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Sex differences in postural control maturation during childhood and adolescence: a cross-sectional study in children between 4 and 17 years old
Diferencias de sexo en la maduración del control postural durante la infancia y la adolescencia: un estudio transversal en niños de 4 a 17 años

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Abstract. Purpose: the aim of this study was to determine the differences between the sexes in the development of postural control during childhood and adolescence. Methods: Three hundred and eighty-nine children were involved in a 30-s trial with eyes open and a 30-s trial with eyes closed. Using a Wii Balance Board, the mean velocity and median frequency in antero-posterior and medio-lateral directions were calculated, as well as the 95% confidence interval ellipse area. Results: The results showed that the youngest boys (4-5 years old) had a greater ellipse area than girls of the same age, while the girls in this age group showed a greater ellipse area ratio, although these differences disappeared until 12-13 years old. At this age, the boys showed greater mean velocity in antero-posterior direction both with eyes open and closed, as well as a greater ellipse area and mean velocity in the medio-lateral direction with eyes open. At 16-17 years old, the boys had lower mean velocity in the medio-lateral direction both with eyes open and eyes closed. Conclusions: In conclusion, the results indicate certain differences in the postural control maturation of girls and boys during childhood and adolescence.
Keywords: motor development; childhood; postural control.

Resumen. Objetivo: el objetivo de este estudio fue determinar las diferencias entre sexos en el desarrollo del control postural durante la infancia y la adolescencia. Material y métodos: Trescientos ochenta y nueve niños participaron en un ensayo de 30s con los ojos abiertos y otro de 30s con los ojos cerrados. Utilizando una Wii Balance Board, se calculó la velocidad media y la frecuencia media en las direcciones anteroposterior y medio-lateral, así como el área de la elipse del intervalo de confianza del 95%. Resultados: Los resultados mostraron que los niños más pequeños (4-5 años) tenían un área de elipse mayor que las niñas de la misma edad, mientras que las niñas de este grupo de edad mostraban una mayor relación de área de elipse, aunque estas diferencias desaparecieron hasta los 12-13 años. A esta edad, los chicos mostraron una mayor velocidad media en dirección anteroposterior tanto con los ojos abiertos como cerrados, así como una mayor área de la elipse y velocidad media en dirección medio-lateral con los ojos abiertos. A los 16-17 años, los chicos presentaban una menor velocidad media en la dirección medio-lateral tanto con los ojos abiertos como cerrados. Conclusiones: los resultados indican ciertas diferencias en la maduración del control postural de chicas y chicos durante la infancia y la adolescencia.
Palabras clave: desarrollo motor; infancia; control postural.

Introduction

The term 'postural control' refers to a broad mixture of abilities used not only to maintain quiet stance but also to be stable under perturbed (e.g. inside a braking bus) and dynamic (e.g. walking) situations. In order to accomplish these functions, humans use sensorial information provided by somatosensory, vestibular and visual systems, which acquire information regarding the orientation and velocity of body segments (Black, et al. 1983; Cumberworth, et al. 2007; Nashner, et al. 1982; Sá, et al. 2018).

Several studies have shown that postural oscillations decrease with age from childhood to adulthood, suggesting that children control their posture less efficiently than adults (Bustillo-Casero, et al. 2017; Cuisinier, et al. 2011; Mallau, et al. 2010; Marco-Ahulló, et al., 2022; Odenrick & Sandstedt, 1984; Peterka & Black, 1990; Riach & Hayes, 1987; Sá, et al. 2018; Sakaguchi, et al. 1994; Smith, et al. 2012). In fact, differences have been found between children/adolescents and adults in the sensory regulation of balance, sensorial reweight and attentional resources related to balance, among others.

