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Changes in postural sway behavior across the life span

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CHANGES IN POSTURAL SWAY BEHAVIOR ACROSS THE LIFESPAN

By

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Changes in postural sway behavior across the life span.

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The present study aimed to investigate human balance control by assessing postural sway on three groups representing three stages of life (6-12, 19-40 and 65-74 years old). There were 14 individuals in each group and they were tested during upright bipedal stance with either eyes open or closed. Focus was given to multiple sway indices representing multi-dimensional features of postural sway in quiet stance and included: the center of pressure area, amplitude, root mean square (RMS), velocity, jerkiness, and sample entropy. Results confirmed that children and seniors swayed more ($p<.004$), faster ($p<.001$) and their body sway was shakier ($p<.001$) than young adults. Seniors also presented faster ($p<.006$) and shakier ($p<.001$) sway than children and a more unpredictable pattern of body sway in time ($p<.002$) than children and young adults. In addition, children presented a more random anterior-posterior sway ($p<.034$) and a more regular medio-lateral sway ($p<.043$) than young adults, and a higher synchronization between anterior-posterior and medio-lateral body sway ($p<.012$) than young adults and seniors. We also observed that postural control of children and young adults becomes relatively more challenged in experimental situations when eyes were closed for most postural indices. In conclusion, this study suggests that multi-dimension posturography is sensitive to detect subtle age-related changes in the postural behavior and each stage of life may have their own signature patterns of postural behavior. Therefore, we expect that quantifications of this nature may be used to assess not only postural instability and fall risk but also to aid the testing of the efficacy of balance interventional protocols.

Changes in postural sway behavior across the life span

1. INTRODUCTION

Balance control is an essential skill necessary for performing activities of daily living and deficits within this ability are considered suggestive of impaired central nervous system (CNS) function (Shumway-Cook and Woollacott 2001). Instrumented assessments of balance control have several clinical applications including diagnosing, documenting rates of recovery, and testing the efficacy of interventional programs. However, in order to further advance its clinical application, the establishment of normative indices are needed from individuals across the lifespan. For full validation/rigor, these data must be obtained using the same methodology and considering multiple aspects of the complex mechanisms of postural control in humans.

Postural studies have traditionally assessed balance control using indices of postural behavior calculated from movements of the body's center of pressure (COP) recorded during a variety of stance tasks. By using this approach, postural control of children, during quiet bipedal stance has been characterized by larger and faster body sway when compared to young adults (Figura et al 1991, Sakaguchi et al 1994). When the individual reaches the late adulthood, their body sway is found to be characterized by larger, faster and more variable compared to young adults (Amiridis et al 2003, Benjuya et al 2004, Demura et al 2008, Seigle et al 2009, Wiesmeier et al 2015).

The aforementioned patterns of body sway are usually attributed to the natural adaptations or deteriorations that both sensory and motor systems undergo across the lifespan. Since the time of birth, humans start developing dedicated neural mechanisms to relay sensory information from the environment (i.e., visual, vestibular and proprioceptive systems) which then goes through the process of sensorimotor integration. In optimal conditions, these afferent inputs are integrated and motor outputs are conveyed via the neuromuscular system in order to accomplish the intended action. Changes in the retrieval of information, neural integration process or motor output can lead to detrimental effects regarding optimal postural control as well as interfere with other actions that depend on optimal postural control (e.g. reaching for objects).

The challenge of standing upright and walking starts in infanthood (0 to 2 years old) and develops in early childhood (2 to 6 years old). During these stages, the CNS develops the ability to organize conflicting sensorial inputs from visual, vestibular and somatosensory systems (Foudriat et al 1993, Bair et al 2007). As the child advances to late childhood (6 to 12 years old) and adolescence (12 to 18 years old), sensorimotor integration is refined, balance control is improved, and the development of both feedback and feedforward (i.e. anticipatory) mechanisms of postural control continues (Haas et al 1989, Hay and Redon 1999, Schmitiz et al 2002). In early adulthood (19 to 40 years old), postural control is mature and physical abilities are at their peak, including balance performance, reaction time, sensorimotor integration and motor responses to perturbations (Shumway-Cook and Woollacott 2001). Then the natural process of aging, beginning during middle adulthood (40 to 65 years old) and late adulthood (over 65 years old), is characterized by declines in sensorial, neural and motor functioning. Such declines include reduced visual, vestibular and kinesthetic functions (Wiesmeier et al 2015), difficulties in multisensory reweighting (Horak et al 1989), progressive degeneration of gray and white matter (Good et al 2001), decrease in axonal conduction velocity (Doherty et al 1993), and reorganization of sensorimotor integration and muscle response to balance adjustments (Horak et al 1989, Papegaaij et al 2014, Wiesmeier et al 2015). It is important to note that both processes of maturation and decline are distinct in their physiology and further information about their resulting postural behavior is necessary to establish useful clinical normative indices of this nature.

