JCPR Journal of Clinical Physiotherapy Research **Original Article**

Development of Static Postural Control: Regulating the Center of Pressure Trajectory

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Submitted: 2022-05-03; **Accepted**: 2022-09-11; **Doi:** https: doi.org.10.22037.jcpr.v7i4.42259

Abstract

Introduction: Introduction: Studying the developmental process, may possible to examine the role of sensory and cognitive systems involved in postural control. The aim of this study was to evaluate and compare the static postural control in both linear and nonlinear methods in 7 to 12 years old children with young-adult. **Materials and Methods:** This research is a descriptive and cross-sectional study. The center of pressure (CoP) in eight postural task was assessed in girls and boys 7 to 12 years old (35 in each age and gender group) and 40 young adults. The linear method included sway, displacement, the amplitude of CoP and velocity. To characterize the nonlinear evaluation, sample entropy was measured for complexity evaluation. The MANOVA and repeated measures ANOVA taesrs was used for between and inter-group comparison. Statistical analysis was performed using SPSS v.21 at significance level of P<0.05. **Results:** The results showed that children in 7 and 8-year-old have the most sway, amplitude, speed and displacement of CoP rather than others age groups (P<0.05), but young adults had the lowest amount in these variables. The complexity, was decreases significantly with age (P<0.01). The base of support was greater effect on linear and nonlinear than that other conditions, especially in 7 to 12 years old children (P< 0.001). The closed-eyes condition, were not aligned in linear and non-linear evaluation (P<0.001). **Conclusion:** The differences between age groups were significant in the challenging situation than that stable condition, due to changes in postural control strategies. Task demands did not have a significant effect on balance complexity in adults, but it did affect children and linear variables.

Key words: Center of Pressure; Linear and Nonlinear Analysis; Postural Control; Sample Entropy

***Please cite this paper as*:** Kamali Bakhtiar P, Azadian E, Majlesi M, Delgado-Bonal A, Rezaie MR. Development of Static Postural Control: Regulating the Center of Pressure Trajectory. J Clin Physio Res. 2022; 7(4): e73. Doi: *https:.doi.org.10.22037.jcpr.v7i4.42259*

Introduction

Balance control involves using sensory systems such as visual, vestibular, and somatosensory, which send environmental information to the central nervous system to activate appropriate motor responses. To maintain balance, the center of gravity must be kept within the base of support, which requires equilibrium between the stabilizing and destabilizing forces. Balance and postural control have been addressed in many studies, including those on remedial interventions and injuries prevention (1-3). Assessing balance performance in childhood and adolescence is a special research area as it can lead to early identification of diseases, movement disorders, and the design of appropriate training programs (4). With maturation, sensory-motor integration and balance control in children continuously improve, reductions in postural sway when standing reflects adult patterns (5, 6).

Using the center of pressure (CoP) data to measure postural sway is the most standard method recorded by force plate (7). Linear evaluations of postural control, such as displacement, sway and CoP displacement, as well as velocity and root mean square (RMS), have traditionally been used in previous studies (8, 9). However, linear analysis of CoP data cannot demonstrate the changes and complexity of postural control over time (10). Meanwhile, the variability and complexity of postural control have become common features in the study of nervous systems (11). Therefore, nonlinear analysis of postural control has recently been adopted, which can evaluate the regularity and variability in a time series, indicating the degree of adaptation and maturity of motor control (12). Tools used for this purpose in the literature include approximate entropy, sample entropy, correlation dimension, largest Lyapunov exponent, and detrended fluctuation analysis (11, 13).

Over the past two decades, the SampEn method has been used to quantify postural control for the pathways of the CoP, a method that determines regularity in a time series and estimates the amount of “complexity” in a physiological system (14-18). Whereby increases in entropy values are indicative of a system exhibiting a greater degree of complex dynamics (19), suggesting a more flexible and adaptable movement pattern (20).

According to the loss of complexity theory, disorder and aging lead to a decrease in variability in behavior, and therefore reduced capacity to respond to perturbations, or a loss of adaptability (21). However, the results of study conducted by Kiefer *et al*., showed that less CoP sway (linear) with more regular CoP patterns reflects more adaptive control due to a more mature sensorimotor system (22). Additionally, Stergiou *et al*. have stated that the principle of optimality in movement variability connects the concept of complexity with the concept of predictability in an inverted U-shaped relationship (23). A reduction or loss of this optimal state of variability makes the system more predictable, stiffer, and with robotic motor-type behavior. Increasing more than optimal variability makes the system noisier and more unpredictable. Both situations lead to reduced complexity, flexibility, and adaptation to perturbations and are associated with poor quality of health (24).

