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ORIGINAL ARTICLE

STANDING BALANCE IN PRESCHOOLERS USING NONLINEAR DYNAMICS AND SWAY DENSITY CURVE ANALYSIS

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Abstract

The aim of the present study was to investigate how age and sensory deprivation affect the temporal organization of CoP sway variability and the postural corrective commands during standing balance in typically developing preschoolers. A sample of 57 children aged 3–5 years participated in the study. Structural stabilometric descriptors of sample entropy (SEn), detrendend fluctuation analysis (DFA), and sway density curve (SDC) analysis were employed to assess features of center of pressure sway. A force platform was used to collect center of pressure data during standing balance over 40 seconds in four conditions: standing on rigid and foam surfaces with eyes open and closed. The main results are as follows: 1) sample entropy decreased and DFA_coefficient increased with age, while the SDC variables remained unaltered among the 3-, 4-, and 5-year-old children; 2) as sensory conditions became more challenging, sample entropy decreased and DFA_coefficient increased, while MT and MD decreased and MD increased; age did not influence the responses to sensorial deprivation. In conclusion, 5-year-old children showed decreased variability of CoP sway during standing balance compared with the younger children, but all children used the same corrective torques to control for perturbations. More challenging sensory deprivation conditions resulted in decreased variability of postural sway, higher amplitudes and more frequent correcting torques for stabilization, but age did not influence these behaviors.

1. Introduction

Linear descriptors for center of pressure (CoP) sway during standing balance have been extensively used to describe postural stability in children (Verbecque et al., 2016a) as the amount of variability around a central point, assuming its sway is a stationary signal. A previous study (Verbecque et al., 2016b) with typically developing children showed that the magnitude of postural sway distinguishes 5-year-olds from 3- and 4-year-olds regardless of the differences in the base of support because of growth. An unexpected result though was the increased sway variability found for the 5-year-olds when compared with the younger children, which could not be explained with the variables used. We previously suggested that this result may be associated with a person's ability to safely explore the limits of his or her base of support (Harbourne et al., 2009; Verbecque et al., 2016b), but this remains to be determined.

Researchers have clearly shown that CoP signals are non-random and contain an underlying structure that carries information (Stergiou and Decker, 2011). Furthermore, the notion that variability is a potential driving force for development (Geert and Dijk, 2002) implies that the presence of variability may not be synonymous with a dysfunctional system (Rhea et al., 2015) or lack of control, but rather as a sign of a highly adaptable system that has the capacity to change when required (Stergiou and Decker, 2011). For these reasons, estimating postural stability using metrics of nonlinear dynamics has been considered a more appropriate method for quantifying CoP sway variability and describing the time-evolving dynamics of the postural control system (Dusing, 2016; Harbourne et al., 2009; Ko and Newell, 2016). Thus the linear descriptors used in our previous study (Verbecque et al., 2016b) describe the amount of variability, but not the dynamics that regulate balance control. This motivated the present study.

Given the central importance of balance control, nonlinear descriptors of CoP variability in young children have helped to describe developmental trends in typical children and even to distinguish typical from atypical postural development. Lower values of the Lyapunov exponent and approximate entropy in children with developmental delay (Harbourne et al., 2009), of sample entropy in children with cerebral palsy (Donker et al., 2008) and lower values of multiscale entropy in children with Autism Spectrum Disorder (Fournier et al., 2014) have evidenced that sitting and standing associated with motor disabilities are characterized by a highly predictable CoP sway with a narrow range of behaviors (Stergiou et al., 2013). Accordingly, when compared with atypical groups, typically developing children show increased variability, and thus, less predictable CoP sway.

However, decreased values of approximate entropy were found as infants became more experienced in controlling their sitting posture (Harbourne et al., 2009; Harbourne and Stergiou, 2003). Similarly, decreased values of sample entropy were also found when 5-11-year-old children were asked to stand with eyes closed compared with eyes open (Donker et al., 2008), as well as after 6 weeks of balance training in healthy adults asked to stand on a foam surface (Strang et al., 2011). However the sway magnitude present in the cited studies either increased (Donker et al., 2008; Harbourne et al., 2009) or did not change (Strang et al., 2011), which indicates that postural sway became more regular with motor development, with restricted vision and after training, despite different changes in sway magnitude.