To date, most postural studies have focused their efforts on only a few indices resulting in an incomplete record which is likely to miss crucial information. Degani (2016) recently stressed the importance of including postural indices from multiple domains to detect additional aspects of balance control, such as the jerkiness and entropy of the COP signal. Studies using different experimental protocols, participant's age, and data processing techniques have also hindered further progress in understanding the mechanisms underlying postural control. In an effort to fill these gaps, the present study investigated body sway behavior in children, adults and seniors using postural indices chosen to represent multiple domains of postural control. In general, we hypothesized that (a) a larger panel of postural indices will reveal important sway characteristics for different stages of life usually missed when just a few indices are measured; and (b) that the lack of visual inputs may have a different impact to the organization of human postural control throughout the lifespan. More specifically, we hypothesized (1) smaller, slower, smoother, less variable and more regular body sway as the individual reaches adulthood, (2) larger, faster, shakier, more variable and more random body sway as the individual reaches late adulthood, (3) larger, faster, shakier, more variable and more random body sway when visual input is temporarily absent.

2. METHODS

2.1. Participants.

All participants recruited were found to be healthy and the exclusion criteria included history of any sensory, neurological or musculoskeletal disorder. Prior to participation, all participants voluntarily gave their informed consent based on the procedures approved by the Institutional Review Board at The University of Montana and conformed to The Declaration of Helsinki.

Forty-two volunteers were stratified into three experimental groups: healthy children (*HC*), healthy young adults (*HA*), and healthy older adults or seniors (*HS*). The *HC* group consisted of 6 females and 8 males between 6 and 12 years old, mean age 9.3 years old (SD = 1.7), mean height 139 cm (SD = 15), and mean weight 36.3 kg (SD = 10.7). The HA group consisted of 9 females and 5 males between 19 and 40 years old, mean age 27.1 years old (SD = 3.9), mean height 173 cm (SD = 9), and mean weight 70.3 kg (SD = 10.5). The *HS* group consisted of 8 females and 6 males between 65 and 74 years old, mean age 68.9 years old (SD = 3.3), mean height 168 cm (SD = 9), and mean weight 73.0 kg (SD = 12.9).

2.2. Apparatus.

A force platform (AMTI BP400600, AMTI Inc.) was used to record COP coordinates in anterior-posterior (*COPap*) and medial-lateral directions (*COPml*). We acquired horizontal and vertical components of the ground reaction force (*Fx, Fy, Fz*) and the moments of force around the frontal, sagittal and vertical axes (*Mx, My, Mz*) to compute the body's center of pressure coordinates, according to manufacturer's directions: *COPap = (-h*Fx-My)/Fz* and *COPml = (-h*Fy-Mx)/Fz*. All signals from the force platform were sampled at either 50 Hz or 2000 Hz with a 16-bit resolution.

2.3. Experimental procedures.

All participants performed two standing tasks: bipedal stance with opened eyes (*Vision*) and bipedal stance with closed eyes (*No Vision*). For both tasks, participants were asked to stand barefoot on the force platform for 120 seconds with arms crossed and feet parallel and 13 cm apart. While performing the *Vision* task, participants were instructed to focus their vision on a static point placed on a parallel surface at eye level and at a distance of approximately one meter; while they were instructed to close their eyes for the *No Vision* task. The *No Vision* task was implemented as a mean to provide a sensory perturbation to the upright posture.

2.4. Signal analysis and conditioning.

COP coordinates were analyzed off-line with a series of custom-written software routines in Matlab R2012b (Mathworks Inc, Natick, MA). Prior to any analysis, COP coordinates in the anterior-posterior (AP) and medio-lateral (ML) directions were down-sampled to 10Hz and, next, detrended by the mean of each time series in order to bring the average position of the COP to the center of the local coordinate system (force plate).

Twelve variables of interest were extracted from COP coordinates:

- the area covered by the COP path (*StabArea*) computed based on the approach of the sector formula of Leibniz;
- the peak-to-peak amplitude of the COP displacement in each direction computed by the difference between the maximum and minimum values ($Amplitude_{ap}$ and $Amplitude_{ml}$);
- the variability of the COP around its mean value (RMS_{ap} and RMS_{ml}) computed by the root mean square (RMS) of the COP displacement in each direction;
- the mean velocity of the COP displacement, computed separately for each direction (MV_{ap} and MV_{ml});
- the mean sway jerkiness of the COP displacement in each direction ($MJerk_{ap}$ and $MJerk_{ml}$) representing the rate of change of the COP acceleration and computed as the third derivative of the COP position with respect to time;
- the sample entropy estimates of the COP displacement in each direction ($SEnt_{ap}$ and $SEnt_{ml}$) assessing the structural complexity in time of the COP displacement in each direction and computed by an algorithm that measures correlation, persistence, and regularity of the COP signal in time; and
- the cross-sample entropy (*CrossSEnt*) representing the degree of asynchrony or dissimilarity between *COPap* and *COPml* signals in time. See previous studies (Duarte and Freitas 2010, Degani et al 2017) for more details regarding computation of these postural indices.