Some studies were published at the end of the 20th century on the maturation of quiet standing during

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childhood and adolescence (Riach & Hayes, 1987), in a study on healthy children between two and 14 years old, found a moderate correlation between age and sway amplitude. They also found higher frequency cues (i.e., 0.8 to 2 Hz) in the youngest children and a weak influence of closed eyes on postural sway in children of all ages. Similarly, (Sakaguchi, et al. 1994) found that the center of pressures and head sways decreased with increasing age and postulated that the point at which children exhibit an adult-like postural control with the eyes open is between nine and 12 years old.

Other researchers have tried to find differences between boys and girls in the postural sway maturation process during quiet standing. Kojima & Takemori (1980) found a reduction of postural sway with age, as previously reported. These authors suggested that girls present a lower sway amplitude until 14 years old but after this point have higher sway amplitude than boys (Kojima & Takemori, 1980). Several studies have corroborated these differences in postural sway between boys and girls (Demura, et al. 2006; Geldhof, et al. 2006; Lee & Lin, 2007; Nolan, et al. 2005; Peterson, et al. 2006; Smith, et al. 2012; Steindl, et al. 2006) up to 12-14 years old.

Postural control development from childhood to adulthood has been studied for many years by many research groups. The importance of this research topic, i.e. how and why postural control develops, is based on two reasons (Peterson, et al. 2006). First, increasing the available knowledge on this topic would help to create early detection systems of atypical postural development in children; and secondly, better interventions could be developed to improve postural control both in typically- and atypically-developed children.

However, to the authors' knowledge, although there are papers that have analyzed differences in the maturation of postural control as a function of age (Sá, et al. 2018), no studies have been published on the differences between boys and girls in the maturation of postural control by means of analyzing time and frequency domain parameters during a wide range of childhood and adolescent ages. Given its potential importance for future interventions to improve the development of young people, our efforts have been focused on this. The main aim of this study was thus to determine the differences in postural control development between the sexes during these stages. The secondary aims were to quantify the changes in postural control during childhood and adolescence due to maturation and to determine the effect of sex on postural control during the entire childhood-to-adolescence stage.

Material and methods

Participants

A cross-sectional, prospective, between-subjects design was used to determine the differences in postural control in children from four to 17-years old. Using a convenience sampling as non-probability sampling method, 389 children were recruited from six primary and secondary schools. The participants were divided into fourteen groups according to age. The inclusion criteria were: i) between four and 17 years old (both inclusive) and ii) absence of any motor control pathology as reported by the parents. The characteristics of the subjects in the 14 groups are shown in Table 1, while the differences in the anthropometric parameters between the sexes at different ages are given in Figure 1.

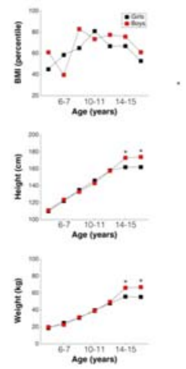

Figure 1. Differences between boys and girls in anthropometric variables during childhood and adolescence. *Significant differences between boys and girls.

Table 1.
Subjects' characteristics.

Age Group	Height (cm)	Weight (kg)	BMI (percentile)	Boys/Girls
4-years	107.63 (6.86)	17.67 (2.31)	45.97 (38.1)	15/12
5-years	114.07 (6.52)	20.6 (3.51)	52.38 (35.13)	18/15
6-years	119.61 (6.72)	22.1 (3.13)	44.87 (33.21)	22/12
7-years	127.69 (6.49)	26.02 (4.47)	49.2 (36.21)	18/11
8-years	134.29 (5.54)	33.94 (6.76)	73.47 (24.12)	9/10
9-years	134.67 (4.69)	32.61 (8.61)	56.29 (31.74)	12/12
10-years	142.33 (8.97)	38.74 (9.2)	65.83 (27.49)	13/11
11-years	146.22 (6.8)	43.1 (12.13)	56.03 (35.62)	14/13
12-years	152.9 (5.65)	43.8 (5.34)	51.36 (26.75)	13/12
13-years	161.5 (7.45)	58.12 (12.42)	75.14 (20.2)	15/15
14-years	165.1 (9.09)	59.56 (12.47)	69.37 (19.47)	15/15
15-years	168.79 (10.49)	61.69 (11.07)	62.9 (23.06)	15/16
16-years	168.0 (8.64)	62.40 (10.41)	61.72 (21.41)	15/16
17-years	162.52 (36.22)	60.0 (18.58)	48.02 (27.36)	12/12

Previous approval was obtained from The Institutional Review Board of our institution. Written informed consent forms were obtained from the parents prior to participation in this study.

