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EFFECT OF MANIPULATION OF BASE OF SUPPORT ON CENTER OF PRESSURE: COMPARISON OF CHILDREN WITH AND WITHOUT INTELLECTUAL DISABILITY

VPLIV STRATEGIJE PROSTOVOLJNEGA NADZORA DRŽE NA SREDIŠČE PRITISKA: PRIMERJAVA OTROK Z INTELEKTUALNO OVIRANOSTJO IN BREZ NJE

ABSTRACT

The postural control (PC) of children with intellectual disabilities (ID) have been extensively studied; however, there is limited information available on the role of PC strategies during manipulated balance conditions. The aim of this study is to investigate the effect of manipulation of the base of support on the center of pressure in the children with and without intellectual disabilities. This study included 34 girls with mild intellectual disabilities and 30 typically developing children of the same sex and age (7-13 years old). The participants as stood as still on a platform and completed four tasks: feet-together on a firm surface, feet-together on a foam surface, tandem stance on a firm surface, and tandem stance on a foam surface. The displacement, sway, amplitude, root mean square (RMS), velocity, and acceleration of the center of pressure (CoP) were calculated. The results indicate significant differences between the two groups in spatial variables of CoP movement ($p < 0.05$). Moreover, sway and amplitude were found to be sensitive to changes in surface factors ($p < 0.05$) and all variables to be sensitive to changes in stance position. There was significant interaction of stance*group in CoP velocity ($p < 0.05$). Based on the results, children with intellectual disabilities demonstrated poorer postural control than the control group, particularly in more demanding PC tasks. However, the quantitative variables of CoP were less impacted by ID characteristics compared to spatial variables. Accordingly, it is suggested that the role of effective balance training on improving postural control strategies in ID children be investigated in future studies.

Keywords: voluntary postural control strategy, intellectual disability, center of pressure

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IZVLEČEK

Posturalni nadzor (PC) otrok z motnjami v duševnem razvoju (ID) je bil obsežno raziskan, vendar je na voljo le malo informacij o vlogi strategij PC v pogojih manipuliranega ravnotežja. Namen te študije je raziskati učinek manipulacije oporne baze na središče pritiska pri otrocih z motnjami v duševnem razvoju in brez njih. V tej študiji je sodelovalo 34 deklic z lažjo motnjo v duševnem razvoju in 30 tipično razvijajočih se otrok istega spola in starosti (7-13 let). Udeleženci so mirno stali na ploščadi in opravili štiri naloge: stoja snožno na trdni površini, stoja snožno na ravnotežni blazini, tandemska stoja na trdni površini in tandemska stoja na ravnotežni blazini. Izračunani so bili premik, nihanje, amplituda, povprečni kvadratni koren (RMS), hitrost in pospešek središča pritiska (CoP). Rezultati kažejo na pomembne razlike med obema skupinama v prostorskih spremenljivkah gibanja CoP ($p < 0.05$). Poleg tega je bilo ugotovljeno, da sta nihanje in amplituda občutljiva na spremembe površinskih dejavnikov ($p < 0.05$), vse spremenljivke pa so občutljive na spremembe položaja stoje. Pri hitrosti CoP je bila ugotovljena pomembna interakcija med vrsto stoje in skupino ($p < 0,05$). Na podlagi rezultatov so otroci z motnjami v duševnem razvoju pokazali slabši posturalni nadzor kot kontrolna skupina, zlasti pri zahtevnejših nalogah na PC. Vendar so na kvantitativne spremenljivke CoP značilnosti ID vplivale manj kot na prostorske spremenljivke. V skladu s tem predlagamo, da se v prihodnjih študijah preuči vloga učinkovite vadbe ravnotežja pri izboljšanju strategij posturalnega nadzora pri otrocih z ID.

Ključne besede: Strategija prostovoljnega nadzora drže, intelektualna oviranost, središče pritiska

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INTRODUCTION

The ability to postural control (PC) in a standing position, as well as in locomotive activities, is developed during natural physical activity in the process of ontogeny. Any dysfunctions in PC are a reflection of pathologies that appear in the human organism (Trew & Everett, 2005). Intellectual disability (ID) is a condition that involves a partial or complete developmental delay of the mind, affecting not only cognitive functions but also motor functions (Organization, 2007). Children with ID have significant delays in motor skill development compared to typically developing peers, and these motor skill deficits can lead to difficulties in learning (Westendorp et al., 2011), performing (Dolva et al., 2004) and executive functioning (Hartman et al., 2010). Children with ID experience limitations in both intellectual and adaptive behavior functioning, which can result in disabilities in conceptual, social, and practical adaptive skills (Schalock et al., 2007).