2.5. Statistical Analysis.

For all twelve response variables, Kruskal-Wallis H test and post-hoc Mann-Whitney U tests were used to investigate the effects of *Age* (*HC*, *HA* and *HS*), whereas Wilcoxon signed-rank tests were used to investigate the effects of *Vision* (*Vision* and *No Vision*). All statistical tests were performed using the IBM SPSS statistics software (version 22, IBM® SPSS®) while keeping a level of significance of 5%. For all response variables, medians across participants were reported.

3. RESULTS

All participants were able to perform both experimental tasks. *Figure 1* shows COP coordinates recorded from one representative participant of each age group performing each of the tasks. Note the visual differences in the magnitude of postural sway among these participants and between tasks. *Figures 2*, *3* and *4* present boxplots of response variables from all participants under both standing tasks (*Vision* and *No Vision*).

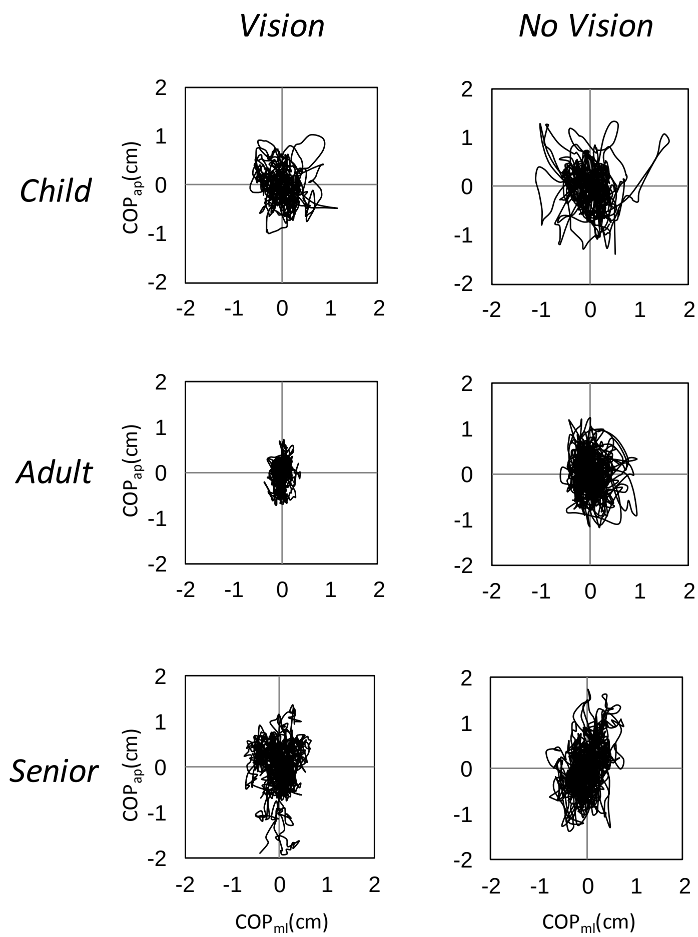

Figure 1. The center of pressure (COP) displacement of one representative participant of each age group (healthy children [*HC*], healthy young adults [*HA*], and healthy older adults or seniors [*HS*]) performing bipedal stance with and without visual input (*Vision* and *No Vision* conditions).

