Reliability and Interrelationships of Center of Pressure Sway Variables During the Stipulated Tempo Step in School Children

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Abstract

This study examines the reliability of the center of pressure (COP) sway variables during specified tempo steps and explores the relationships among these variables in school children. The study included 50 school children (25 boys and 25 girls) aged 6–12 years. Participants performed two 40-second trials at tempos of 40 bpm, 60 bpm, 90 bpm, and 120 bpm using a dynamic/static balance measuring system (From TAKEI SCIENTIFIC INSTRUMENTS CO., LTD.). Total path length, peripheral area, standard deviation X, and standard deviation Y were used as evaluation variables. Reliability of the COP sway variables was assessed using the intraclass correlation coefficient (ICC), and their interrelationships were analyzed using Pearson's correlation coefficient. ICCs exceeded 0.7 for all variables, except for the standard deviation Y at 40 bpm. Total path length and peripheral area were highly correlated, except at 40 bpm and 120 bpm. Standard deviation X showed high correlation across all tempos, while standard deviation Y showed high correlations only between 90 bpm and 120 bpm. The remaining variables showed moderate correlations across tempos. In contrast, within each tempo, correlations were high between total path length and peripheral area, between peripheral area and standard deviation Y across all tempos, between total path length and standard deviation X in 60 bpm, and between total path length and standard deviation Y at 120 bpm. The other variables exhibited moderate correlations. In conclusion, the reliability of the COP sway variables during the stipulated tempo step in the school children was relatively high regardless of a tempo difference. The COP sway variables have high relations among three tempos of 40 bpm, 60 bpm, and 120 bpm except for a few variables, and regardless of the tempo difference, the relation between total path length and peripheral area, and between peripheral area and standard deviation Y was high.

Keywords: school children, stipulated tempo, step

1. Introduction

Center of pressure (COP) sway has long been used to evaluate human's postural control ability (Imaoka et al., 1997; Baloh et al., 1998; Demura et al., 2001; Kitabayashi et al., 2003; Fujimoto et al., 2010). The COP sway during static standing posture is the result of postural reflexes that integrate various sensory information including somatosensory and visual information, and regulate them with appropriate muscle output (Aoki et al., 2024). Until now, the COP sway during static standing has been examined in both sexes and between people of a wide age range. Many studies have reported gender- and age-related differences in sway variables (Masani et al., 2007; Lin et al., 2008; Kitabayashi et al., 2018).

Postural control plays a role in basic dynamic movements, such as standing up and walking; hence, in recent years, it has also been examined during dynamic movements in addition to the static standing position (Ohnishi et al., 2010;

Aoki et al., 2012; Yamaji et al., 2015). Ohnishi et al. (2010) measured the COP sway of the supporting leg during a quick one-legged step from a standing position, following directional cues (left or right leg) displayed on a front-facing screen, and reported that the total path length of the COP in the 80%, 70%, and 60% conditions of the maximum step length was significantly longer in older adults than in young adults. Aoki et al. (2012) reported that older people exhibited greater COP sway (e.g., in the peripheral and rectangular areas) during a 100-bpm-stipulated tempo than younger adults. The stipulated tempo step is considered more difficult than the abovementioned rapid step because it requires controlling the body's center of gravity while also supporting the body with one leg during the step. Additionally, COP sway during each step differs because the one-leg stance duration varies between the slow and fast tempos.

When evaluating human COP sway, it is desirable to select reliable sway variables. Until now, the intertrial reliability of COP sway variables (also referred to as sway variables) has been primarily examined in youth and older adults (Lin et al., 2008；Russo et al., 2015; Pineda et al., 2020). Recently, their reliability has also been examined in children (Parameyong et al., 2018; Mizohata et al., 2021; Juneja et al., 2023). Regarding the reliability of sway variables during children's static standing, Mizohata et al. (2021) reported that distance, position, and velocity demonstrated high reliability, while Juneja et al. (2023) reported that velocity and area were high. However, the reliability of sway variables during the stipulated tempo step, which is a dynamic movement, has not been investigated. In contrast, studies on the relationships between sway variables during static standing in adolescents, have reported that, according to Demura et al. (2001) reported that), the relationships between variables such as speed and variance were moderate or higher, while Kitabayashi et al. (2003) reportedfound that thosethe relationships between variables such as distance, area, amplitude, and vector were high. However, the relationships between sway variables during the stipulated tempo step have not been examined. Their relationships during the stipulated tempo step differ from those during static standing, and may also differ among tempos because one-leg standing time during the step differs.