Children with ID are a group identified with postural disturbances, immature PC (Kachouri et al., 2016) and weaker body balance (Enkelaar et al., 2012), comparison to the PC of children without ID. This can be explained by deficits in visual, vestibular and proprioceptive systems (Galli et al., 2008; Lipowicz et al., 2019; Rigoldi et al., 2011). Furthermore, some individuals with ID may experience various anomalies in their central nervous systems (CNS) (Yu et al., 2008), which can impact the integration of sensory inputs and increase the risk of falls (Hall & Thomas, 2008). Most studies surrounding postural stability have utilized traditional analyses of the center of pressure (CoP) and found that children with ID demonstrated a greater sway path in anterior-posterior and medial-lateral directions (Lipowicz et al., 2019) and sway area (Bibrowicz et al., 2019).

CoP displacement during quiet standing has been used to assess postural control abilities (Masani et al., 2014). These abilities are divided into 1) spatial variables, including sway amplitude of CoP and root mean square distance (RMS), which quantifies the CoP variability around the mean CoP trajectory. 2) Quantitative variables that reflecting PC strategy, including mean velocity and acceleration of CoP (Rocchi et al., 2002). PC strategies is also divided into voluntary control and automatic control. The PC strategies were effect on spatial and quantitative variables have been reported by Ueta et al. (2015). Using automatic motor control, when participants are instructed to perform dual-task paradigms, can potentially reduce postural sway, but some studies have reported an increase in postural sway (Fraizer & Mitra, 2008). Also, studies have reported that, for voluntary control, instructing individuals to stand as still as possible can reduce spatial variables of COP displacement, such as area, mean distance, and range, compared to simply standing quietly in healthy persons (Zok et al., 2008).

Research into the effects of automatic PC strategies in children with ID is infrequently pursued. The findings from (Laatar et al., 2023) suggested that employing dual-tasking (an automatic strategy) had a similar impact on the balance performance of both the control group children and those with ID. Moreover, the focus on which variables are more sensitive to PC strategies or postural changes has rarely captured researchers' attention. Studies indicate that COP velocity stands out as the most sensitive parameter for comparing individuals across different age groups and various neurological disorders (Masani et al., 2014; Paillard & Noé, 2015). They have emphasized the fundamental role of COP velocity in the mechanisms governing anticipatory postural adjustments during quiet standing. Jancova (2013) also highlighted the significant role of COP velocity in the feedforward mechanisms of the postural control system during quiet stance. Mohammadi et al. (2021) further demonstrated that in patients with low back pain, COP velocity shows a heightened sensitivity to postural changes.

Additional studies are required to investigate the impact of applying PC strategies on CoP variables in children with ID. These studies enhance our understanding of the mechanics involved in posture control among these children and assist in developing approaches to enhance their motor skills. The objective of this study was to evaluate spatial and quantitative variables related to postural control, as well as to assess the sensitivity of these measurements under varying surface conditions. The comparison was made between children with ID and an age-matched control group while employing a voluntary postural control strategy.

METHODS

Participants

The study involved 64 girls aged 7-13 years, with 34 children having mild intellectual disabilities (with IQs ranging from 50 to 70 as documented in school records) (Dekker et al., 2014) from elementary schools, and 30 age-matched typically developing children included as the control group. The exclusion criteria for all children included neurological disorders (other than ID), chronic medical disorders, visual impairments and physical impairments that could affect balance (Capio et al., 2015). The consent forms were signed by the children's parents. The research protocol was approved by the ethics committee of Islamic Azad University of

Hamedan (code no.: IR.IAU.H.REC.1402.008). The study was in accordance with the Declaration of Helsinki in its newest revision.