Experimental procedure

Postural control was measured in a quiet well-lit room in each of the six schools involved in the study, after registering the subjects' anthropometric variables, sex and age. Each participant carried out one 30-s trial with eyes open and one 30-s trial with eyes closed. The order of performance was randomized to avoid undesirable order effects. The participants were asked to stand in a bipedal standing position with the feet separated by the width of the shoulders, while keeping the arms relaxed and as still as possible during the tests. A reference point was placed 2 m in front of the subjects for the open eyes test.

CoP signals were acquired from a Wii Balance Board (WBB), which has been validated as a good means of analyzing postural control in the bipedal standing position with eyes open and with eyes closed in a number of studies in both adults, which indicate high reliability (ICC > 0.8) (Clark, et al. 2010; Koslucher, et al. 2012; Park & Lee 2014), and children (also high reliability; CCC > 0.7) (Larsen, et al. 2014). Raw data was acquired on WiiLab software (University of Colorado Boulder, Colorado, USA) for Matlab R2007 (Mathworks Inc, Natick, USA). The WBB was placed on a firm surface on the floor and the data signals were recorded at a frequency of 40 Hz.

Data analysis

Digital signal processing was performed on Matlab (Mathworks Inc, Natick, USA). First, CoP displacement signals in the mediolateral (ML) and anteroposterior (AP) directions were digitally filtered by a Butterworth low-pass filter with a 12 Hz cut-off frequency. The mean velocity in the antero-posterior (MV_{AP}) and medio-lateral directions (MV_{ML}) and the 95% confidence interval ellipse area (EA) were then calculated. EA is an index of overall postural performance (the smaller the surface, the better the performance). Mean velocity reflects the efficiency of the postural control system (the smaller the velocity, the more efficient the postural control) while characterizing the net neuromuscular activity required to maintain balance. Sway frequency was assessed by means of the power spectral density. Spectra were estimated by the Matlab 'periodogram' function in a rectangular window with no overlapping, after which median frequency was computed in AP (MdF_{AP}) and ML (MdF_{ML}). Finally, the ratios were computed by normalizing the eyes closed value by the eyes open value of each variable.

Statistical analysis

The statistical analysis was carried out on SPSS 20 (IBM, Armonk, USA). The normality assumption was first checked and as some of the variables did not pass this test, a non-parametric test was performed. A Kruskal-Wallis test was applied to determine the effect of age on the postural control variables, followed by Dunn's tests with Bonferroni correction. A Mann Whitney U-test was applied to the entire sample to find any significant differences between boys and girls. The same test was applied to each age group to find any significant sex differences. Finally, Spearman correlations were requested to determine the relationships between age and the postural control variables. The level of significance was set at $p = 0.05$.

Results

Effects of age on postural control variables

An age effect was found in EA with eyes open (H_{13}= 155.39; p < 0.001) and closed (H_{13} = 115.99; p < 0.001), MV_{AP} with eyes open (H_{13}= 278.9; p < 0.001) and closed (H_{13} = 214.12; p < 0.001), as well as MV_{ML} with eyes open (H_{13} = 304.47; p < 0.001) and closed (H_{13}= 300.24; p < 0.001). Pairwise comparisons are shown in Figure 2 (layer A). As can be seen, MV_{AP} and MV_{ML} lessen with age, regardless of the visual condition, although the ellipse area shows two turning points, the first at nine-10 years old and the second at 13-14 years old.