Studies have shown that complexity is affected in older adults(25, 26), individuals with Traumatic Brain Injury(TBI) (15), Autism Spectrum Disorders(ASD) (27), vestibular disorder (28, 29), Multiple Sclerosis(MS)(30, 31)and also cognitive load and attention(25, 32).The loss of complexity is indicatory of reduced capacity to respond to perturbations; or a loss of adaptability (21). Researchers have also shown that lower complexity represent a more regular and predictable CoP pattern (18, 33).

Some studies have examined growth status in postural control from childhood to young adults. These studies have shown that postural sway is smaller in adults compared to children, they showed that children adopt different strategies to perform balance tasks compared to adults(34, 35). Research has shown that the concurrent performance of cognitive and motor tasks can affect the motor skills of children in the 7-9 age group (34, 36). Additionally, studies have found that 4-6-year-old children have difficulty combining visual and sensory information to control posture, while 7-10-year-old children do not experience these difficulties and can process visual and sensory information for balance control(37, 38). Olivier *et al.* have also demonstrated that attentional constraints play a crucial role in cognitive-motor interference(39).

However; few studies have used nonlinear analysis to examine postural control across ages, and they have mainly focused on the effect of biomechanical demands such as the base of support (22, 40) or the effect of vision on regular CoP patterns (41, 42). Therefore, in this study, in addition to manipulation of task demands on postural control in late childhood to adolescents and used linear and nonlinear (SampEn) analyses to more accurately determine the factors affecting the growth of postural control. Based on what has been mentioned, we assumed that the displacement, amplitude, sway and velocity of the CoP, as well as the amount of complexity decrease with age.

Materials and Methods

Participants

This research is a descriptive cross-sectional study. In this study 460 children and adults participated. The children were divided into six age groups from 7 to 12 years old based on their chronological age. In each age group, 35 girls and 35 boys participated. In addition, twenty women and twenty men with an average age of 24.3 years participated in the study as adults group. The inclusion criteria for this study were age range between 7 and 12 years old for children age range between 20 and 25 years for adults who were able to perform the required tests (43). The exclusion criterion for all participants was neurological, musculoskeletal, or sensory-motor disorder that could affect balance and cognitive function. The participants were recruited from primary schools in Hamedan province between February 2021 and July 2021. Data were collected between September 1, 2021, and November 20, 2021, for research purposes. The consent forms were collected from the adult participants, and for children their parent was signed the forms. The protocol of this study was approved by the Ethics Committee of the Islamic Azad University, Hamadan Branch, with the ethical number of “IR.IAU.H.REC.1400.002”.

Data analysis

CoP was measured using the Kistler Force Platform (dimensions of 40 x 60,Type 9286BA, Kistler Instrument AG, Winterthur, Switzerland) at a frequency of 1000 Hz(7). The data were then filtered using a fourth-order low-pass Butterworth filter with a20 Hz cut-off frequency. Participants completed24 trials (three trials for eight tasks) each in 20 seconds while the order of trials

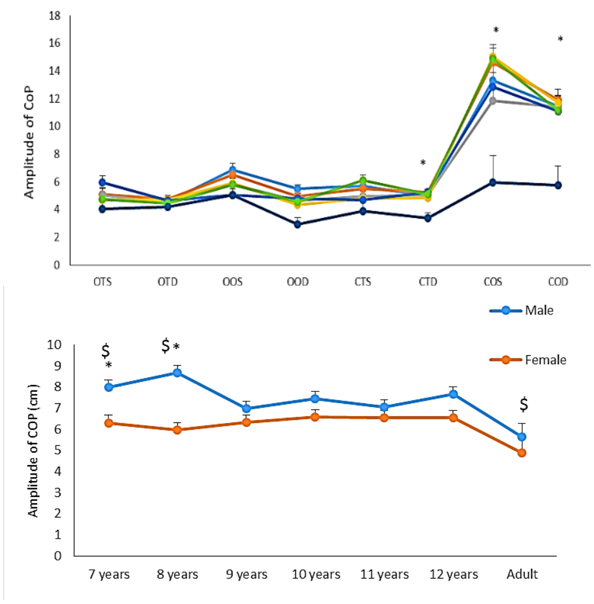

Figure 1. *A*) Interaction of age-visual-stability-task,*: the significant differences between ages. There was a difference between ages in challenging task; *B*) Interaction between of age× gender in amplitude of CoP, *: the significant differences between male and female, $: the significant differences between ages, in this variable, adults and ages 7 and 8 years had a significant difference with other age groups. (Error bars: SE)