This study aimed to assess the reliability of the sway variables during the stipulated tempo step in school children and their relationships.

2. Method

2.1 Participants

The study included 50 school children: 25 boys (age 8.5 ± 1.9 years, height 136.6 ± 8.1 cm, weight 32.4 ± 6.0 kg) and 25 girls (age 9.2 ± 1.5 years, height 133.7 ± 5.6 cm, weight 30.5 ± 4.8 kg). No significant sex differences were observed in age, height, and weight. We explained them and their parents the purpose, methods, and risks of the experiment, and obtained their consent. The study protocol was approved by the National Institute of Technology, Fukui College.

2.2 Measurement Device

The stipulated tempo step test was conducted using the dynamic/static balance measuring system (From TAKEI SCIENTIFIC INSTRUMENTS CO., LTD.: S-21218). It can calculate the COP of the vertical load as the center of foot pressure from the values of the built-in vertical load sensors. The data were recorded on a computer at a sampling frequency of 20 Hz.

2.3 Measurement Procedure

Participants were instructed to stand with their arms at their sides and their feet together on the device mentioned above, and to focus on an indicator set at eye level. The participants then performed stepping for 40 seconds, matching the beeping sound (at the stipulated tempo).

Consistent with a previous study (Shin & Demura, 2007), for the stipulated tempo, we selected 120 bpm as the fast tempo, which is considered to have the best energy efficiency during walking (Toyama, 1990), 90 bpm as the middle tempo, 60 bpm as the slow tempo, and 40 bpm as the slower tempo. The subjects performed two trials after one practice trial for all tempos.

2.4 Variables

The sway variables included total path length, peripheral area, standard deviation of X (standard deviation X), and standard deviation of Y (standard deviation Y), consistent with a previous study (Aoki et al., 2012).

2.5 Analysis Method

Intraclass correlation coefficients (ICC (1,2)) were calculated to examine the intertrial reliability of the sway variables. In this study, we judged the ICC size as follows: 0.6 or less as questionable, 0.6–0.7 as possible, 0.7–0.8 as normal, 0.8–0.9 as good, and 0.9 or above as excellent. The relationships between the sway variables were examined using Pearson's correlation coefficient. Correlation coefficients were categorized as low (0.2–0.4), moderate (0.4–0.7), and high (over 0.7). A statistical significance level of 5% ($p < 0.05$) was used throughout this study.

3. Results

Table 1 shows the basic statistics of each sway variable and their ICC. The ICC was 0.70 or higher, except for 0.64 at 40 bpm for standard deviation Y. The ICCs for trajectory length and standard deviation X were very high, ranging from 0.87 to 0.95 across all tempos. Therefore, the average of the two trials was used as the representative value in subsequent analyses.

Table 1. Basic Statistics of Evaluation Variable and Reliability Coefficient

		first trial		second trial		
		Mean	SD	Mean	SD	ICC
total path length (mm)	40bpm	5258.9	695.7	5263.1	679.2	0.87
	60bpm	7164.2	964.9	7070.1	902.8	0.91
	90bpm	9988.7	1346.7	9980.7	1470.0	0.95
	120bpm	13231.9	1888.8	13145.9	1822.7	0.95
peripheral area (mm^2)	40bpm	12238.0	3610.6	12645.4	4140.6	0.70
	60bpm	13465.4	4232.8	12804.2	3228.4	0.79
	90bpm	14543.5	4525.4	14358.2	4506.4	0.76
	120bpm	15983.2	4830.4	15705.4	5209.5	0.85
standard deviation X (mm)	40bpm	55.7	6.1	55.5	6.3	0.92
	60bpm	55.6	6.1	55.3	6.4	0.94
	90bpm	53.6	5.2	53.8	6.4	0.92
	120bpm	52.6	5.4	52.4	5.0	0.93
standard deviation Y (mm)	40bpm	17.1	3.9	17.6	4.9	0.64
	60bpm	18.2	4.1	17.7	3.5	0.70
	90bpm	20.4	5.8	20.3	5.3	0.72
	120bpm	22.4	5.5	22.3	6.0	0.82

Table 2 presents the correlation coefficients between tempos in each variable. The total path length and peripheral area had a high value of 0.75 or more, except for the range between 40 bpm and 120 bpm. The standard deviation X had a value of 0.72 or higher in all tempos. The standard deviation Y had a high value (0.77) between 90 bpm and 120 bpm, but moderate values (0.53 to 0.69) for the other tempos.