In addition, it would be interesting to understand the adaptive responses to perturbations and their relation to changes in CoP sway variability in young children. Because small threats to standing balance may be counterbalanced by ankle strategy (Horak and Nashner, 1986), a Sway Density Curve analysis of CoP sway (Jacono et al., 2004; Vieira et al., 2009) would provide information related to the process of generating sequences of corrective ankle torque commands.

Thus, to understand how individual characteristics and constraints of the task affect the dynamics of balance control in young children, the aim of the present study was to investigate how age and sensory deprivation affect the temporal organization of CoP sway variability and the postural corrective commands during standing balance in preschoolers aged 3–5 years. The hypotheses were as follows: 1) given their developmental status, five-year-old children present decreased CoP sway variability and need less corrective commands to control for postural instabilities; 2) under sensory deprivation, because some components required for having smooth balance control are absent, CoP sway variability increases, requiring more frequent corrective commands, and age affects these responses.

2. Methods

The present research was a cross-sectional study investigating standing balance under different sensory conditions in typically developing children aged 3–5 years. The nonlinear variability of CoP sway was computed using a Detrended Fluctuation Analysis (DFA) and Sample Entropy (SEn), while Sway Density Curve (SDC) parameters were computed to provide information regarding corrective torque commands.

2.1 Subjects and ethics statement

Seventy-nine preschool children participated in the current study, and their parents or guardians provided written consent. Before assessing postural sway, a questionnaire was completed by the parents to identify the presence of developmental problems, the use of orthoses and cochlear implants, or no interest in cooperation, which were all considered exclusion criteria. The children were grouped according to chronological age: 3, 4, and 5 years old. Data were collected in primary schools in Antwerp, Belgium between October 2013 and February 2014. Before starting, the study was approved by the ethical committee of the University of Antwerp (B300201316328).

2.2 Data collection

The participants stood barefoot on a force plate (0.4 x 0.5 m, 100 samples/s, model OR 6-5-2000, AMTI Inc., USA) for 40 seconds with a standardized distance of 10 cm between the medial borders of their feet. They were asked to keep both arms against their bodies. Postural sway was measured in four non-randomized test conditions: 1) EO: standing on a rigid surface with eyes open; 2) EC: standing on a rigid surface with eyes closed; 3) FEO: standing on a foam surface with eyes open; 4) FEC: standing on a foam surface with eyes closed. All children could rest between the trials. For both eyes-open conditions, the children were watching a movie projected with a 9.7-inch tablet that was positioned 1.5 m away, adjusted for the eye height of each child. More details about the foam's characteristics and inclusion and exclusion criteria were previously published (Verbecque et al., 2016b). Each child performed one successful trial in each condition. Failure to maintain balance for the 40 seconds in any one of the sensory conditions was defined as follows: 1) one of the child's feet lost contact with the force plate or foam; 2) the child's arms or head moved, indicating a loss of balance; 3) the child's eyes were not closed during the entire eyes-closed conditions; or 4) a lack of comprehension or cooperation. In these cases, the child could rest and then repeat the trial one more time or refrain from participation. All data were collected by the same researchers (EV, PHLC).

2.3 Data analysis

The entire temporal series were used to calculate SEn and DFA applied to the signals in the anterior-posterior (AP) and mediolateral (ML) directions. To calculate the sway density curve (SDC) parameters, the force platform data were filtered using a fourth-order zero-lag low-pass Butterworth filter with a cut-off frequency of 12.5 Hz, and the data's linear trend were removed by subtracting them from their mean.

The SDC analysis relies on the biomechanics of the inverted pendulum model, providing information related to the physiological process of generating sequences of ankle torque commands (Barbosa and Vieira, 2016; Jacono et al., 2004; Vieira et al., 2009). The SDC curve is defined as a time-dependent curve that counts the number of consecutive CoP samples falling within a circle that has a 2.5-mm radius centered at each CoP sample for each instant of time. The peaks of the resulting curve represent instants of momentary postural stabilization, while the valleys are related to shifts between stabilization events (Vieira et al., 2009).