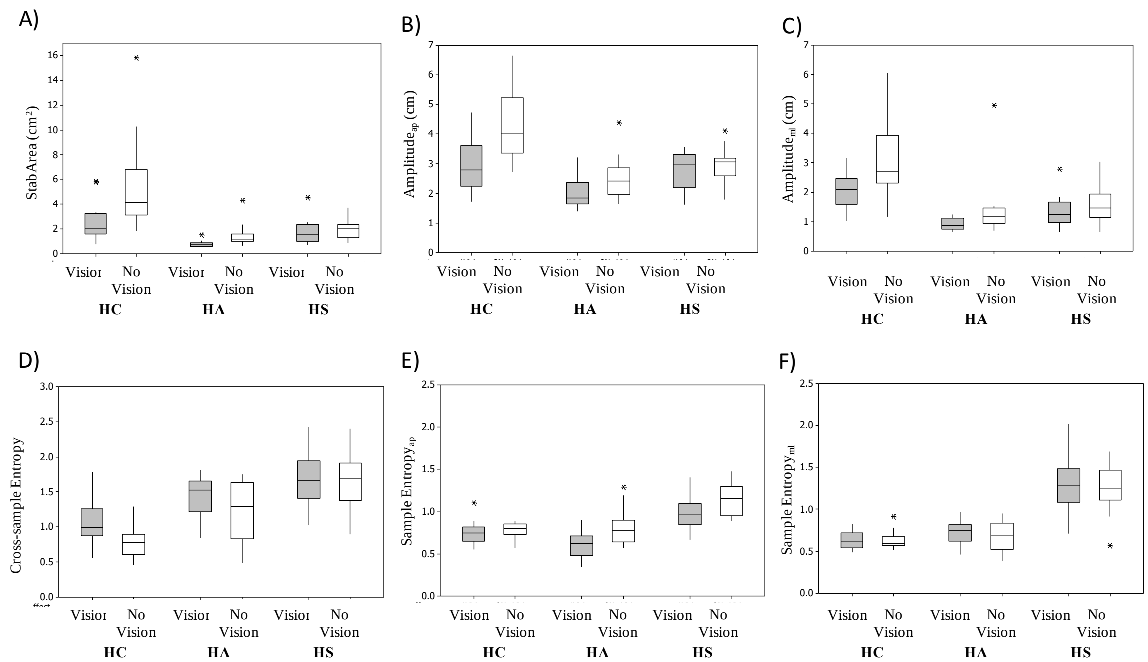

Figure 2. Boxplot with postural indices (*StabArea*, *Amplitude$_{ap}$*, *Amplitude$_{ml}$*, *Sample Entropy$_{ap}$*, *Sample Entropy$_{ml}$*, and *Cross-sample Entropy*) of healthy children (*HC*), healthy young adults (*HA*), and healthy older adults or seniors (*HS*) performing upright stance with opened and closed eyes (*Vision* and *No Vision* conditions, respectively).

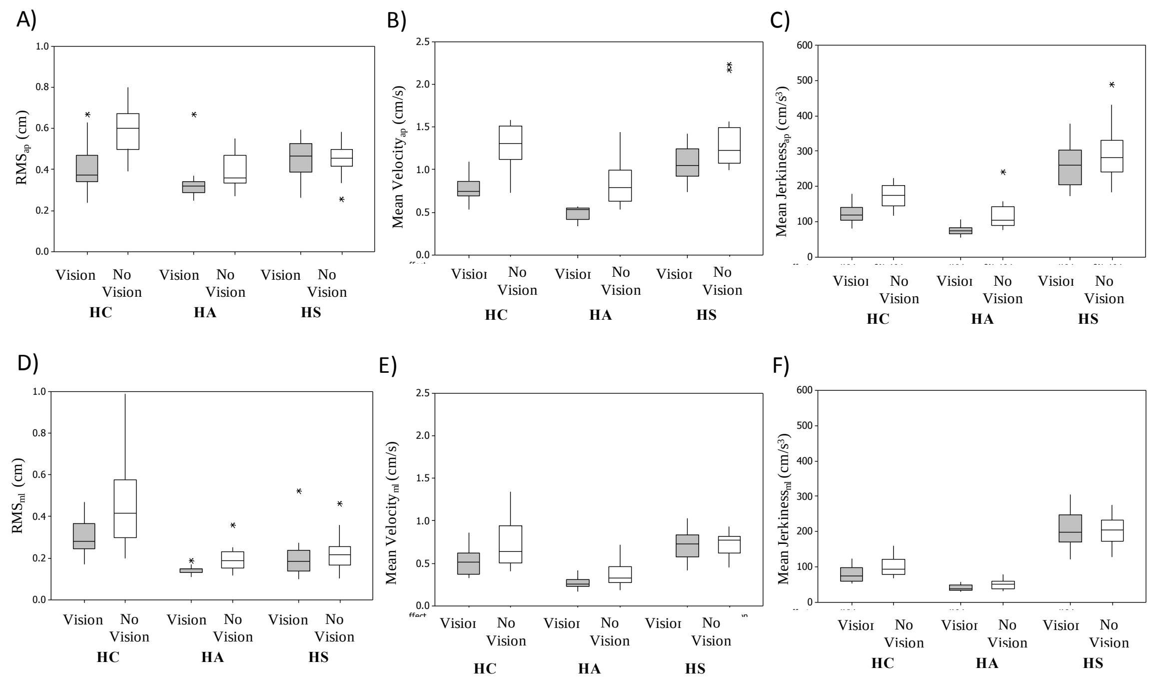

Figure 3. Boxplot with postural indices (*RMS_{ap}*, *RMS_{ml}*, *Mean $Velocity_{ap}$*, *Mean $Velocity_{ml}$*, *Mean $Jerkiness_{ap}$*, and *Mean $Jerkiness_{ml}$*) of healthy children (*HC*), healthy young adults (*HA*), and healthy older adults or seniors (*HS*) performing upright stance with opened and closed eyes (*Vision* and *No Vision* conditions, respectively).