Instrumentation and protocol

The Kistler Force Platform (Type 9286BA, Kistler Instrument AG, Winterthur, Switzerland) was used to measure CoP at a frequency of 1000 Hz. The data were filtered using a fourth-order low-pass Butterworth filter with a 20 Hz cut-off frequency. The participants completed 12 trials, with four tasks performed three times each, within a 20-second time frame (Ross et al., 2011): 1) Feet-together on a firm surface (FT-firm), 2) Feet-together on a foam surface (FT-foam), 3) Tandem stance on a firm surface (TS-firm), and 4) Tandem stance on a foam surface (TS-foam). The statistical analysis utilized the average of three repetitions.

During the assessment, the participants were asked to stand barefoot on the platform and were instructed to concentrate fully on their body movement and try hard to minimize it as far as possible. The foam surface was comprised of a foam block measuring 466 mm in length, 467 mm in width, and 134 mm in height above the ground, with a density of 21.3 kg/m^3 and an elastic modulus of 20.900 N/m^2 (Kachouri et al., 2016). The CoP displacement normalized by foot size away from the heel on the longitudinal axis between toe to heel (Chan & Sigward, 2020), sway (cm), amplitude (cm) and RMS (square centimeter) were used to compare the spatial variables. Mean velocity (cm/s) and acceleration (cm/s^2) was utilized to compare postural control strategies. The aforementioned variables of postural control were calculated using Bioware software v3.5.2 (Kistler Nordic AB, Sweden).

Statistical analysis

Statistical analysis was performed using SPSS software (version 21.0; SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk test was used to assess the normality of the outcome measures. Descriptive statistics were computed for all the demographic and outcome measures. As the data for balance variables had a normal distribution, parametric statistics were utilized for analysis. The balance variables in this study involved two inter-group factors: stance position (feet together/tandem stance) and surface (firm/foam), along with a between-group factor (ID/control group). Hence, a three-way repeated measures ANOVA was employed for comparisons. Demographic variables between groups were compared using the independent sample T-test.

RESULTS

Table 1 presents the demographic characteristics of the participants and a comparison of these characteristics between the two groups.

Table 1. Baseline characteristics in the control and ID groups.

	n= 18			n= 16			P-value
	ID			Control			
	Mean	SD	SE	Mean	SD	SE	
Age (year)	11.33	1.94	0.46	11.88	2.03	0.51	0.43
Mass (Kg)	45.3	12.24	2.89	48.81	9.09	2.27	0.24
Height (m)	1.54	0.13	0.03	1.57	0.96	0.02	0.81
BMI	19.39	4.07	0.96	19.56	2.55	0.64	0.88
Leg height (cm)	79.22	6.75	1.59	82.81	5.58	1.39	0.83

Abbreviations: SD, standard deviation; SE, standard error; ID, intellectual disability; n, number of participants; BMI, body mass index.