Table 2. The Correlation Coefficients between Tempos in Each Sway Variable

		40bpm	60bpm	90bpm	120bpm
total path length	40bpm	1.00			
	60bpm	0.84*	1.00		
	90bpm	0.75*	0.79*	1.00	
	120bpm	0.65*	0.76*	0.87*	1.00

Table 2. The Correlation Coefficients between Tempos in Each Sway Variable(continued)

		40bpm	60bpm	90bpm	120bpm
peripheral area	40bpm	1.00			
	60bpm	0.76*	1.00		
	90bpm	0.77*	0.83*	1.00	
	120bpm	0.68*	0.78*	0.83*	1.00
standard deviation X	40bpm	1.00			
	60bpm	0.82*	1.00		
	90bpm	0.72*	0.84*	1.00	
	120bpm	0.72*	0.83*	0.90*	1.00
standard deviation Y	40bpm	1.00			
	60bpm	0.65*	1.00		
	90bpm	0.58*	0.69*	1.00	
	120bpm	0.53*	0.61*	0.77*	1.00

*p<0.05

Table 3. The Correlation Coefficients between Sway Variables in Each Tempo

		total path length	peripheral area	standard deviation X	standard deviation Y
40bpm	total path length	1.00			
	peripheral area	0.86*	1.00		
	standard deviation X	0.68*	0.59*	1.00	
	standard deviation Y	0.67*	0.86*	0.37*	1.00
60bpm	total path length	1.00			
	peripheral area	0.87*	1.00		
	standard deviation X	0.71*	0.55*	1.00	
	standard deviation Y	0.64*	0.86*	0.30*	1.00
90bpm	total path length	1.00			
	peripheral area	0.80*	1.00		
	standard deviation X	0.65*	0.52*	1.00	
	standard deviation Y	0.67*	0.90*	0.21	1.00
120bpm	total path length	1.00			
	peripheral area	0.86*	1.00		
	standard deviation X	0.59*	0.47*	1.00	
	standard deviation Y	0.82*	0.94*	0.23	1.00

*p<0.05

Table 3 shows the correlation coefficients among variables in each tempo. The 40-bpm tempo had a high value (0.86) between total path length and the outer peripheral area, as well as between the outer peripheral area and standard deviation Y. However, it had a range of moderate to low values (0.37 to 0.68) between the other variables. The 60 bpm tempo had high values (0.71～0.87) between total path length and the outer peripheral area, between total path length and standard deviation X, and between outer peripheral area and standard deviation Y, but had moderate to low (0.30～0.64) values between the other variables. The 90-bpm tempos had high values (0.80～0.90) between total path length and the outer peripheral area, and between the outer peripheral area and standard deviation Y, but had moderate to low (0.21～0.67) values between the other variables. At the 120-bpm tempo, high values (0.82～0.94) between total path length and the outer peripheral area, between total path length and standard deviation Y, and between outer peripheral area and standard deviation Y, but had moderate to low (0.23～0.59) values between the other variables.

4. Discussion

The ICC exceeded 0.7, except for the standard deviation Y at 40-bpm tempo. Aoki et al. (2024) examined the reliability of sway variables in healthy individuals across a wide age range, from 10 to 87 years, during static standing. They reported that the ICCs between the three trials were high (ICC > 0.6) for unit time trajectory length, peripheral area, average position X, average position Y, standard deviation X, and standard deviation Y. Mizohata et al. (2021) reported that, among fourth-grade elementary school children, the ICC of length- and position-related variables during static standing with open- and closed-eye conditions, and on velocity with the closed-eye condition, were 0.7 or higher. Bruyneel et al. (2022) measured COP sway during static sitting on an unstable platform in middle-aged and older adults, reporting that the ICC of velocity variables was high. Based on the present results, it can be concluded that the reliability of sway variables during the stipulated tempo step in children is relatively high, irrespective of tempo differences.