3.1. The effects of age on postural sway.

In general, postural sway in children and seniors was found to be larger, faster and less smooth compared to young adults. The median across participants of the response variables extracted from the COP signal during both standing tasks are presented in *Table 1*, along with *p*-values from Mann Whitney U tests on factor *Age* for these postural indices.

Table 1. Median and quartiles within parentheses (*Q1, Q3*) across participants (healthy children [*HC*], healthy young adults [*HA*], and healthy older adults or seniors [*HS*]) of response variables extracted from the center of pressure signal during upright stance with opened eyes (*Vision* condition). Note: * indicates significant *Age* effect ($p < 0.05$).

	Vision condition			*Age* effect		
	Healthy Children	Healthy Adults	Healthy Seniors	(*HC* x *HA*) *p*-value	(*HA* x *HS*) *p*-value	(*HC* x *HS*) *p*-value
StabArea (cm^2)	2.10 (1.70, 3.06)	0.76 (0.61, 0.89)	1.53 (1.09, 2.23)	< .001*	< .001*	.089
$Amplitude_{ap}$ (cm)	2.93 (2.46, 3.87)	1.84 (1.69, 2.26)	2.96 (2.36, 3.27)	.004*	.003*	1.00
$Amplitude_{ml}$ (cm)	2.19 (1.83, 3.02)	0.87 (0.76, 1.06)	1.25 (1.00, 1.59)	< .001*	.004*	.003*
RMS_{ap} (cm)	0.41 (0.35, 0.59)	0.32 (0.29, 0.34)	0.46 (0.40, 0.51)	.007*	.001*	.089
RMS_{ml} (cm)	0.34 (0.27, 0.43)	0.15 (0.13, 0.15)	0.19 (0.15, 0.23)	< .001*	.017*	.005*
MV_{ap} (cm/s)	0.75 (0.71, 0.85)	0.53 (0.42, 0.55)	1.05 (0.93, 1.21)	< .001*	< .001*	.001*
MV_{ml} (cm/s)	0.52 (0.39, 0.61)	0.26 (0.23, 0.30)	0.73 (0.59, 0.82)	< .001*	< .001*	.006*
$MJerk_{ap}$ (cm/s^3)	119 (109, 135)	75 (67, 82)	261 (212, 299)	< .001*	< .001*	< .001*
$MJerk_{ml}$ (cm/s^3)	75 (62, 95)	38 (35, 48)	199 (177, 238)	< .001*	< .001*	< .001*
$SEnt_{ap}$	0.75 (0.65, 0.80)	0.62 (0.50, 0.70)	0.96 (0.88, 1.08)	.034*	< .001*	.002*
$SEnt_{ml}$	0.62 (0.55, 0.70)	0.75 (0.64, 0.81)	1.28 (1.11, 1.47)	.043*	< .001*	< .001*
CrossSEnt	0.99 (0.91, 1.19)	1.52 (1.24, 1.62)	1.66 (1.44, 1.94)	.012*	.129	< .001*

During bipedal stance with opened eyes (*Vision* task), both children and seniors presented significant larger spatio-temporal indices (*StabArea*, $Amplitude_{ap}$, $Amplitude_{ml}$, RMS_{ap}, RMS_{ml}, MV_{ap}, MV_{ml}, $MJerk_{ap}$ and $MJerk_{ml}$) compared to young adults. In addition, seniors presented significant higher ML oscillation and variability ($Amplitude_{ml}$ and RMS_{ml}) and higher sway velocity and jerkiness (MV_{ap}, MV_{ml}, $MJerk_{ap}$ and $MJerk_{ml}$) compared to children. In the structural domain, there was a significant increase in the irregularity of the body sway pattern in time in both directions ($SEnt_{ap}$ and $SEnt_{ml}$) in seniors compared to children and young adults. Interestingly, children presented a more random body sway in the AP direction ($SEnt_{ap}$) and a more regular sway in the ML direction ($SEnt_{ml}$) than young adults did. There was also a significant increase in the asynchrony between AP and ML sway (*CrossSEnt*) in young adults and seniors compared to children. See all *p*-values for the effects of *Age* on postural indices extracted from the COP in *Table 1*.