SEn quantifies the regularity of a time series (Pincus and Goldberger, 1994) and is the negative natural logarithm of the conditional probability that a series of data points that repeats itself for m samples within a tolerance r will also repeat itself for m + 1 samples, without creating any self-matches (Ramdani et al., 2009). Lower SEn values indicate a more regular and predictable CoP time series, whereas higher values indicate a less predictable signal. SEn was calculated from the raw CoP time series using m (embedded dimension) = 2 and r (tolerance range) = 0.2 for AP and ML directions (Barbosa and Vieira, 2016).

DFA describes the presence of long-range correlations in a time series and is based on a classic root-mean square analysis of a random walk process; it numerically defines the scale-invariant structure in movement variability (Ihlen and Vereijken, 2013). In summary, the integrated time series of length N is divided into intervals of length t without overlapping, and its corresponding mean is subtracted. In each interval of length t, a least squares line fitted to the data is subtracted. The root-mean-squared fluctuation of this integrated and detrended time series is calculated. This computation is repeated for AP and ML directions over all interval sizes to characterize the relationship between F(t), the average fluctuation, and the interval size t. Intervals ranging from 12 to N/4 data points were used. The slope of the adjusted line of the plot log(F(t)) versus log(t) is the DFA coefficient (α). When the DFA coefficients (α) are > 0.5, they indicate a more structured signal with long-term correlations, and thus low variability. When $\alpha < 0.5$, the signal has negative correlations, and $\alpha = 0.5$ indicates a non-correlated random series (Barbosa and Vieira, 2016; Blázquez et al., 2009). Thus, both DFA and SEn represent non-linear variability measures of a CoP time series with opposed directionalities.

All variables were calculated using a custom-designed Matlab (version R2013a, The MathWorks Inc., USA) code (Barbosa and Vieira, 2016).

2.4 Variables of interest

The following SDC parameters were selected for analysis: MP, the mean peak amplitude, which is an estimate of the degree of the postural stability; MD, the mean distance between successive peaks, which corresponds to the amplitude of torque required for stabilization; MT, the mean time interval between successive peaks, which is related to the rate of torque production (Vieira et al., 2009). For SEn and DFA, the variables of interest were SEn and DFA_coefficient (α), respectively, in the AP and ML directions.

2.5 Statistical analysis

The data distribution for all variables was Gaussian (Shapiro-Wilk test, $p > 0.05$). A mixed repeated-measures analysis of variance (ANOVA) with three between-subject factors (age) and two (vision) vs. two (surface) as within-subject factors was conducted to detect the main effects of "age," "vision," "surface," and the interactions effects for all the variables. The homogeneity of the variance was tested using Levene's test. Post-hoc procedures of pairwise Gabriel's or Games-Howell's tests were conducted. Statistical significance was conducted as a two-tailed test and set at $p < 0.05$. SPSS Software (version 17, SPSS Inc., USA) was used. The effect sizes for the main effects were calculated using omega squared (ω^2), indicating a large effect size when ω^2 is above 0.5.

3. Results

After excluding data because of test failure, refusal to collaborate, and corrupted data, the mean results ± standard deviations of 57 typically developing children are presented (Table 1), which consists of 16 3-year-olds (42.3 ± 3.2 months-old; 0.93 ± 0.23 m height), 18 4-year-olds (52.4 ± 3.8 months-old; 1.07 ± 0.05 m height), and 23 5-year-olds (65.3 ± 3.6 months-old; 1.15 ± 0.05 m height).

Insert Table 1

The influence of tasks constraints on CoP sway is exemplified (Figure 1) for a 3-year-old child.