For total path length, outer peripheral area, and standard deviation of Y, the correlation between the 40-bpm and 120-bpm tempos was relatively low (r < 0.68). The 40-bpm tempo has a longer one-leg standing time during the step than the 120-bpm tempo. Thus, children with underdeveloped leg strength and balance may have difficulty maintaining a stable one-leg standing position. These findings suggest that differences in one-leg standing time between two tempos contributed to the lower correlations among sway variables. In contrast, the total path length, outer peripheral area, and standard deviation X showed high correlation between adjacent tempos 40-bpm and 60-bpm, between 60-bpm and 90-bpm, and between 90-bpm and 120-bpm (r < 0.75). In the stipulated tempo step, the high correlations among sway variables can be attributed to the similarity in one-leg standing time across adjacent tempos.

The relationship between the total path length and outer peripheral area was strong across all tempos. According to Demura et al. (2001), strong correlations (above 0.90) were reported among variables such as distance, area, and speed. When left–right and front–back fluctuations are large, sway distance increases, resulting in a larger area (Aoki et al., 2023). Therefore, the relationship between distance and area variables is expected to be stronger. Furthermore, regardless of the tempo difference, the outer peripheral area was higher in relation to standard deviation Y than standard deviation X. This suggests that, during the stipulated tempo step, the outer peripheral area is more affected by a front–back sway than by a left–right sway. Across all tempos, the relationship between the standard deviations of X and Y was weak. Aoki et al. (2024) reported that the correlation between the standard deviations of X and Y during static standing was moderate. During the stipulated tempo step, it is considered that the body sway was essentially a front–back rather than a right–left direction, hence their relationship was low. In contrast, the relationship between the total path length and standard deviation Y was high only in a 120-bpm tempo. During stepping with a fast tempo, it was suggested that the sway distance is more affected by the front–back than the right–left direction. Based on the results of this study, it is evident that, with a few exceptions, the interrelationships of sway variables show no significant differences between tempos.

From the above, the following was revealed: their reliability during the stipulated tempo step is generally high, regardless of the tempo; their relationships are not high between the slowest 40-bpm tempo and the fastest 120-bpm tempo; and those between the tempos of sway variables do not show a significant difference. From now on, it will be necessary to select effective tempos for evaluating posture control ability during the stipulated tempo step. Furthermore, although this study focused only on school children, future research should examine the reliability of sway variables and their interrelationships among people of a wide age range.

5. Conclusion

This study examined the reliability and interrelationships of sway variables during prescribed tempo steps among school children. Within the limitations of the subjects, evaluation variables, and analysis methods, the following findings were obtained.

The reliability of sway variables (total path length, outer peripheral area, standard deviation X and Y) during the stipulated tempo steps is relatively high across different tempos.

The relationship among sway variables at adjacent tempos is high, with the exception of a few variables.

Regardless of tempo differences, strong relationships were observed between total path length and the outer peripheral area, and between the outer peripheral and the standard deviation Y. At the fastest tempo of 120 bpm, the relationship between the total path length and standard deviation Y is particularly high.

The findings clarify that the COP sway during school children's stipulated tempo steps has high reproducibility, and specifically, the distance and size of sway in faster tempos are largely influenced by vertical sway than by lateral one.

References

Aoki H., Demura S., Kawabata H., Sugiura, H., Uchida Y., Xu N., & Murase H. (2012). Evaluating the effects of open/closed eyes and age-related differences on center of foot pressure sway during stepping at a set tempo. *AAR*, *1*, 72-77. https://doi.org/10.4236/aar.2012.13009

Aoki H., Demura S., Yamaji S., Nagasawa Y., Murase T., Miyaguchi K., Yokoya T., & Minami M. (2024). The Reliability of Center of Pressure Sway Variables and Their Interrelationships in Healthy Individuals. *International Journal of Clinical and Experimental Medicine Research*, *8*, 597-605. https://doi.org/10.26855/ijcemr.2024.10.011

Aoki H., Demura S., Yamaji S., Nagasawa Y., Nakatani T., & Nadamoto M. (2023). Sex and age-level differences of center of pressure sway variables and their inter-relations during static standing posture in healthy people. *The Journal of Education and Health Science*, *66*, 247-257.