was selected randomly (34). They stood on the force plate under 8tasks: (1. Open-eye, feet together, single task (OTS), 2. Open-eye, feet together, dual task (OTD), 3. Open-eye, one foot stance, single task (OOS), 4. Open-eye, one foot stance, dual task (OOD), 5. Closed-eye, feet together, single task (CTS), 6. Closed-eye, feet together, dual task (CTS), 7. Closed-eye, one foot stance, single task (COS), 8. Closed-eye, one foot stance, single task (COD) (8). The Digit Span Forward (the Wechsler working memory subtest) was used to assess the dual task (8). In this test, the numbers are read by the examiner and the participant must repeat them in the order they are presented. The number of correct answers was calculated within twenty seconds with and without the motor task at the same time (44).

Throughout the tests, the subjects stood barefoot on the platform and were asked to look steadily at a black point marked on the wall at eye level, three meters away. When each subject stood on the platform, the amount of CoP movement was measured in both of anterior–posterior (AP), and medial–lateral (ML) directions. Sway of CoP (movement of the center of pressure (CoP) over time), amplitude (computed as maximum distance of the CoP time series that travels in each direction), velocity (calculated by taking the total distance traveled and dividing it by the time of the trial (m/s)), CoP displacement (Standard deviation of the CoP provides a measure of the variation in the distribution of the CoP position (cm)) (45, 46) as linear evaluations of postural control were calculated by Bioware software v3,5,2 (Kistler Nordic AB, Sweden).

Sample entropy does not depend on record length and is characterized by relative consistency (47). More rigid postural behavior results in fixed balance control patterns and consequently dysfunctional balance control during perturbations. Therefore, for nonlinear evaluation of postural control, sample entropy of CoP displacement in AP and ML direction, are mathematically computed as follows:

Firstly, CoP time-series were down sampled with a factor of 5 to achieve an effective frequency of 20 Hz, which resulted in time-series with a length of N=1200 data points (20 Hz, 60 s). This operation was performed in order to introduce a time lag of 5 for the computation of SampEn (*i.e.* including every 5th point of the original time-series in their computation). This procedure has been applied in previous studies in order to reduce redundancy while preserving essential information (48, 49). Subsequently, SampEn were computed for m=(50) and r={0.3}. A detailed description of the algorithms used to compute SampEn can be found in (51-55).

Statistical analysis

This study had two between-group factors (age and gender) and four inter-group factors including base of support (BoS) (feet together/single limb), vision (open eyes/closed eyes), task (dual-task/single task), and direction (AP/ML). The repeated measures analysis was used for assessing the effect of inter-group factors for each variable separately. The ANOVA and Tukey post-hoc analyses were performed on age differences. All the statistical analyses were performed using SPSS v.21 and the statistical significance level was $P<0.05$.

Results

Amplitude of CoP

Table 1 shows height, weight and BMI of the participants. The results showed that the main effects of visual ($M_{open\text{-}eye}=5.2\pm0.2$, $M_{eye\text{-}closed}=8.3\pm0.1$, $F=329.2$, $P=0.000$, $\eta2p=0.4$), BoS ($M_{two\ leg}=5.02\pm0.2$, $M_{one\ leg}=8.5\pm0.1$, $F=312.9$, $p=0.000$, $\eta2p=0.4$) and task conditions($M_{single\ task}=7.3\pm0.1$, $M_{dual\ task}=6.21\pm0.1$, $F=48.2$, $P=0.000$, $\eta2p=0.1$) were significant in CoP amplitude (Table 1). As indicated by the results, manipulation of vision and BoSincreased amplitude significantly more than open eyes and feet together (59%, 69% respectively). Moreover, compared to the single task condition, dual-task performance significantly reduced CoP (17%) (Figure 1 A). In general, the results showed

Table 1.Demographic characteristics of the participants, means (SD)

