it can be inferred that the soleus is important for maintaining balance during standing, and it can be explained why the standing score of PBS had a strong correlation with the CoP parameters in the AP direction.

In contrast to the standing trial, the PBS scores in the sitting trial had more negative correlation with velocity and displacement in the ML direction than in the AP direction. This finding agrees with a previous study that found that the CoP displacement in unstable sitting was greater in the ML direction than in the AP direction [14]. In the side-by-side stance during quiet standing, the hips and ankles work independently to control balance [15]. Ankle engagement is dominant in AP direction balance control, while hip engagement is dominant in ML direction balance control [8]. During sitting, the trunk and hips, rather than the ankles, are used to control and maintain balance [16], which may be why the PBS score correlated more with the CoP movement in the ML direction than in the AP direction during sitting. Anyway, the balance control mechanism in the AP and ML directions may occur differently depending on the causes of balance impairment such as cerebellar injury, vestibular disease, limb and body posture etc. Therefore, further study is needed to calculate the optimal metrics from AP and ML displacement which is correlated to the cause of balance impairment.

However, there are some limitations for CoP measurement. First, the ground reaction force was measured at a sampling rate of 100 Hz, which can eliminate subtle directions of sway and obscure the value of parameters. Second, CoP was measured by placing the four legs of the bench on the force plate, not including the two legs of the children on the floor for analysis. The feet came into contact with the floor outside the force plate during sitting CoP measurement because we wanted to measure sitting balance in the posture similar to sitting in real daily life. However, the force transmitted to the ground through the feet can affect values of CoP parameters measured from force plates. In the further study, it would be good if all four legs of the chair and two feet of the child were placed on the force plates to obtain integrated CoP parameters.

Third, it is necessary to study various parameters that can be obtained by CoP measurement. It would be good to compare overall Path Length and Average Radial Displacement, developed by Collins et al. in further study.

In addition, there were some limitations to interpreting the sitting balance assessment using CoP measurements in our study. We recruited children who could perform both sitting and standing tasks for CoP measurements and who met the inclusion criteria of standing independently for at least 10 s. As a result, most children were GMFCS level I and II, which indicates good sitting balance. All children received the maximum scores for sitting without support for 10 s, the only task in the PBS that measures static balance in the sitting position. Therefore, we could not analyze the correlation of CoP measurements with the static PBS score during sitting. In addition, more than half of the study participants received the maximum scores in three dynamic sitting balance tasks, such as sitting to standing, standing to sitting, and transfer. The unexpected correlation coefficients between the PBS scores and the CoP parameters during sitting could be due to ceiling effects. Future studies should recruit and analyze subjects with various sitting balance control abilities, including GMFCS levels III–V.

We also measured the balance of children with CP using only the PBS. We analyzed the balance scores measured in the PBS by classifying tasks into "sitting balance," "standing balance," "static balance," or "dynamic balance." However, only one item in the PBS was classified as a static sitting balance task, and all children in this study received the highest score of 4 on this task. In future studies, various clinical measurements, such as the Sitting Assessment for Children with Neuromotor Dysfunction, the Segmental Assessment of Trunk Control, and the Trunk Control Measurement Scale should be used for more accurate assessment of sitting balance control ability.

Also, CoP measurement using force plates can only measure static balance control and is not suitable for measuring dynamic balance control. An objective and quantitative method for measuring dynamic balance during movements such as walking, running, and daily activities is needed. New technologies using wearable sensors (i.e., an inertial measurement unit sensor) should be developed to measure dynamic balance ability in disabled persons.

In conclusion, this study demonstrates that CoP measurement during sitting trials has a weak to moderate correlation with the PBS and CoP measurement during standing trials has a moderate to strong correlation with the PBS in children with CP. CoP measurement also shows significant reliability. Considering each sitting and standing trial, ML displacement and ML velocity are better parameters for assessing sitting balance control, and AP displacement and AP velocity are better parameters for assessing standing balance control.