Baloh R. W., Jacobson, K. M., Beykirch K., & Honrubia V. (1998). Static and Dynamic Posturography in Patients with Vestibular and Cerebellar Lesions. *JAMA Neurology,* *55*, 649-654. https://doi.org/10.1001/archneur.55.5.649

Bruyneel A-V., Mesure S., Reinmann A., Sordet C., Venturelli P., Feldmann I., & Guyen E. (2022). Validity and reliability of center of pressure measures to quantify trunk control ability in individuals after stroke in subacute phase during unstable sitting test. *Heliyon, 8*, e10891. https://doi.org/10.1016/j.heliyon.2022.e10891

Demura S., Yamaji S., Noda M., Kitabayashi T., & Nagasawa Y. (2001). Examination of parameters evaluating the center of foot pressure in static standing posture from the viewpoints of trial-to-trial reliability and interrelationships among parameters. *Equilibrium Research*, *60*, 44-55. https://doi.org/10.3757/jser.60.44

Fujimoto C., Murofushi T., Chihara Y., Ushio M., Yamaguchi T., Yamasoba T., & Iwasaki S. (2010). Effects of Unilateral Dysfunction of the Inferior Vestibular Nerve System on Postural Stability. *Clinical Neurophysiology*, *121*, 1279-1284. https://doi.org/10.1016/j.clinph.2010.02.149

Imaoka K., Murase J., & Fukuhara M. (1997). Collection of data for healthy subjects in stabilometry. *Equilibrium Research*, *12*, 1-84. https://doi.org/10.3757/jser.56.12Supplement_1

Juneja H., Frandsen C., Nielsen N. O., Larsen K., & Praestegaard J. (2023). Reliability of the Wii Balance Board for measurement of steady state balance in children aged 6-9 years. *J Pediatr Rehabil Med*, *16*, 369-380. https://doi.org/10.3233/PRM-210106

Kitabayashi T., Demura S., & Aoki H. (2018). Examination of effective body sway parameters for healthy elderly. *American Journal of Sports Science and Medicine*, *6*, 50-55. https://doi.org/10.12691/ajssm-6-1-5

Kitabayashi T., Demura S., & Noda M. (2003). Examination of the factor structure of center of Foot pressure movement and cross-validity. *J Physiol Anthropol Appl Human Sci*, *22*, 265-272. https://doi.org/10.2114/jpa.22.265

Lin D., Seol H., Nussbaum M. A., & Madigan M. L. (2008). Reliability of COP-based postural sway measures and age-related differences. *Gait Posture*, *28*, 37-42. https://doi.org/10.1016/j.gaitpost.2008.01.005

Masani K., Vette A. H., Kouzaki M., Kanehisa H., Fukunaga T., & Popovic M. R. (2007). Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing. *Neurosci Lett*, *422*, 202-206. https://doi.org/10.1016/j.neulet.2007.06.019

Mizohata J., Koyama H., & Toji H. (2021). Examination of Intra-trial and intra-day reliability for the center of foot pressure in static standing posture of fourth grade primary school students. *Osaka research journal of physical education*, *59*, 9-17.

Ohnishi A., Togo F., & Ishimatsu K. (2010). Influence of age, falls, and step length on the postural sway during rapid stepping. *Dynamics & Design Conference*, section ID: 621. https://doi.org/10.1299/jsmedmc.2010._621-1_

Parameyonga A., Boripuntakula S., Kamnardsirib T., & Chawawisuttikool J. (2018). The validity and reliability of the Swaymeter for postural sway measurement in typically developing children aged between 7–12 years. *Gait & Posture*, *66*, 273-277. https://doi.org/10.1016/j.gaitpost.2018.09.004

Pineda R. C., Krampe R. T., Vanlandewijck Y., & Van Biesen D. (2020). Reliability of center of pressure excursion as a measure of postural control in bipedal stance of individuals with intellectual disability: A pilot study. *PLoS One*, *15*, e0240702. https://doi.org/10.1371/journal.pone.0240702

Russo L., D'Eramo U., Padulo J., Foti C., Schiffer R., & Scoppa F. (2015). Day-time effect on postural stability in young sportsmen. *Muscles Ligaments and Tendons Journal*, *5*, 38-42. https://doi.org/10.11138/mltj/2015.5.1.038

Shin S., & Demura S. (2007). Effective tempo of the step test for dynamic balance ability in the elderly. *J Physiol Anthropol*, *26*, 563-567. https://doi.org/10.2114/jpa2.26.563

Toyama H., & Fujiwara K. (1990). Interference of upper limbs exercise with different automatized levels. *Physical Fitness Sports Med*, *39*, 44-52. https://doi.org/10.7600/jspfsm1949.39.44

Yamaji S., Demura S., Aoki H., & Ohno M. (2015). Effect of Visual Input and Foam Rubber on Leg-Joint Angles and Sway of Center of Pressure during Stepping on the Spot. *APE*, *5*, 204-210. https://doi.org/10.4236/ape.2015.53025

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