Insert Figure 1

3.1 The main effect of age

Significant main effects for “Age” were found for SEn_ap, SEn_ml, DFA_ap, and DFA_ml (Table 2). No age-related differences were found for the SDC variables. Post-hoc tests revealed that SEn_ap and SEn_ml were not statistically different for the 3- and 4-year-old children (p=0.96 for both variables) while SEn_ap and SEn_ml were significantly lower for the 5- than 4-year-old children (p=0.02 for both variables). DFA_ap was significantly higher for the 5-year-old children than for the 3- (p=0.02) and 4-year-olds (p=0.02); DFA_ml was also higher for the 5-year-old children than for the 3- (p=0.02) and 4-year-olds (p=0.03). Low effect sizes were found for SEn and DFA, ranging from 0.29 to 0.31 (Table 2). SEn decreased, and DFA increased as age increased, while the SDC variables remained unaltered among the 3-, 4-, and 5-year-old children.

Insert Table 2

3.2 Main effect of vision

SEn_ap, SEn_ml, MT, and MP significantly decreased with vision deprivation, while DFA_ap and MD increased. No significant vision effect was found for DFA_ml. Low to high effect sizes were found, ranging from 0.30 to 0.72 (Table 3).

Insert Table 3

3.3 Main effect of surface

All variables were significantly affected by the altered somatosensory information provided by the foam surface. SEn_ap, SEn_ml, MT and MP significantly decreased, while DFA_ap, DFA_ml, and MD increased when standing on the compliant surface compared with the rigid one. Effect sizes were modest to high, ranging from 0.42 to 0.86 (Table 4).

Insert Table 4

3.3 Interaction effects

No interaction effects were found between vision and age or surface and age (Table 5). However, significant interaction effects between vision and surface were found for SEn, DFA and MT. SEn and MT significantly decreased, and DFA increased when the children were standing on foam with eyes closed, whereas vision deprivation produced no significant differences for these variables when the children were standing on the rigid surface.

Insert Table 5

4. Discussion

The goal of the current study was to examine age-related changes and the effects of sensory deprivation on postural sway variability and corrective torque commands among preschoolers. The main findings are as follows: 1) 5-year-old children showed decreased variability and more regular CoP sway than the 3- and 4-year-olds; 2) postural corrective commands regarding ankle torques were the same for 3-, 4- and 5-year-old children; 3) as the sensory conditions became more challenging, variability decreased and more corrective torque commands were necessary, but age did not influence this behavior. These results will be discussed below.

4.1- Older children showed decreased variability of CoP sway

In the present study, the variability of CoP sway decreased for the 5-year-old children when compared to 3- and 4-year-old children, as shown by the lower SEn and higher DFA values. These results indicate that 3- and 4-year-old children present a more irregular and unpredictable, along with less auto-correlated postural sway, than 5-year-old children (Tables 1 and 2). This increased variability of the younger children may reflect the need to explore a large number of strategies (Murillo et al., 2017; Wu et al., 2014) in an unpredictable manner (Dusing, 2016) to provide augmented information that can drive the postural system to the emergence of a new behavioral state. By these means, younger children may be flexible and improve the functional role of variability as a learning facilitator (Murillo et al., 2017; Wu et al., 2014).

On the other hand, decreased variability and higher auto-correlated CoP sway for the 5-year-old children may reflect their ability to dynamically assemble strategies in a more repeatable way (Harbourne et al., 2009), thus showing they have a more regular and structured solution to postural control. These children respond more appropriately to instabilities, because successive CoP positions relate to previous positions and, hence, the correlation is strong, increasing regularity (Bruijn et al., 2013).

An optimal state of variability may be the goal of a healthy postural control system (Stergiou et al., 2013; Stergiou and Decker, 2011); however, when achieved in the development of young children, it can only be confirmed with longitudinally-designed studies.

Based on a previous study (Verbecque et al., 2016b) the participants of the current study were grouped according to their chronological ages. Thus age-related changes may be interpreted with caution, because motor developmental levels may bias the age categorization. Indeed, the between-groups design reveals that the CoP sway variability of 3- and 4-year-old children have a similar time structure and may constitute the same developmental category when compared with the 5-year-olds.