Age (year)	N	Height (m)		Weight (kg)		BMI	
		Female	Male	Female	Male	Female	Male
7	70	1.23 (0.05)	1.22 (0.05)	23.75 (3.57)	22.85 (2.70)	15.47 (1.78)	15.26 (1.08)
8	70	1.27 (0.06)	1.29 (0.06)	24.79 (4.81)	26.64 (4.44)	15.13 (2.28)	15.78 (1.82)
9	70	1.33 (0.07)	1.34 (0.06)	30.39 (6.86)	29.44 (6.10)	16.79 (2.51)	16.25 (2.43)
10	70	1.41 (0.04)	1.40 (0.06)	32.49 (5.80)	33.42 (7.03)	16.24 (2.50)	16.98 (2.91)
11	70	1.46 (0.04)	1.47 (0.06)	37.77 (5.19)	38.32 (7.46)	17.59 (2.42)	17.60 (2.55)
12	70	1.52 (0.06)	1.48 (0.05)	41.59 (9.55)	39.12 (5.98)	17.85 (3.33)	17.77 (2.01)
Adult	40	1.62 (0.06)	1.82 (0.07)	52.32 (6.73)	84.26 (10.3)	19.94 (2.74)	24.67 (2.70)

N: number. M: meter. Kg: kilogram.

Table 2.Factor analysis of amplitude, velocity, Sway and Displacement of CoP and SampEn. F (P.value)

Factors	Amplitude	Velocity	Sway	Displacement	complexity
Age	3.1 (0.006)*	4.9 (0.00)*	3.9 (0.001)*	12.2 (0.00)*	25.3 (0.00)*
Gender	26.7 (0.00)*	45.0 (0.00)*	30.9 (0.00)*	3.4 (0.07)	0.6 (0.43)
Age× Gender	2.4 (0.03)*	1.6 (0.13)	1.9 (0.08)	1.3 (0.25)	1.6 (0.15)
Visual	329.2 (0.00)*	194.1 (0.00)*	416.7 (0.00)*	32.5 (0.00)*	27.8 (0.00)*
Visual×Age	8.7 (0.001)*	10.6 (0.00)*	8.0 (0.00)*	1.5 (0.17)	1.6 (0.16)
Visual× Gender	0.1 (0.76)	0.4 (0.52)	0.4 (0.53)	5.0 (0.03)*	4.6 (0.03)*
BoS	312.9 (0.00)*	460.4 (0.00)*	347.8 (0.00)*	80.8 (0.00)*	213.5 (0.00)*
BoS×Age	4.12 (0.00)*	6.7 (0.00)*	3.5 (0.002)*	4.0 (0.001)*	13.0 (0.00)*
BoS×Gender	7.6 (0.006)*	3.2 (0.07)	13.0 (0.00)*	3.3 (0.07)	41.4 (0.00)*
Task	48.5 (0.00)*	41.3 (0.00)*	70.5 (0.00)*	6.2 (0.01)*	29.9 (0.00)*
Task×Age	0.1 (0.44)	3.9 (0.001)*	1.1 (0.34)	1.3 (0.27)	7.3 (0.001)*
Task× Gender	7.8 (0.006)*	22.6 (0.00)*	22.7 (0.00)*	6.1 (0.01)*	11.9 (0.00)*
Direction	71.5 (0.00)*	1433.3 (0.00)*	36.4 (0.00)*	268.8 (0.00)*	11.1 (0.001)*
Direction×Age	2.9 (0.009)*	5.02 (0.00)*	1.2 (0.36)	6.1 (0.00)*	18.5 (0.00)*
Direction×Gender	16.2 (0.00)*	20.2 (0.00)*	21.3 (0.00)*	5.5 (0.02)*	43.8 (0.00)*
Visual×BoS	360.5 (0.00)*	219.9 (0.00)*	432.1 (0.00)*	0.01 (0.91)	104.3 (0.00)*
Visual×Task	0.06 (0.81)	2.7 (0.1)	0.03 (0.87)	0.1 (0.73)	0.5 (0.83)
Visual×Direction	4.3 (0.04)*	132.5 (0.00)*	22.7 (0.00)*	34.0 (0.00)*	233.8 (0.00)*
BoS×Task	20.4 (0.00)*	6.1 (0.01)*	41.1 (0.00)*	0.1 (0.81)	10.1 (0.002)*
BoS×Direction	95.8 (0.00)*	269.0 (0.00)*	18.5 (0.00)*	849.5 (0.00)*	213.5 (0.00)*
Task×Direction	2.6 (0.11)	17.8 (0.00)*	9.6 (0.01)*	1.1 (0.29)	6.7 (0.01)*