Displacement of CoP

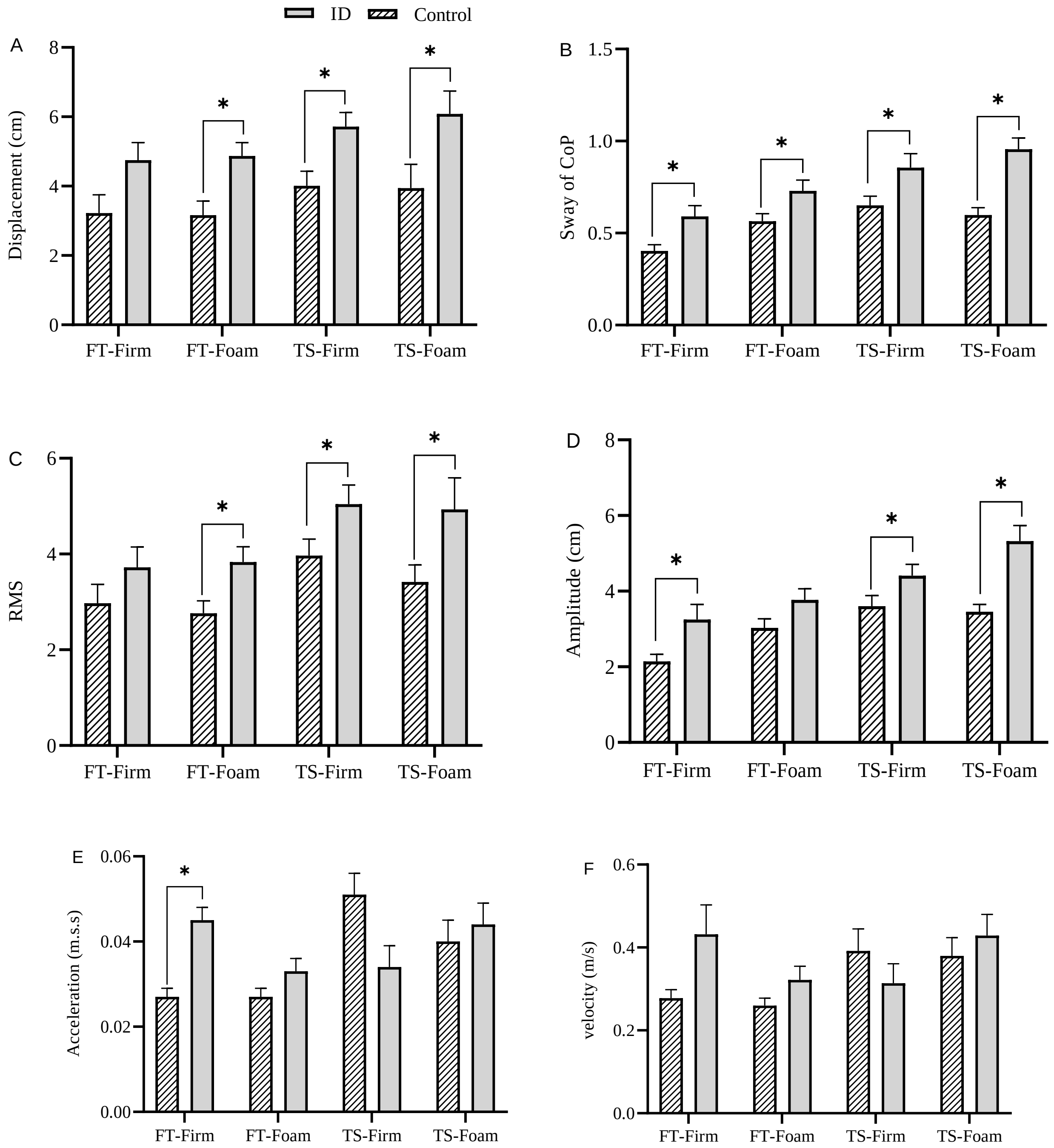
The findings indicated significant main effects of stance position (p=0.013) and group factors (p=0.000) on CoP displacement. Pairwise comparisons revealed that CoP displacement notably increased in tandem stance compared to feet-together, as well as in the ID group compared to the control group (Table 2). However, the main effect of surface (p=0.826) and the interaction between factors (p<0.05) did not significantly impact CoP displacement. The contrast between the two groups in tasks is illustrated in Fig 1.A.

Table 2. The results of factor analysis of spatial and quantitative variables.

Factors	Displacement			Sway			RMS			Amplitude			Acceleration			Velocity		
	F	P	Eta	F	P	Eta	F	P	Eta	F	P	Eta	F	P	Eta	F	P	Eta
Stance	6.78	**0.013**	0.18	31.80	**0.000**	0.50	10.29	**0.003**	0.24	34.96	**0.000**	0.52	4.66	**0.038**	0.13	3.47	0.07	0.10
Surface	0.06	0.826	0.02	8.28	**0.007**	0.21	0.40	0.530	0.01	8.60	**0.006**	0.21	0.40	0.531	0.01	0.03	0.861	0.001
Group	17.73	**0.000**	0.36	16.40	**0.000**	0.34	9.78	**0.004**	0.23	13.84	**0.001**	0.30	0.23	0.638	0.007	1.54	0.224	0.05
Stance/ Surface	0.06	0.816	0.002	4.22	**0.048**	0.12	0.50	0.490	0.02	1.02	0.319	0.03	0.48	0.495	0.02	5.14	**0.030**	0.14
Stance/ Group	0.17	0.679	0.005	2.37	0.134	0.07	0.37	0.549	0.01	1.14	0.293	0.03	4.52	**0.040**	0.12	4.22	**0.048**	0.12
Surface/ Group	0.14	0.712	0.004	1.17	0.287	0.04	0.42	0.523	0.01	0.90	0.350	0.03	0.30	0.589	0.009	0.06	0.817	0.002
Stance/ Surface/ Group	0.07	0.793	0.002	2.12	0.155	0.06	0.02	0.880	0.001	5.08	**0.031**	0.14	4.18	**0.049**	0.12	4.61	**0.039**	0.13

Note:1×2: interaction between stance-surface. 1×3: interaction between stance-direction. 2×3: interaction between surface-direction.