4.2- Corrective commands were the same for 3-, 4-, and 5-year-old children

Similar studies could not be found in the literature, thus the current study may be the first to use SDC descriptors to investigate ankle torque commands in young children.

It was expected that as age increases, MD would decrease meaning lower torque amplitudes and less postural activity would be needed to correct for CoP sway, and MT and MP would increase meaning lower rates of torque production and higher degrees of postural stability, respectively. However, no age-related changes were found for these descriptors (Table 2). These findings indicate that 3-5-year-old children use the same corrective commands regarding ankle torques to stabilize their standing balance.

It is known that sway around the ankle is already present in 10-month-old infants (Roncesvalles et al., 2004). However, larger threats to standing balance, such as standing on foam with eyes closed, require trunk flexion or hip strategy (Horak and Nashner, 1986), which is limited in younger children because of their small stature and limitations in the ability of their muscles to produce faster responses (Sundermier et al., 2001). Active hip strategies, involving the activation of quadriceps and abdominal muscles, begin to predominate at about the age of 5 years and continue until ages 7 to 10 years (Roncesvalles et al., 2004). Thus, it seems that a muscle-controlled hip strategy is still developing in children aged 3 to 5 years. However, the reliability of the SDC parameters in children still needs to be tested to confirm the meaning of these results. Additionally, only electromyographic studies could clarify this issue and identify when important developmental transitions in postural synergies are made.

4.3- As sensory conditions became more challenging, more corrective commands were necessary and variability of CoP sway decreased

All the variables were sensitive to the different sensorial conditions tested, as reflected by the larger effect sizes. As the sensory conditions became more challenging, MT and MP decreased, indicating higher rates of torque production and lower level of postural stabilization; at the same time, MD increased, meaning that higher amplitudes of postural commands were present to correct for CoP sway when the children's eyes were closed while standing on foam. Additionally, variability of CoP sway decreased, as defined by lower values of SEn and higher values for DFA, indications of a more predictable and regular postural response.

The presence of a decreased variability CoP of sway under deprivation of vision or altered somatosensory information (Tables 3 and 4) may have been necessary for all children to offset any external perturbations by means of increasing the amount of attention shift to regulate standing balance in these conditions. This attention shift may have allowed the children to choose a reference frame to recalibrate and fine-tune the sensorial information available, thus letting them properly react to the environment. Additionally, these results indicate that task constraints reshape the structure of variability, and the required adjustments to accomplish the more difficult postural tasks may have been achieved by means of exploiting the available solutions when precision was crucial (Wu et al., 2014). However, increased age did not influence the responses to sensory deprivation (Table 5).

Regarding the results on "surface versus vision" interactions (Table 5), on the rigid surface, variability of CoP sway and corrective torque commands were similar for the eyes-open and eyes-closed conditions, probably because the children were watching the video while standing. According to evidence that eye movements are linked to postural control, visual pursuit and target fixation are considered attention-tasks that decrease postural stability (Bucci et al., 2015). Although head movements could not be detected because of the small tablet screen, the cartoon being watched may have stimulated the children enough to focus their attention on following the video and performing gaze shifts in the eyes-open conditions instead of controlling their standing, especially when support was not a problem (standing on the rigid surface). However, problems in sharing attention capabilities may have emerged for all children in the present study, and a condition that did not involve following a video was not tested to account for this confounding effect. In fact, following the cartoon may have demanded extra attention from all children, but the postural sway of the older children was more regular and predictable.

Thus, the hypotheses were in part confirmed: 5-year-old children indeed presented decreased variability of CoP sway compared with 3- and 4-year-olds, but all children used the same corrective torque commands to control instabilities. However, sensorial deprivation also resulted in decreased variability CoP sway and more frequent corrective commands.

The results may have been influenced by important limiting factors: a) the lack of randomization of the test conditions could have systematically induced fatigue in the more difficult task (standing on foam with eyes closed) and a trend in the variable values according to the order of the experimental condition; b) following the video cartoon for 40 seconds may have distracted the children from properly selecting the cues to help regulate posture; and c) no electromyography methods were used to identify postural muscle synergies.