** indicated a significant (P<0.05). BoS: Base of support*

that CoP amplitude increases with increasing task demands or in difficult tasks. The interaction between factors are shown in Table 2.The results of between-group comparisons showed that the main effect of age was significant (F=3.2, *P*=0.006, η2p=0.04) (Figure 1B). The post-hoc findings indicated that children aged 7 and 8 years had the highest amplitude of CoP, while adults had the lowest. As shown in Fig.1, the amplitude of CoP was significantly higher in men than in women (M_{male}=7.3±0.15, M_{female}=6.2±0.15, F=26.7, *P*=0.000, η2p=0.06).

Velocity of CoP

The results showed that the main effects of visual ($M_{open-eye}$=3.85±0.1, $M_{eye-closed}$=6.0±0.2, F=194.1, *P*=0.000, η2p=0.31), BoS ($M_{two\ leg}$=3.1±0.08, $M_{one\ leg}$=6.7±0.15, F=460.4, *P*=0.000, η2p=0.52) and task ($M_{single\ task}$=5.3±0.1, $M_{dual\ task}$ =4.6±0.1, F=41.3, *P*=0.000, η2p=0.09) were significant (Table 2). The velocity of CoP increased significantly in closed-eye compared to open-eye and single-limb compared to feet-together stance conditions (56% and 116% respectively); however, velocity significantly decreased while performing a dual vs single task (15%).Therefore, with increasing task demands, CoP velocity increases (Figure 2A). Additionally, the post-hoc results showed that CoP velocity in children aged 7, 8, and 9 were significantly higher than those for 11-year-old children and adults (Figure 2B). Also, velocity in women was significantly lower than that in men (M_{male}=5.5±0.13, M_{female}=4.3±0.12, F=45.7, *P*=0.000, η2p=0.1) (Figure 2A). Furthermore, the results of the interaction between age and gender were not significant, while the influence of age was found to be significant on BoS, visual, and task, which are shown in Table 2.

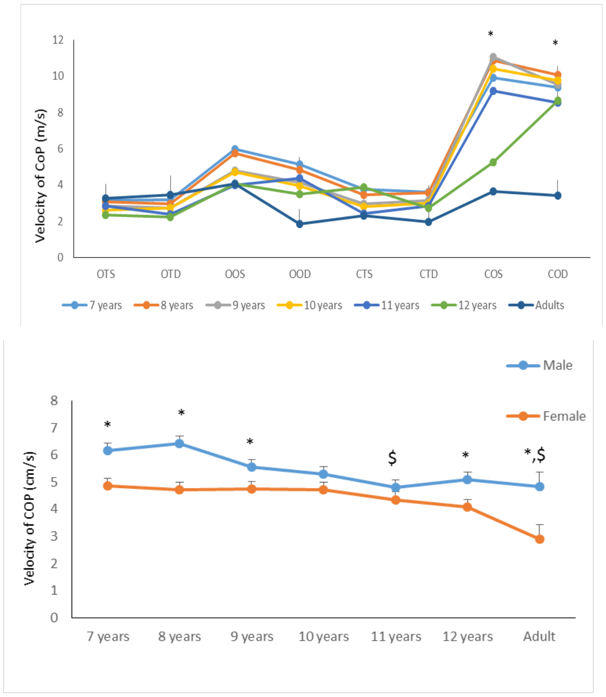

***Figure* 2**. *A*) Interaction of age-visual-stability-task, *: the significant differences between ages. There was a difference between ages in challenging task. ; *B*) Interaction between of age× gender in velocity of CoP, *: the significant differences between male and female, $: the significant differences between ages, in this variable, adults and 11 years old have a lower velocity and ages 7 and 8 years had a higher velocity. (Error bars: SE)