3.2. The effects of visual input on postural sway.

The more challenging task of upright stance with closed eyes presented different impacts on postural control in children, young adults, and seniors. In general, children and young adults presented more changes on postural sway than seniors when visual input was not available. The median across participants of the response variables along with *p*-values from Wilcoxon signed-rank tests are presented in *Tables 2, 3* and *4*.

Table 2. Median and quartiles within parentheses (*Q1, Q3*) across healthy children [*HC*] of response variables extracted from the center of pressure signal during upright stance during bipedal stance with opened and closed eyes (*Vision* and *No Vision* conditions, respectively). Note: ***** indicates significant *Vision* effect ($p < 0.05$).

	Healthy Children		
	Vision	*No Vision*	*p*
StabArea (cm^2)	2.10 (1.70, 3.06)	4.14 (3.33, 6.26)	***.001****
$Amplitude_{ap}$ (cm)	2.93 (2.46, 3.87)	4.24 (3.50, 5.98)	***.001****
$Amplitude_{ml}$ (cm)	2.19 (1.83, 3.02)	2.96 (2.60, 4.48)	***.003****
RMS_{ap} (cm)	0.41 (0.35, 0.59)	0.62 (0.55, 0.76)	***.001****
RMS_{ml} (cm)	0.34 (0.27, 0.43)	0.45 (0.39, 0.60)	***.003****
MV_{ap} (cm/s)	0.75 (0.71, 0.85)	1.39 (1.12, 1.54)	***.001****
MV_{ml} (cm/s)	0.52 (0.39, 0.61)	0.79 (0.61, 1.07)	***.001****
$MJerk_{ap}$ (cm/s^3)	119 (109, 135)	170 (144, 211)	***.001****
$MJerk_{ml}$ (cm/s^3)	75 (62, 95)	104 (84, 124)	***.001****
$SEnt_{ap}$	0.75 (0.65, 0.80)	0.80 (0.75, 0.85)	*.172*
$SEnt_{ml}$	0.62 (0.55, 0.70)	0.60 (0.57, 0.66)	*1.00*
CrossSEnt	0.99 (0.91, 1.19)	0.78 (0.64, 0.86)	***.001****

Table 3. Median and quartiles within parentheses (*Q1, Q3*) across healthy young adults [*HA*] of response variables extracted from the center of pressure signal during upright stance during bipedal stance with opened and closed eyes (*Vision* and *No Vision* conditions, respectively). Note: ***** indicates significant *Vision* effect (p < 0.05).

	Healthy Adults		
	Vision	*No Vision*	*p*
StabArea (cm^2)	0.76 (0.61, 0.89)	1.21 (1.03, 1.46)	***.001****
$Amplitude_{ap}$ (cm)	1.84 (1.69, 2.26)	2.40 (2.03, 2.75)	*.064*
$Amplitude_{ml}$ (cm)	0.87 (0.76, 1.06)	1.17 (0.98, 1.43)	***.004****
RMS_{ap} (cm)	0.32 (0.29, 0.34)	0.36 (0.34, 0.45)	***.035****
RMS_{ml} (cm)	0.15 (0.13, 0.15)	0.19 (0.17, 0.22)	***.008****
MV_{ap} (cm/s)	0.53 (0.42, 0.55)	0.79 (0.68, 0.96)	***.001****
MV_{ml} (cm/s)	0.26 (0.23, 0.30)	0.33 (0.29, 0.44)	***.001****
$MJerk_{ap}$ (cm/s^3)	75 (67 82)	105 (91, 134)	***.001****
$MJerk_{ml}$ (cm/s^3)	38 (35, 48)	52 (41, 58)	***.001****
$SEnt_{ap}$	0.62 (0.50, 0.70)	0.78 (0.66, 0.86)	***.001****
$SEnt_{ml}$	0.75 (0.64, 0.81)	0.68 (0.55, 0.81)	*.158*
CrossSEnt	1.52 (1.24, 1.62)	1.30 (0.89, 1.58)	*.084*

Table 4. Median and quartiles within parentheses (*Q1*, *Q3*) across healthy older adults or seniors [*HS*] of response variables extracted from the center of pressure signal during upright stance during bipedal stance with opened and closed eyes (*Vision* and *No Vision* conditions, respectively). Note: ***** indicates significant *Vision* effect ($p < 0.05$).