5. Conclusion

In conclusion, 5-year-old children showed decreased variability of CoP sway during standing balance compared with the younger children, but all children used the same corrective torques to control for perturbations. More challenging sensory deprivation conditions resulted in decreased variability of postural sway, higher amplitudes and more frequent correcting torques for stabilization, but age did not influence these behaviors.

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Conflict of interest statement: The authors confirm that there are no known conflicts of interest associated with this publication.

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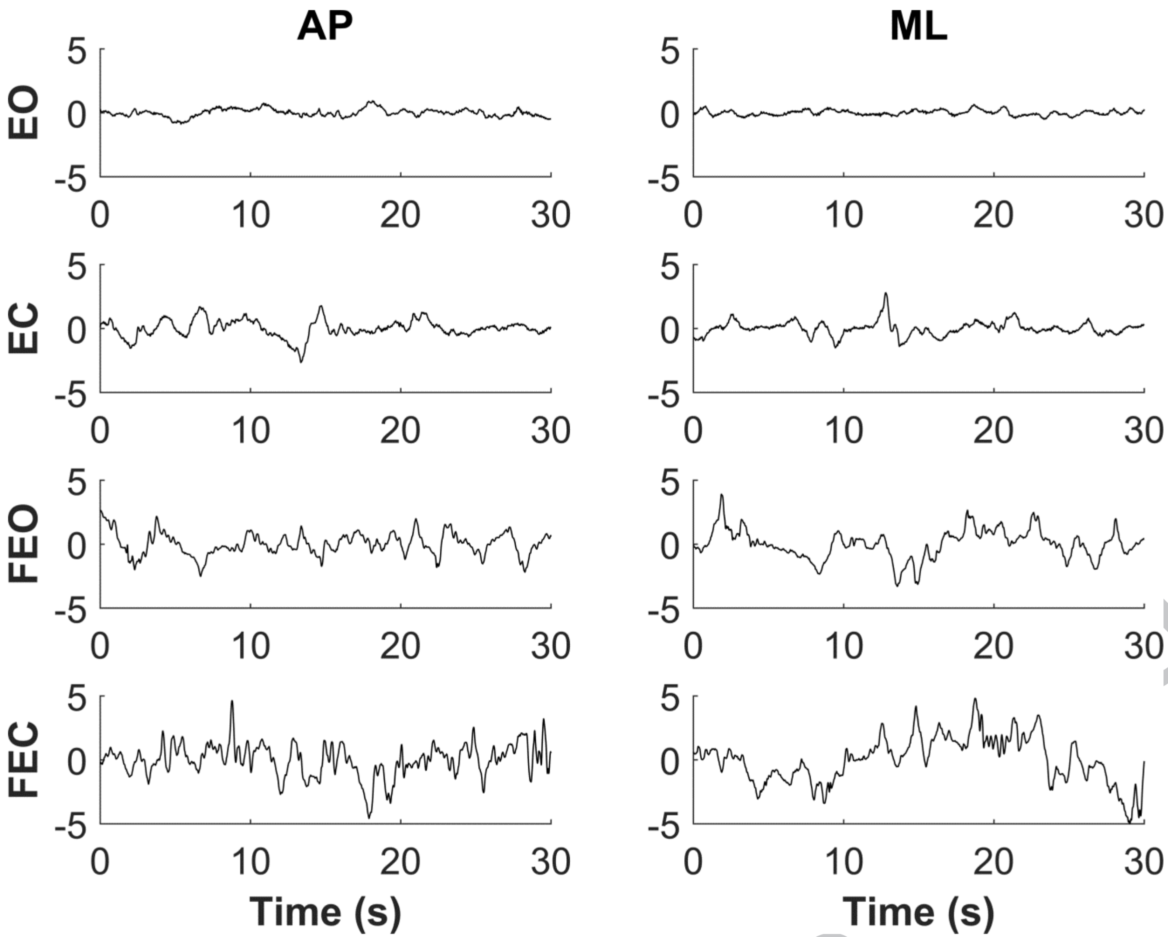
Descriptive captions for the Figure 1:

Figure 1 - Typical CoP sway (cm) in the anterior-posterior (AP) and medial-lateral (ML) directions for each condition: eyes open on firm surface (EO), eyes closed on firm surface (EC), eyes open on foam surface (FEO) and eyes closed on foam surface (FEC) (subject #12). The effects of vision and surface on the magnitude of CoP sway are well observable.