A close linear relationship was found between age and MV_{AP} in eyes open and MV_{ML} in both conditions (i.e., > 0.8) (Figure 2), although the relationship between age and EA in both conditions and MV_{AP} in eyes closed was moderate (i.e. > 0.4 and < 0.8).

The EA ratio was also found to have an age effect (H_{13} = 32.76, p = 0.002), but not MV_{AP} (H_{13} = 20.28, p = 0.09) and MV_{ML} ratio (H_{13} = 20.55, p = 0.08). The pairwise comparison did not show any significant differences between the age groups due to the large number of comparisons (i.e., 91), although the EA ratio tended to be lower at higher ages (Figure 2).

Regarding the frequency variables, there was an effect of age on MdF_{AP} with eyes closed (H_{13} = 40.26; p < 0.001) but not with eyes open (H_{13} = 21.44; p =

0.065). Pairwise comparisons revealed lower MdF_{AP} in five-year-old children than in 13, 14, 15 and 17-year-olds with eyes closed (Figure 2). There was a main age effect on MdF_{ML} with eyes open ($H_{13} = 98.65$; $p < 0.001$) and closed ($H_{13} = 62.4$; $p < 0.001$). The older the children the lower the MdF_{ML}. The Spearman correlations showed a less significant relationship between MdF and age (Figure 2).

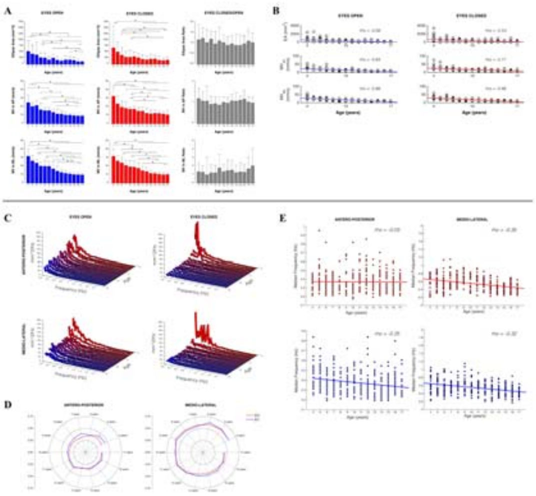

Figure 2. Effect of age on postural control variables. A: Differences between ages in postural control variables. The bars represent the median and the error bar the interquartile range. * Indicate significant differences between groups ($p < 0.05$). MV = mean velocity; AP = antero-posterior direction; ML = medio-lateral direction. B: Spearman correlations between postural control variables and age. The circles represent the subject while the lines represent the regression line. EA = ellipse area; MV_{AP} = mean velocity in antero-posterior direction and MV_{ML} = mean velocity in medio-lateral direction. C: power spectral density in each age group, direction and condition. D: polar plot representing the median frequency in each age group in both directions and conditions. E: scatterplot with correlation value between median frequency and age in each direction and condition. The red dots represent cases with eyes open while the red points represent cases with eyes closed.

Effect of sex on postural control variables

The Mann Whitney U-test revealed significant differences between boys and girls in EA with eyes open ($z = 3.06$; $p = 0.002$) and closed ($z = 2.38$; $p = 0.017$), as well as in MV_{AP} with eyes open ($z = 2.02$; $p = 0.04$), regardless of age (Table 2).

Table 2.
Differences between girls and boys in postural control variables.