Figure 1. The means and SD, represented for both groups in variables.



*: Significant difference between groups (p<0.05)

Sway of CoP

The results presented in Table 2 indicated significant main effects for stance position (p=0.000), surface (p=0.007), and group (p=0.000) regarding CoP sway. Pairwise comparisons revealed that CoP sway was significantly higher in the TS task compared to the FT task and on the foam surface compared to the firm surface. Additionally, the sway was greater in the ID group than in the control group. Interaction between factors was generally not significant except for stance*surface. The differences between the two groups in all tasks were significant, as depicted in Fig 1.B.

RMS of CoP

The factor analysis results for RMS revealed significant main effects for stance position (p=0.003) and group (p=0.004). RMS was significantly higher in the tandem stance compared to the feet-together stance, and the RMS value was greater in the ID group than in the control group. However, the main effect of surface (p=0.530) and the interaction between factors were not significant (p>0.05) (Table 2). The differences between the two groups are illustrated in Fig 1.C.

Amplitude of CoP

The results, as demonstrated in Table 2, revealed significant main effects for stance position (p=0.000), surface (p=0.006), and group (p=0.001) in the amplitude of CoP. Pairwise comparisons indicated a significant increase in this variable during tandem stance compared to feet-together stance and on foam surfaces compared to firm surfaces. Similarly, the amplitude was greater in the ID group than in the control group, as depicted in Fig 1.D.

Acceleration of CoP

The factor analysis revealed a significant main effect of stance position (p=0.038) on CoP acceleration. Pairwise comparisons indicated that in the tandem stance, acceleration was higher than in the feet-together stance. The interactions of stance*group (p=0.040) and stance*surface*group (p=0.048) were significant. The means indicated a significant increase in CoP acceleration in the control group during the TS-Firm task compared to the others tasks (Fig 1.E). Other factors and their interactions did not significantly impact CoP acceleration (p>0.05) (Table 2).

Mean velocity of CoP

The results indicated significant interactions of stance*group (p=0.049), stance*surface (p=0.03), and stance*surface*group (p=0.039) in CoP velocity. Overall, there was no significant difference in mean velocity between the two groups (Table 2). Mean comparisons revealed that in the ID group, the mean velocity in all conditions was higher compared to the control group, except in the TS-firm task (Fig 1.F).

DISCUSSION

The objective of this study was to compare spatial and quantitative variables related to postural control and assess their sensitivity under various surface conditions. This was done by examining voluntary postural control strategies in children with ID and an age-matched control group for comparison. The results of this study showed that, in general, the amount spatial variables included displacement, sway, amplitude, and RMS of CoP, were significantly higher in ID group than control group. The stance factor (reduction in base of support) significantly impacted all four scrutinized variables. Moreover, the COP sway and amplitude variables were notably affected by the diminished sensory-depth information attributed to the foam condition.

Consistent with these findings, studies have shown that standing on foam induces greater system instability compared to a firm surface, leading to heightened engagement of distal muscles to counteract this instability (Patikas et al., 2019). Conversely, individuals standing on a foam surface or those with compromised postural control tend to favor the hip strategy (Wiegmann et al., 2019).

In previous studies have shown that individuals with ID have poorer postural control outcomes compared to typically developing individuals (Chen et al., 2015; Habibi Masouleh et al., 2021; Wang et al., 2012). A study of (Zok et al., 2008) which is consistent with the present study, showed that decreases in the spatial variables of CoP are related to postural control strategies. In our study, it was found that children with ID had significant increases in sway and amplitude of CoP compared to the control group, suggesting that postural control strategies may be more developed in children in the control group. The studies demonstrated that individuals without ID experience a lack of integration between visual and vestibular stimuli when maintaining an upright posture until the age of 15-16. It is reasonable to expect that in individuals with ID, this issue may persist for an even longer time period (Leyssens et al., 2022; Steindl et al., 2006). Therefore, the reason for the difference in balance in children with ID may be weakness in their postural control strategies.