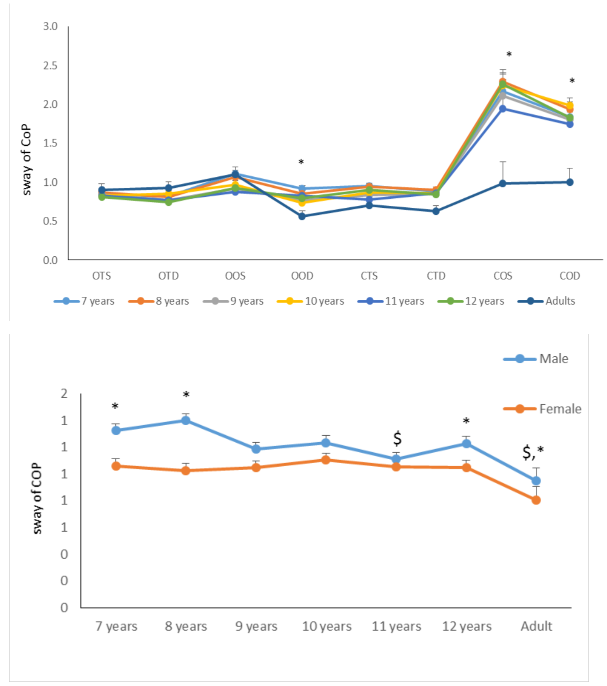

Figure 3. *A*) Interaction of age-visual-stability-task, *: the significant differences between ages. There was a difference between ages in challenging task; *B*) Interaction between of age× gender in sway of CoP,*: the significant differences between male and female, $: the significant differences between ages, in this variable, adults and 11 years old have a lower sway and ages 7 and 8 years had a higher sway than other ages. (Error bars: SE)

Sway of CoP

The results of sway showed that the main effects of visual ($M_{open-eye}$=0.87±0.03, $M_{eye-closed}$=1.36±0.01, F=416.8, *P*=0.000, η2p=0.5), BoS ($M_{two\ leg}$=0.84±0.03, $M_{one\ leg}$=1.38±0.01, F=347.8, *P*=0.000, η2p=0.45) and task ($M_{single\ task}$=1.18±0.03, $M_{dual\ task}$=1.04±0.02, F=70.5, *P*=0.000, η2p=0.14) were all significant (Table 2).Sway increased significantly in closed-eyes compared to open eyes (56%), and single-limb compared to feet together stance conditions (62%), but the sway of CoP decreased more significantly while performing a dual-task than that single task (13%).In other words, in more difficult task, the sway of CoP increases (Figure 3A). The post-hoctest also indicated that the amount of sway at all ages was significantly higher than in adults, and that sway in 7 and 8 year-old children was significantly higher than in 11 year-old children. Additionally, the sway of CoP in women was significantly lower than in men (M_{male}=1.2±0.02, M_{female}=1.02±0.02, F=30.9, *P*=0.000, η2p=0.07) (Figure 3B). The interactions between gender with BoS and task were significant.

CoP displacement

The results of CoP displacement showed that the main effects of visual ($M_{open-eye}$=4.24±0.06, $M_{eye-closed}$=4.6±0.07, F=32.4, *P*=0.000, η2p=0.07), BoS ($M_{two\ leg}$=4.1±0.05, $M_{one\ leg}$=4.7±0.06, F=80.8, *P*=0.000, η2p=0.16) and task ($M_{single\ task}$=4.36±0.06, $M_{dual\ task}$ =4.49±0.07, F=6.2, *P*=0.01, η2p=0.01) were significant (Table 2). The amount of displacementincreased significantly in closed-eyes compared to open eyes (8%), in single-limb compared to feet together stance (15%), and in the dual-task vs single task conditions (3%). In general, the results showed that with increasing task demands, the CoP displacement increases (Figure 4A).It was also found that displacement at all ages was significantly higher than that obtained for 12 years and adults, but the observed differences between men and women were not significant (M_{male}=4.5±0.08, M_{female}=4.3±0.07, F=3.4, *P*=0.06, η2p=0.008) (Figure 4B); however, the interaction between gender and visual and task conditions were significant.

SampEn of CoP

As the results indicated, the main effects of visual ($M_{open-eye}$=0.08±0.001, $M_{eye-closed}$=0.076±0.001, F=27.8, *P*=0.000, η2p=0.06), BoS ($M_{two\ leg}$=0.06±0.001, $M_{one\ leg}$=0.09±0.001, F=213.5, p=0.000,