AP
ML
EO
EC
FEO
FEC
5
0
-5
0
10
20
30
Time (s)

Descriptive captions for the Tables and Legends:

Table 1: Means and standard deviations for all variables and conditions. 3-year-olds (n =16), 4- year-olds (n = 18), and 5-year-olds (n = 23).

Legend 1: 3-year-old children (3 y.o.), 4-year-old children (4 y.o.), 5-year-old children (5 y.o.). EO (Rigid_Eyes Open), EC (Rigid_Eyes Closed), FEO (Foam_Eyes Open), FEC (Foam_Eyes Closed). SEn_ap and SEn_ml, DFA_ap and DFA_ml in anterior-posterior and mediolateral directions; MT (mean time interval between successive peaks), MD (mean distance between successive peaks), and MP (mean peak amplitude).

Table 2: Entropy, DFA, and SDC of postural sway depicting the main effects of age (between subject factor, three levels: 3-, 4- and 5-year-old children) on mean SEn_ap, SEn_ml, DFA_ap, DFA_ml, MT, MD, and MP for all children.

Legend 2: Post-hoc tests for p≤0.05: (#) 3-year-old children ≠ 4-year-old children; (*) 3-year-old children ≠ 5-year-old children for p≤ 0.05; (+) 4-year-old children ≠ 5-year-old children.

Table 3: Entropy, DFA, and SDC of postural sway depicting the main effects of vision (within-subject factors, two levels: eyes open, eyes closed) on mean SEn_ap, SEn_ml, DFA_ap, DFA_ml, MT, MD, and MP for all children.

Table 4: Entropy, DFA, and SDC of postural sway depicting the main effects of surface (within-subject factors, two levels: rigid, foam) on mean SEn_ap, SEn_ml, DFA_ap, DFA_ml, MT, MD, and MP for all children.

Table 5: Interaction effects for “Age x Vision,” “Age x Surface,” “Age x Vision x Surface,” and “Vision x Surface” on mean SEn_ap, SEn_ml, DFA_ap, DFA_ml, MT, MD, and MP for all children.

Table 1:

	EO			*EC*			*FEO*			*FEC*		
	3 y.o.	4 y.o.	5 y.o.	3 y.o.	4 y.o.	5 y.o.	3 y.o.	4 y.o.	5 y.o.	3 y.o.	4 y.o.	5 y.o.
SEn_ap	0.79 (±0.29)	0.92 (±0.25)	0.62 (±0.30)	0.75 (±0.24)	0.79 (±0.22)	0.65 (±0.25)	0.62 (±0.21)	0.56 (±0.24)	0.46 (±0.20)	0.41 (±0.12)	0.41 (±0.13)	0.32 (±0.12)
SEn_ml	0.82 (±0.38)	0.83 (±0.31)	0.63 (±0.30)	0.78 (±0.37)	0.93 (±0.34)	0.60 (±0.27)	0.58 (±0.17)	0.54 (±0.27)	0.41 (±0.20)	0.40 (±0.14)	0.38 (±0.14)	0.29 (±0.13)
DFA_ap	0.34 (±0.08)	0.33 (±0.06)	0.42 (±0.1)	0.36 (±0.09)	0.35 (±0.06)	0.40 (±0.08)	0.42 (±0.07)	0.44 (±0.09)	0.46 (±0.09)	0.47 (±0.05)	0.47 (±0.06)	0.52 (±0.07)
DFA_ml	0.34 (±0.12)	0.35 (±0.11)	0.41 (±0.08)	0.34 (±0.13)	0.30 (±0.09)	0.41 (±0.09)	0.46 (±0.07)	0.48 (±0.09)	0.50 (±0.08)	0.49 (±0.07)	0.52 (±0.07)	0.58 (±0.08)
MT (s)	0.62 (±0.04)	0.63 (±0.04)	0.62 (±0.04)	0.60 (±0.04)	0.61 (±0.03)	0.63 (±0.03)	0.61 (±0.04)	0.64 (±0.06)	0.62 (0.04)	0.60 (±0.03)	0.58 (±0.03)	0.58 (±0.03)
MD (mm)	8.08 (±3.37)	6.64 (±2.42)	8.66 (±5.08)	9.82 (±4.33)	7.52 (±2.79)	8.33 (±3.11)	12.23 (±4.76)	11.37 (±3.19)	13.30 (±6.89)	16.39 (±3.91)	15.80 (±4.14)	17.94 (±5.30)
MP (s)	0.48 (±0.19)	0.58 (±0.13)	0.52 (±0.16)	0.40 (±0.20)	0.47 (0.14)	0.49 (±0.19)	0.35 (±0.09)	0.37 (±0.09)	0.36 (±0.12)	0.26 (±0.06)	0.25 (0.06)	0.24 (±0.07)