In this study, the use of foam-surface led to an increase in spatial variables in both groups. Among the evaluated variables, sway and amplitude of CoP were sensitive to the disturbance in proprioceptive information created by foam, which was particularly evident in the ID group. Therefore, impaired proprioceptive systems in children with ID, compared to the control group, could result in heightened amplitude and sway of COP, as well as changes in postural control strategy, and consequently, a propensity toward employing hip-centric strategies. These findings are consistent with the hypothesis of proprioceptive deficits has been supported by authors like (Moldrich et al., 2007), who suggest that individuals with ID have difficulty integrating afferent and efferent information at the cerebellar level due to lower cerebellar weight. According to the study by Ueta et al. (2015) standing on foam may lead to individuals focusing on their body and exercising voluntary control over their posture.

The results showed that the velocity and acceleration of CoP were higher in the ID group compared to the control group, but this difference was not significant.

The results of this study highlighted two significant points regarding the quantitative variables. Firstly, these variables were sensitive to changes in the stance position, resembling the sensitivity observed in spatial variables. The tandem condition notably affected the velocity and acceleration of CoP movements concerning the feet position. Secondly, there was no significant interaction observed between stance*group concerning spatial variables. This implies that alterations in the stance position led to a similar increase in spatial variables for both groups. However, in terms of quantitative variables, the interaction between stance/group was significant. As per the findings, within the control group, the stance position increased CoP velocity by approximately 43.5%, whereas in the ID group, it was around 1%.

In a study conducted by (Masani et al., 2014), it was found that the velocity of the CoP reflects the acceleration of the center of mass (COM), rather than its velocity. Also, the central nervous system (CNS) may utilize COM sway as a means of exploration to ensure that continuous dynamic inputs are received from multiple sensory systems. As the velocity increased under still conditions, it is possible that the acceleration of the COM also increased (Carpenter et al., 2010). Through a voluntary control strategy, the necessary sensory information may be sent to the CNS by increasing the acceleration of the COM, which in turn controls the amplitude of CoP displacement based on this sensory information (Ueta et al., 2015).

Changes in surface and stance position resulted in significant increases in the spatial and quantitative variables of CoP especially in the ID group. The previous studies showed that several factors may contributed to limitations in PC capacity in individuals with ID. Firstly, motor functions disorders due to incomplete development of the CNS (Organization, 2007). Secondly, premature aging may worsen balance and strategy of postural control due to declines in muscle strength and sensory functions (Enkelaar et al., 2013). Thirdly, the inactive lifestyle of persons in individuals with ID relatively may lead to lower physical functioning levels (Cartwright et al., 2017; Kachouri et al., 2022). The study's findings are influenced by a few limitations. Firstly, the participants were exclusively females. Secondly, the velocity and acceleration of CoP were not normalized in this study.

CONCLUSION

The results showed spatial variables of CoP were significantly higher in the ID group, than that in control group. However, the quantitative variables of CoP were less impacted by ID characteristics compared to spatial variables. Furthermore, the results indicated that the spatial and quantitative variables of the CoP increased with changes in the support position. Among the variables assessed, sway and amplitude of CoP were found to be more sensitive to disruptions in proprioceptive information caused by foam, particularly noticeable within the ID group. The ID group is likely inclined to employ a hip strategy more than the control group to regulate sway. Accordingly, it is recommended to explore the effects of balance exercises involving foam surfaces or positioning the feet in different stances on the postural control of children with ID.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Bibrowicz, K., Szurmik, T., Wodarski, P., Michnik, R., Mysliwiec, A., Barszcz, J., Mikołajewski, G., & Mitas, A. (2019). Quality of body posture and postural stability in people with intellectual disability playing volleyball. *Acta of bioengineering and biomechanics*, *21*(1), 23-30.

Capio, C. M., Sit, C. H., Eguia, K. F., Abernethy, B., & Masters, R. S. (2015). Fundamental movement skills training to promote physical activity in children with and without disability: A pilot study. *Journal of Sport and Health Science*, *4*(3), 235-243.

Carpenter, M., Murnaghan, C., & Inglis, J. (2010). Shifting the balance: evidence of an exploratory role for postural sway. *Neuroscience*, *171*(1), 196-204.