	Healthy Seniors		
	Vision	*No Vision*	*p*
StabArea (cm^2)	1.53 (1.09, 2.23)	2.07 (1.46, 2.33)	*.233*
$Amplitude_{ap}$ (cm)	2.96 (2.36, 3.27)	3.05 (2.66, 3.14)	*.551*
$Amplitude_{ml}$ (cm)	1.25 (1.00, 1.59)	1.47 (1.18, 1.83)	*.198*
RMS_{ap} (cm)	0.46 (0.40, 0.51)	0.45 (0.43, 0.49)	*.730*
RMS_{ml} (cm)	0.19 (0.15, 0.23)	0.22 (0.17, 0.25)	*.414*
MV_{ap} (cm/s)	1.05 (0.93, 1.21)	1.22 (1.09, 1.45)	***.002****
MV_{ml} (cm/s)	0.73 (0.59, 0.82)	0.78 (0.63, 0.81)	*.551*
$MJerk_{ap}$ (cm/s^3)	261 (212, 299)	282 (244, 321)	***.041****
$MJerk_{ml}$ (cm/s^3)	199 (177, 238)	205 (174, 229)	*.826*
$SEnt_{ap}$	0.96 (0.88, 1.08)	1.15 (0.98, 1.28)	***.006****
$SEnt_{ml}$	1.28 (1.11, 1.47)	1.25 (1.16, 1.44)	*.638*
CrossSEnt	1.66 (1.44, 1.94)	1.68 (1.44, 1.83)	*.730*

Children and young adults swayed more (p<.035), faster (p<.001) and less smoothly (p<.001) when they closed their eyes. Statistical tests confirmed significant increase in *StabArea*, $Amplitude_{ap}$, $Amplitude_{ml}$, RMS_{ap}, RMS_{ml}, MV_{ap}, MV_{ml}, $MJerk_{ap}$ and $MJerk_{ml}$ for children and young adults during the *No Vision* task compared to the *Vision* task. On the other hand, seniors only presented a significant faster (p<.002) and shakier (p<.041) AP body sway (*Mean* $Velocity_{ap}$ and *Mean* $Jerkiness_{ap}$) when they closed their eyes. Regarding structural domain, young adults and seniors presented significant higher irregularity of the AP body sway in time ($SEnt_{ap}$) with closed eyes compared to open eyes. No significant changes in the level of irregularity of the ML body sway in time ($SEnt_{ml}$) were found for children, young adults or seniors. In addition, children presented a significant increase in the synchrony between AP and ML sway (*CrossSEnt*) when they closed their eyes ($p<.001$). See all *p*-values for the effects of *Vision* on postural indices extracted from the COP in *Tables 2, 3* and *4*.

4. DISCUSSION

The present investigation focused on age-related aspects of postural behavior. In general, results suggest that postural sway in quiet stance seems to become smaller, less variable, slower, smoother and more predictable as the individual achieves their sensorial, neural and motor maturation. Later in life, a larger, more variable, faster, shakier and more irregular body sway to control upright posture seems to reflect the natural decline in structural and physiological functions.

Despite the removal of vision revealing a few changes on postural sway characteristics for all three experimental groups, the temporary lack of visual input affected mostly children and young adults, as we hypothesized. The removal of vision affected mostly the children and the young adult groups, as we hypothesized, the senior group did not demonstrate significant changes in their sway pattern when vision was removed.

4.1. Postural control across lifespan.

In the first years of life, young children learn how to organize redundant sensory inputs and coordinate multiple muscles, joints and body segments in order to control balance and improve motor performances. Increased body sway area, amplitude, variability and velocity in children during unperturbed stance reported in the current study have been previously described (Figura et al 1991, Sakaguchi et al 1994, Rival et al 2005). Our results went further and showed shakier body sway in children compared to young adults accompanied by a more unpredictable AP sway, a more predictable ML sway and a greater synchronization between AP and ML oscillations. This body sway pattern seems to reflect the immaturity of the sensorial, neural and motor systems in children aging 6-12 years old. The fact that children do not present adult-like postural behavior by age 12 corroborates the incomplete development of balance reported in children up to age 7-10 years (Cherng et al 2001) and 12-14 years (Ferber-Viart et al 2007). Previous reports have suggested that motor strategies, involving coordination and musculoskeletal responses, start developing in early childhood, whereas sensory organizational processes, involving sensory integration within the Central Nervous System, are hierarchically higher and develop slower through childhood and adolescence (Forssberg and Nashner 1982). Therefore, it seems that children may not only scale the relative importance of each sensory input on balance responses differently from adults, they may also adopt different motor strategies to maintain balance.