Table 2:

Main effect: AGE						
	3 y.o.	**4 y.o.**	**5 y.o.**			
	mean	mean	mean	F(2,54)	p-value	Effect size (ω^2)
SEn_ap	0.64	0.67+	0.51+	4.59	0.01	0.28
SEn_ml	0.63	0.66+	0.48+	4.94	0.01	0.29
DFA_ap	0.40*	0.40+	0.45*+	5.56	<0.01	0.31
DFA_ml	0.41*	0.41+	0.47*+	5.30	<0.01	0.30
MT (s)	0.61	0.61	0.61	0.55	0.58	0.10
MD (mm)	12.57	10.33	12.06	1.57	0.22	0.17
MP (s)	0.37	0.42	0.40	0.89	0.42	0.13

Table 3:

Main Effect: VISION					
	Eyes Open	**Eyes Closed**			
	mean	mean	F(1,54)	p-value	Effect size (ω^2)
SEn_ap	0.66	0.55	20.86	<0.01	0.54
SEn_ml	0.62	0.56	5.14	0.03	0.30
DFA_ap	0.40	0.43	15.05	<0.01	0.47
DFA_ml	0.42	0.44	1.61	0.21	0.17
MT (s)	0.62	0.60	21.75	<0.01	0.54
MD (mm)	10.05	13.26	17.28	<0.01	0.49
MP (s)	0.44	0.35	56.99	<0.01	0.72

Table 4

Main Effect: SURFACE					
	Rigid	**Foam**			
	mean	mean	F(1,54)	p-value	Effect size (ω^2)
SEn_ap	0.75	0.46	130.27	<0.01	0.84
SEn_ml	0.76	0.42	112.11	<0.01	0.82
DFA_ap	0.37	0.46	78.9	<0.01	0.77
DFA_ml	0.36	0.50	154.10	<0.01	0.86
MT (s)	0.62	0.60	11.43	<0.01	0.42
MD (mm)	8.80	14.50	59.77	<0.01	0.72
MP (s)	0.49	0.30	110.69	<0.01	0.82

Table 5:

	Age X Vision		Age X Surface		Age X Vision X Surface		Vision X Surface	
	F(2,54)	p-value	F(2,54)	p-value	F(2,54)	p-value	F(1,49)	p-value
SEn_ap	1.65	0.20	2.59	0.08	3.41	0.04	17.98	<0.01
SEn_ml	0.52	0.59	2.42	0.10	1.15	0.32	9.77	<0.01
DFA_ap	0.42	0.66	0.85	0.43	3.18	0.05	13.5	<0.01
DFA_ml	0.85	0.43	2.16	0.12	1.04	0.36	12.98	<0.01
MT	2.34	0.11	1.42	0.25	1.77	0.18	8.37	<0.01
MD	1.07	0.35	2.22	1.12	1.78	0.18	2.90	0.09
MP	1.25	0.29	1.96	0.15	1.85	0.17	4.05	0.05