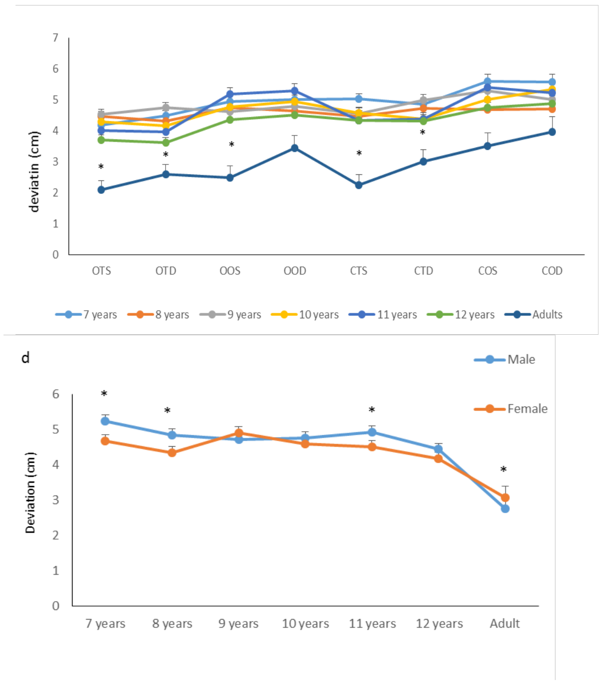

Figure 4. *A*) Interaction of age-visual-stability-task, *: the significant differences between ages. There was a significant difference between adults and other ages; *B*) Interaction between of age× gender in displacement of CoP, $: the significant differences between ages, in this variable, adults and 12 years old have a lower displacement and ages 7 and 8 years had a higher than other ages. (Error bars: SE)

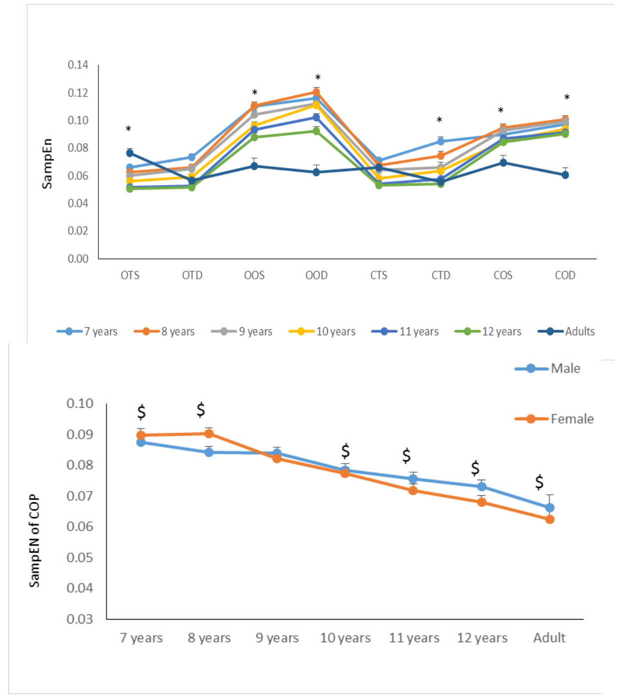

Figure 5. *A*) Interaction of age-visual-stability-task, *: Changing the BoS increases entropy and closed-eyes decreases it in children aged 7 to 12 years. But in adults, task demands did not have a significant effect on entropy; *B*) Interaction between of age× gender in Entropy. $: a significant decrease was observed in this entropy variable at all ages. (Error bars: SE)

$\eta 2p$=0.7) and task conditions ($M_{single\ task}$=0.076±0.001, $M_{dual\ task}$=0.08±0.001, F=29.9, *P*=0.000, $\eta 2p$=0.07) were significant (Table 1). The SampEn significantly decreased in the closed eye condition compared to the open-eye (5%); however, it significantly increased in single-limb compared to feet together stance (50%) and in the dual-task compared to single-task conditions (5%) (Table 2).There were significant differences between age groups in SampEn (F=25.3, *P*=0.000, $\eta 2p$=0.26).The results showed that adults in OTS task have greater variability than other ages and other tasks (Fig. 5. left). Overall, the differences between men and women were not significant (M_{male}=0.078±0.001, M_{female}=0.077±0.001, F=0.4, *P*=0.43, $\eta 2p$=0.001) (Figure 5. right), but the interaction of task, visual and BoS factors on gender were all significant.

As shown in Table 2, the main effect of direction showed that in all linear analyses AP was significantly greater than ML, but in SampEn, ML was greater than AP.