Cartwright, L., Reid, M., Hammersley, R., & Walley, R. M. (2017). Barriers to increasing the physical activity of people with intellectual disabilities. *British Journal of Learning Disabilities*, *45*(1), 47-55.

Chan, M.-S., & Sigward, S. M. (2020). Center of pressure predicts Intra-limb compensatory patterns that shift demands away from knee extensors during squatting. *Journal of biomechanics*, *111*, 110008.

Chen, H.-L., Yeh, C.-F., & Howe, T.-H. (2015). Postural control during standing reach in children with Down syndrome. *Research in developmental disabilities*, *38*, 345-351.

Dekker, A., Safi, M., van der Zon-van Welzenis, E., Echteld, M. A., & Evenhuis, H. M. (2014). Sexuality and contraception in young people with mild intellectual disability; a qualitative study on the basis of 28 interviews. *Nederlands tijdschrift voor geneeskunde*, *158*, A8010-A8010.

Dolva, A.-S., Coster, W., & Lilja, M. (2004). Functional performance in children with Down syndrome. *The American journal of occupational therapy*, *58*(6), 621-629.

Enkelaar, L., Smulders, E., van Schrojenstein Lantman-de Valk, H., Geurts, A. C., & Weerdesteyn, V. (2012). A review of balance and gait capacities in relation to falls in persons with intellectual disability. *Research in developmental disabilities*, *33*(1), 291-306.

Enkelaar, L., Smulders, E., van Schrojenstein Lantman-de Valk, H., Weerdesteyn, V., & Geurts, A. C. (2013). Clinical measures are feasible and sensitive to assess balance and gait capacities in older persons with mild to moderate Intellectual Disabilities. *Research in developmental disabilities*, *34*(1), 276-285.

Fraizer, E. V., & Mitra, S. (2008). Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. *Gait & posture*, *27*(2), 271-279.

Galli, M., Rigoldi, C., Mainardi, L., Tenore, N., Onorati, P., & Albertini, G. (2008). Postural control in patients with Down syndrome. *Disability and Rehabilitation*, *30*(17), 1274-1278.

Habibi Masouleh, Z., Shamsi Majalani, A., & Sedaghati, P. (2021). Comparing the Postural Control Among Different Age Ranges in Intellectually Disabled Girls. *Journal of Sport Biomechanics*, *6*(4), 240-249.

Hall, J. M., & Thomas, M. J. (2008). Promoting physical activity and exercise in older adults with developmental disabilities. *Topics in Geriatric Rehabilitation*, *24*(1), 64-73.

Hartman, E., Houwen, S., Scherder, E., & Visscher, C. (2010). On the relationship between motor performance and executive functioning in children with intellectual disabilities. *Journal of Intellectual Disability Research*, *54*(5), 468-477.

Jancova, J. (2013). What is the role body sway deviation and body sway velocity play in postural stability in older adults? *Acta medica (Hradec Kralove)/Universitas Carolina, Facultas Medica Hradec Kralove*, *56*(3), 117-123.

Kachouri, H., Borji, R., Baccouch, R., Laatar, R., Rebai, H., & Sahli, S. (2016). The effect of a combined strength and proprioceptive training on muscle strength and postural balance in boys with intellectual disability: An exploratory study. *Research in developmental disabilities*, *53*, 367-376.

Kachouri, H., Jouira, G., Laatar, R., Borji, R., Rebai, H., & Sahli, S. (2022). Different types of combined training programs to improve postural balance in single and dual tasks in children with intellectual disability. *Journal of Intellectual Disabilities*, 17446295221148585.

Laatar, R., Kachouri, H., Borji, R., Ben Waer, F., Rebai, H., & Sahli, S. (2023). Dual-task affects postural balance performance in children with intellectual disability. *Somatosensory & Motor Research*, *40*(1), 33-38.

Leyssens, L., Van Hecke, R., Moons, K., Luypaert, S., Danneels, M., Patru, J., Willems, M., & Maes, L. (2022). Postural balance problems in people with intellectual disabilities: Do not forget the sensory input systems. *Journal of Applied Research in Intellectual Disabilities*, *35*(1), 280-294.

Lipowicz, A., Bugdol, M. N., Szurmik, T., Bibrowicz, K., Kurzeja, P., & Mitas, A. W. (2019). Body balance analysis of children and youth with intellectual disabilities. *Journal of Intellectual Disability Research*, *63*(11), 1312-1323.