The development of sensory integration and motor strategies of balance control in children has been addressed in the literature (Haas et al 1989, Foudriat et al 1993, Hirabayashi and Iwasaki 1995, Hay and Redon 1999, Schmitiz et al 2002). It seems that somatosensory function may become close to adult-like by age 3-4 years, visual function by age 15 years, and vestibular function is still not complete by age 15 (Hirabayashi and Iwasaki 1995). Researchers also suggested a shift from a predominant visual-vestibular input to control balance to a more somatosensory-vestibular control by age 3 (Foudriat et al 1993). In addition, it seems that multisensory reweighting by age 6 is still different from that in adults (Foudriat et al 1993). Regarding motor strategies of balance control, feedback and feedforward (anticipatory) mechanisms become more efficient as children grow up. Feedback responses to perturbations can be observed early in life and a decrease in feedback latency has been reported through the first 14 years of life (Haas et al 1989). Effective anticipatory postural adjustments (feedforward responses) seem to be elicited only after 4 years of age (Haas et al 1989). The slow maturation of anticipatory control as well as the mastering of timing parameters during childhood has also been suggested (Hay and Redon 1999, Schmitiz et al 2002). In addition, physical changes in bone size, muscle mass and body part proportions during childhood should be taken into account and the CNS is constantly adjusting these new parameters to control upright stance. Therefore, children start building a repertoire of postural strategies and learning to select the appropriate strategy to maintain balance while performing motor tasks (Assaiante et al 2005).

When the individual reaches adulthood, sensorial, neural and motor systems are mature and at their best functioning level, as well as balance performance. Our results showed a smaller, slower and smoother postural sway in young adults compared to children. Postural sway was also more predictable in the AP direction and more random in the ML direction than it used to be. This new postural sway behavior seems to be a combination of optimized reweighting of multisensory inputs, adequate sensorimotor integration, and efficient feedback and feedforward mechanisms of postural control.

As sensory, neural and motor functions start to deteriorate in the middle and late adulthood, balance performance declines and older individuals start to experience episodes of balance instability. This natural age-related decline was detected in the study by changes in multiple postural indices. Body sway was larger, faster, shakier and more unpredictable in seniors compared to young adults. Increased COP area, amplitude, variability, mean velocity and irregularity in time in seniors have been previously reported (Amiridis et al 2003, Benjuya et al 2004, Demura et al 2008, Duarte and Sternard 2008, Seigle et al 2009, Borg and Laxaback 2010, Wiesmeier et al 2015).

4.2. The effects of temporary removal of visual input on postural sway across lifespan.

Visual input is an important sensory feedback to control balance. Our study showed that the temporary removal of visual information had different impacts on the control of upright stance across lifespan. In general, children and young adults swayed more, faster and shakier when they closed their eyes. Seniors also swayed faster and shakier, but they did not increase their sway area, amplitude or variability when they closed their eyes. In addition, children did not change significantly their level of COP irregularity in time, whereas young adults and seniors presented a more unpredictable AP sway when they closed their eyes.

Differences on postural sway when visual input is not available may be related to how the individual integrates feedback from remaining sensory systems. Independent of age, the individual must adapt to the new situation by quickly reorganizing somatosensory and vestibular inputs and generating efficient postural responses. Our findings pointing dissimilar effects of visual deprivation on body sway among children, young adults and seniors reveal the age-related dependence of visual input on postural control.

We suggest a few hypotheses regarding the effect of vision on balance across lifespan. Considering that both feedback and feedforward mechanisms of postural control are still in development in children, they have to deal with information from sensory receptors not yet fully developed and a limited repertoire of motor strategies to control balance. Young adults also have to reweight sensory inputs and reorganize motor responses to maintain balance. However, the maturity of sensory feedback mechanisms, sensorimotor integration and anticipatory responses in adults may explain different effects of visual disruption on postural control between children and adults. Following this rationale, it was also expected different effects of vision on balance in seniors. Actually, our results showed that seniors presented fewer changes in postural indices when they closed their eyes than children and young adults. This hypothesis corroborate other studies pointing out greater modifications on postural sway indices in young adults compared to seniors when visual input is not allowed (Benjuya et al 2004). We speculate that age-related progressive deterioration of visual acuity and accommodation, contour and depth perception, contrast sensitivity, peripheral vision, and pupil size and agility (Kelly 1993, Wiesmeier et al 2015) is accompanied by a decrease in the contribution of visual input on postural control as the individual grows older.

5. CONCLUSIONS

Balance assessment using multiple indices were able to better characterize postural control across lifespan by detecting subtle changes in postural sway. Dissimilar postural sway behavior in children compared to young adults suggests that postural control and balance responses are still immature by age 12. This immature postural control in children may be associated with the progressive development of sensorimotor integration and motor responses during childhood. As sensorial, neural and motor functions start to deteriorate in late adulthood, balance control is affected and it was detected by changes in most postural indices in seniors compared to young adults. In addition, results showed that the contribution of visual input on postural control is age-dependent.

In conclusion, children, adults and seniors present dissimilar postural sway characteristics, and postural control assessment should include postural indices from multiple domains. This knowledge is crucial not only in assessing balance deficits at different stages of life, but also in directing interventional protocols aiming at balance training and fall prevention for individuals with different levels of balance deficits and at different ages.

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