Discussion

The aim of present study was to identify postural control in 7 to 12 years old children by using linear and nonlinear analyses and comparing them with young adults. The results showed that children aged 7 and 8 years old had more sway, amplitude, displacements and velocity of CoP than those aged 9 to 12, but there was no significant difference between consecutive ages. Also, the difference between all parameters of postural control in children and adults was significant. Our findings suggested that postural control does not fully develop until the age of 12, irrespective of the task demands. Previous studies have also supported this notion, indicating that postural control may reach adult-like levels around the age of 14 yr. Therefore, during adolescence, the central and environmental systems responsible for postural control are still in the process of developing (6, 56, 57). During growth, as a result of the growth of sensory and musculoskeletal systems, the ability to differentiate and (reciprocal interweaving) resulting in increased motor control (58).

The results of the SampEn analyses in this study showed that complexity significantly decreases from one age group to the next, continuing until young adulthood. However, only adults in the OTS task exhibited greater complexity than other age groups and tasks. A similar study by da Costa et al. (2019) found comparable results to ours (59), where the complexity of CoP decreased in 5-year-old children compared to 3- and 4-year-old children. These findings may suggest that children develop the ability to assemble strategies dynamically in a more repeatable way, thus exhibiting more regular and structured solutions to postural control (60). In the past, greater variability and complexity was considered indicative of injuries or diseases that alter motor control patterns. However, recent studies have shown that some degree of complexity is usually necessary to adapt to environmental constraints and successfully perform movement (61). Therefore, increased regularity and decreased CoP displacement with age can be a sign of improved mechanical structures and physical development, as well as better postural control strategies due to an individual's ability to control degrees of freedom, resulting in more accurate and regular movements (62).

The results of factor analysis showed that manipulation of the BoS and vision had a greater effect on postural control than dual-task did across all variables. The effects of task demands changes were less pronounced in young-adults rather than in children, especially in complexity. In children aged 7 to 12 years, balance function in standing with feet together was similar to that of adults, but with a decrease in BoS (single-limb stance), sway, amplitude, and especially CoP velocity variability also increased. Consistent with previous studies, it appears that children are more sensitive to changing biomechanical demands (23, 63).

Based on the results, the visual factor led to a change of about 60% in the CoP displacement, and only 5% in complexity. At the ages of 7 to 12 years, manipulation of visual information, increased all variables. With vision deprivation, complexity of CoP decreased, especially in children. These results are consistent with previous findings that showed children learn to manage available mechanical degrees of freedom [31] through sensorimotor reweighting for more efficient integration (59).

The results of this study showed that the dual task performance reduced the velocity, amplitude and sway of CoP while increasing postural displacement a cross all ages. However, in adults, dual task performance also reduced the complexity of CoP movement, where as in children, complexity increased compared to single-task performance. Previous studies suggested that performing a dual-task may shift motor control from conscious to unconscious (8, 34),Therefore, attention to the motor tasks that are in the single-task conditions, leads to the involvement of more motor units (especially the lower limbs), which reduces the postural stability (39).

In this study, complexity decreased with age, and increased with task manipulation. Therefore, it may be concluded that greater complexity and variability in children may be related to lack of experience and motor coordination in controlling degrees of freedom, rendering the system more noisy and unpredictable. Thus, it is assumed that a combination of regularity and randomness (i.e. increased complexity) in the postural control system is a clear sign of adaptation in the face of such limitations(64). Although there is still no consensus on the exact age at which postural responses in children fully develop, the ability to achieve adult postural control behaviors is likely related to the child's ability to integrate sensory information (39).

Conclusion

The results of this study revealed that postural control in children during a quiet stance is comparable to that in adults. However, when manipulating task demands, especially BoS, children aged 7 to 9 exhibited greater CoP displacement compared to those aged 10 to 12, as well as in comparison to young adults. According to the results, complexity in adults was less affected by different situations and tasks than children. Increased complexity in children, in closed-eye and unstable condition, can be a sign of noise and unpredictable of motor control. Therefore, in conditions that require the change in postural control strategies, children cannot show adult-like abilities.

Acknowledgments

The authors are thankful to all the participants and their families for their participation in this study.

Ethical considerations

There were no ethical considerations to be considered in this research.

Practical application of the study

Based on the findings, balance control in individuals up to the age of 12 differs from that in adults, especially in more challenging conditions. Consequently, it is recommended to modify the attributes of movement skills that involve balance to reduce the risk of injury in children. Engaging in balance exercises under various conditions may influence children's postural control.

Conflict of interest

None.

Funding support

None.

Authors' contributions

All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

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