Variable	Boys	Girls	z	p	r
EA EO (mm²)	196.39 (279.62)	144.05 (172.65)	3.06	0.02	0.15
EA OC (mm²)	250.83 (273.39)	200.19 (272.32)	2.38	0.017	0.12
EA ratio	1 (0.45)	1 (0.61)	-0.56	0.57	-0.03
MV_{AP} EO (mm/s)	13.11 (8.36)	11.23 (8.08)	2.02	0.04	0.1
MV_{AP} EC (mm/s)	15.12 (6.84)	15.31 (8.41)	1.61	0.1	0.08
MV_{AP} ratio	1 (0.39)	1 (0.39)	-0.02	0.98	-0.001
MV_{ML} EO (mm/s)	15.81 (12.36)	12.57 (11.4)	0.72	0.47	0.03
MV_{ML} OC (mm/s)	16.41 (11.83)	13.82 (12.61)	0.79	0.43	0.04
MV_{ML} ratio	1.25 (1.06)	1.36 (1.18)	-0.78	0.44	-0.04
MdF_{AP} EO (Hz)	0.35 (0.14)	0.35 (0.14)	0.24	0.81	0.01
MdF_{AP} EC (Hz)	0.35 (0.18)	0.35 (0.16)	-0.31	0.75	-0.01
MdF_{AP} ratio	0.99 (0.1)	0.98 (0.1)	0.14	0.89	0.007
MdF_{ML} EO (Hz)	0.53 (0.28)	0.53 (0.23)	-0.38	0.7	-0.02
MdF_{ML} OC (Hz)	0.52 (0.21)	0.55 (0.23)	-0.74	0.46	-0.04
MdF_{ML} ratio	0.88 (0.23)	0.86 (0.21)	1.33	0.18	0.07

Differences between sexes in postural control maturation

Figure 3 shows the maturation of postural control in both girls and boys between four and 17 years old. The youngest boys can be seen to have a larger ellipse area than girls of the same age (four-5 years old). At this age, girls showed a greater ellipse area ratio. Nevertheless, these differences disappeared until 12-13 years old, when boys showed greater MV_{AP} both with eyes open and closed as well as greater ellipse area and MV_{ML} with eyes open. At 16-17 years old, boys had lower MV_{ML} both with eyes open and eyes closed.

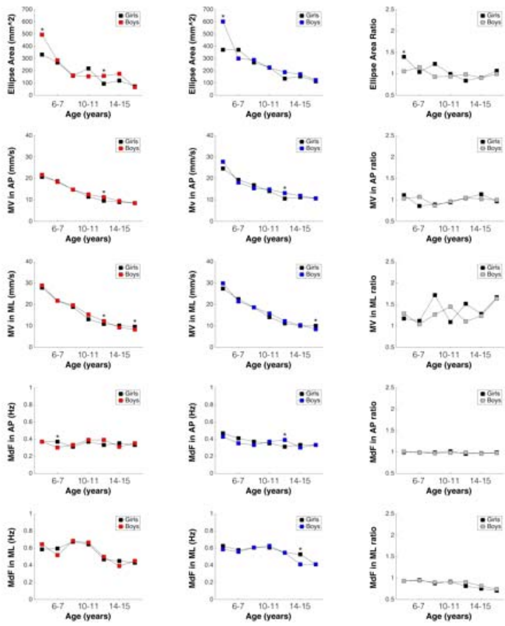

Figure 3. Gender differences in postural control variables. MV = mean velocity; AP = antero-posterior direction; ML = medio-lateral direction; MdF = median frequency. * Indicates significant differences ($p < 0.05$) between girls and boys.

Discussion

As far as the authors are aware, this is the first study with a relatively high sample to analyze the sex effect on postural control maturation in a wide age range in both childhood and adolescence (4 to 17 years old) in which not only time domain variables but also frequency domain variables were used to acquire further knowledge of the postural control changes that occur as children get older. The results of this study corroborate some previously published findings and suggest some new insights.

First, the value of the postural control variables analyzed during childhood and adolescence were found to fall steadily throughout this period. However, no clear turning point was found at 6-8 years, as has been described in previous studies (Assaiante & Amblard, 1995; Rival, et al. 2005), but at both nine-10 and 13-14 years the postural control variables appeared to suffer a lack of development. This result is in agreement with the linear development without any turning point between childhood and adolescence in sensory reweighting for postural strategies (Mallau, et al. 2010). It therefore seems that postural control develops steadily from four to 17 years old. It is possible that the ages in which no changes were presented in postural control corresponded with changes in postural control strategies (Rival et al., 2005).