Declaration of Competing Interest

None of the authors have financial or personal relationships with other people or organizations that could inappropriately influence their work.

Acknowledgements

This study was supported by a faculty research grant of Yonsei University College of Medicine (6-2018-0162). The authors thank Medical Illustration & Design, part of the Medical Research Support Services of Yonsei University College of Medicine, for all artistic support related to this work.

References

[1] P.L. Rosenbaum, S.D. Walter, S.E. Hanna, R.J. Palisano, D.J. Russell, P. Raina, et al., Prognosis for Gross Motor Function in Cerebral Palsy Creation of Motor Development Curves, JAMA 288 (11) (2002) 1357–1363.
[2] H. Cohen, C.A. Blatchly, L.L. Gombash, A study of the clinical test of sensory interaction and balance, Phys. Ther. 3 (6) (1993) 346–351.
[3] Don R. Jessica Rose, Vincent K. Wolff, Daniel A. Jones, John W. Bloch, Oehlert, G. Gamble James, Postural balance in children with cerebral palsy, Dev. Med. Child Neurol. 44 (2002) 58–63.
[4] Joo Yeon Ko, Gi. Won Kim Test-retest, Inter-rater, and intra-rater reliability of a pediatric balance scale in children with cerebral palsy, J. Korean Soc. Phys. Ther. (2010) 43–48.
[5] Jin-Gang Her, Ji-Hea Woo, Jooyeon Ko, Reliabiltiy of the pediatric balance scale in the assessment of the children with cerebral palsy, J. Phys. Ther. Sci. 24 (2012) 301–305.
[6] Mary Franjoine, M.S. Rose, Pediatric balance scale: a modified version of the berg balance scale for the school-age child with mild to moderate motor impairment, Pediatr. Phys. Ther. 15 (2) (2003) 114–128.
[7] Myung-sook Ko, Jae-hoon Chung, Hye-seon Jeon, Correlation between Pediatric Balance Scale(PBS) and Gross Motor Function Measurement(GMFM) Scores in Children with Cerebral Palsy, J. Korean Soc. Phys. Med. 5 (2) (2010) 281–288.
[8] Dong-wook Rha, Dong Jin Kim, Eun Sook Park, Effect of hinged ankle-foot orthoses on standing balance control in children with bilateral spastic cerebral palsy, Yonsei Med J. 51 (5) (2010) 746–752.
[9] Gunilla Elmgren Frykberg, Birgitta Lindmark, Håkan Lanshammar, Jörgen Borg. Correlation between clinical assessment and force plate measurement of postural control after stroke, J. Rehabil. Med 39 (2007) 448–453.
[10] D. Reid, The effects of the saddle seat on seated postural control and upper-extremity movement in children with cerebral palsy, Dev. Med. Child Neurol. 38 (1996) 805–815.
[11] Patrick Schober, Christa Boer, Lothar A. Schwarte, Correlation coefficients: appropriate use and interpretation, anesthesia & analgesia 126 (5) (2018) 1763–1768.
[12] Anastasia Kyvelidou, Regina T. Harbourne, Valerie K. Shostrom, Nicholas Stergiou, 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. 91 (10) (2010) 1593–1601.
[13] P.D. Gollnick, B. Sjödin, J. Karlsson, et al., Human soleus muscle: a comparison of fiber composition and enzyme activities with other leg muscles, Pflug. Arch. 348 (1974) 247–255.
[14] J. Cholewicki, G.K. Polzhofer, A. Radebold, Postural control of trunk during unstable sitting, J. Biomech. 33 (2000) 1733–1737.
[15] D.A. Winter, et al., Unified theory regarding A/P and M/L balance in quiet stance, J. Neurophysiol. 75 (1996) 2334–2343.
[16] Anastasia Kyvelidou, Regina T. Harbourne, Wayne A. Stuberg, Junfeng Sun, Nicholas Stergiou, The relationship between trunk control in sitting and during gait in children and adolescents with cerebral palsy, Arch. Phys. Med Rehabil. 90 (7) (2009) 1176–1184.