Masani, K., Vette, A. H., Abe, M. O., & Nakazawa, K. (2014). Center of pressure velocity reflects body acceleration rather than body velocity during quiet standing. *Gait & posture*, *39*(3), 946-952.

Mohammadi, M., Ghamkhar, L., Alizadeh, A., Shaabani, M., Salavati, M., & Kahlaee, A. H. (2021). Comparison of the reliance of the postural control system on the visual, vestibular and proprioceptive inputs in chronic low back pain patients and asymptomatic participants. *Gait & posture*, *85*, 266-272.

Moldrich, R. X., Dauphinot, L., Laffaire, J., Rossier, J., & Potier, M.-C. (2007). Down syndrome gene dosage imbalance on cerebellum development. *Progress in neurobiology*, *82*(2), 87-94.

Organization, W. H. (2007). ICD-10. International Statistical Classification of Diseases and Related Health Problems: Tenth Revision 1992, Volume 1= CIM-10. Classification statistique internationale des maladies et des problèmes de santé connexes: Dixième Révision 1992, Volume 1.

Paillard, T., & Noé, F. (2015). Techniques and methods for testing the postural function in healthy and pathological subjects. *BioMed Research International*, *2015*.

Patikas, D. A., Papavasileiou, A., Ekizos, A., Hatzitaki, V., & Arampatzis, A. (2019). Swaying slower reduces the destabilizing effects of a compliant surface on voluntary sway dynamics. *PLoS One*, *14*(12), e0226263.

Rigoldi, C., Galli, M., Mainardi, L., Crivellini, M., & Albertini, G. (2011). Postural control in children, teenagers and adults with Down syndrome. *Research in developmental disabilities*, *32*(1), 170-175.

Rocchi, L., Chiari, L., & Horak, F. (2002). Effects of deep brain stimulation and levodopa on postural sway in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *73*(3), 267-274.

Ross, L. M., Register-Mihalik, J. K., Mihalik, J. P., McCulloch, K. L., Prentice, W. E., Shields, E. W., & Guskiewicz, K. M. (2011). Effects of a single-task versus a dual-task paradigm on cognition and balance in healthy subjects. *Journal of sport rehabilitation*, *20*(3), 296-310.

Schalock, R. L., Luckasson, R. A., & Shogren, K. A. (2007). The renaming of mental retardation: Understanding the change to the term intellectual disability. *Intellectual and developmental disabilities*, *45*(2), 116-124.

Steindl, R., Kunz, K., Schrott-Fischer, A., & Scholtz, A. (2006). Effect of age and sex on maturation of sensory systems and balance control. *Developmental medicine and child neurology*, *48*(6), 477-482.

Trew, M., & Everett, T. (2005). *Human movement: an introductory text*. Churchill Livingstone.

Ueta, K., Okada, Y., Nakano, H., Osumi, M., & Morioka, S. (2015). Effects of voluntary and automatic control of center of pressure sway during quiet standing. *Journal of motor behavior*, *47*(3), 256-264.

Wang, H.-Y., Long, I.-M., & Liu, M.-F. (2012). Relationships between task-oriented postural control and motor ability in children and adolescents with Down syndrome. *Research in developmental disabilities*, *33*(6), 1792-1798.

Westendorp, M., Hartman, E., Houwen, S., Smith, J., & Visscher, C. (2011). The relationship between gross motor skills and academic achievement in children with learning disabilities. *Research in developmental disabilities*, *32*(6), 2773-2779.

Wiegmann, S., Felsenberg, D., Gast, U., Börst, H., Armbrecht, G., & Dietzel, R. (2019). Balance performance across the lifespan assessed by the Leonardo mechanograph®: A cross-sectional study. *Journal of Functional Morphology and Kinesiology*, *5*(1), 1.

Yu, C., Li, J., Liu, Y., Qin, W., Li, Y., Shu, N., Jiang, T., & Li, K. (2008). White matter tract integrity and intelligence in patients with mental retardation and healthy adults. *Neuroimage*, *40*(4), 1533-1541.

Zok, M., Mazzà, C., & Cappozzo, A. (2008). Should the instructions issued to the subject in traditional static posturography be standardised? *Medical engineering & physics*, *30*(7), 913-916.