Regarding the influence of the visual system in maintaining balance, an age effect was found in the ellipse area ratio, suggesting that the absence of visual cues to regulate posture produces less postural control disturbance as children get older, as has previously been postulated (Shumway-Cook & Woollacott 1985). However, there was no clear point at which the children reached adult-like postural control in situations with absence of visual information (Figure 2A). The lowest ellipse area ratio was reached at 14 years old, which is later than the age suggested previously as the point of complete development of the visual system used to maintain quiet standing (Shumway-Cook & Woollacott 1985).

Sex was found to affect postural control development. The differences between boys and girls were found mainly in three different stages; first, the youngest boys had a higher ellipse area than the girls of the same age, in both the eyes open and eyes closed conditions. However, it was more interesting to note that in this age period the girls had a significantly higher ellipse area ratio, indicating that a higher percentage of girls than boys increased their ellipse area during the eyes closed condition, suggesting that girls are more visually dependent than boys in maintaining quiet standing balance at this age. These findings are similar to those reported by Riach & Hayes (1987) (Riach & Hayes 1987) who found by regression analysis that the youngest males had greater sway amplitude than females. Usui et al. (1995), also found significantly higher sway in five years old boys than girls (Usui, et al. 1995).

After that, the differences between the sexes disappeared until 12-13 years of age. At this age, boys had a higher ellipse area with eyes open as well as higher MV_{AP} in both eyes open and closed, and higher MV_{ML} in eyes open. Finally, boys used higher frequency cues than girls in the AP direction with the eyes closed, unlike some studies that reported a greater sway area and velocity in boys than girls between seven-11 years old (Nolan, et al. 2005; Smith, et al. 2012; Usui, et al. 1995). Nolan et al. (2005) did not find differences between boys and girls in sway amplitude nor velocity at 12-13 years old (Nolan, et al. 2005).

Again, the differences between the sexes disappeared (or were reduced) until 16-17 years of age. At this stage, girls exhibited higher MV_{ML} both during eyes open and eyes closed conditions, in disagreement with Nolan et al. (2005) (Nolan, et al. 2005) who did not find any differences between 15-16 year old boys and girls. However, Dorneles et al., (2013) found greater sway in 15 year old males than females in both eyes open and eyes closed conditions (Dorneles, et al. 2013).

Taking all this into account, our results suggest that girls develop the systems involved in maintaining an upright posture before boys at two different ages (four-five and 12-13 years of age). However, almost at the end of the maturation process (16-17 years of age) males showed lower MV values, which could be explained by differences in the anthropometric values of boys and girls (see Figure 1). These results reveal a greater range of postural control development in boys than girls during the entire age range studied, in agreement with those reported by Riach & Hayes (1987) (Riach & Hayes 1987), who found that males reduced their postural sway more than females during the maturation process (from two to 14 years of age).

Having stated the above, we consider that the objectives of the study have been met. Both the main objective, which was to determine the differences between sexes in the development of postural control, and the secondary objectives, which were to quantify the changes in postural control during childhood and adolescence due to maturation and to determine the effect of sex on postural control throughout childhood and adolescence.

This study has some limitations that should be highlighted. First, other variables related to kinematics or muscle activity during quiet standing could help to increase the understanding of how postural control matures during childhood and adolescence. Secondly, as the cross-sectional study design used provides a lower level of evidence than follow-up studies, future research should study the maturation of postural control by means of longitudinal designs.

Conclusions

In conclusion, some differences were found in the postural control maturation of girls and boys during childhood and adolescence. Up to 12-13 years old, the girls had lower sway amplitude and mean velocity, while the boys showed a lower velocity in the ML direction than girls from 14 to 17 years old. There was also a reduction in sway amplitude and velocity as children got older, although our data did not show any clear turning points. Instead, two stagnation points were detected in the form of lower or lack of change in the postural control variables. The former occurred around nine-10 years old and the second around 13-14 years old.

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