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Effect of whole-body vibration on center-of-mass movement during standing in children and young adults

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Abstract

Whole body vibration (WBV) can affect postural control and muscular activation. The purpose of this study was to investigate the center-of-mass (COM) movement of children and young adults before, during, immediately after, and 5 minutes after 40-second WBV in quiet standing. Fourteen young adults (mean age 24.5 years) and fourteen children (mean age 8.1 years) participated in the study. A full-body 35-marker set was placed on the participants and used to calculate COM. Forty-second standing trials were collected before, during, immediately after, and 5 minutes after WBV with an frequency of 28Hz and an amplitude of <1mm. Two visual conditions were provided: eyes-open (EO) and eyes-closed (EC). COM variables included time-domain measures (average velocity, range, sway area and fractal dimension), frequency-domain measures (total power and median frequency), and detrended fluctuation analysis (DFA) scaling exponent in both anterior-posterior (AP) and medial-lateral (ML) directions. Results show that during WBV both children and adults increased average velocity and median frequency, but decreased range and the DFA scaling exponent. Immediately after WBV both groups increased the range, but showed pre-vibration values for most of the COM variables. Comparing to adults, children displayed a higher COM velocity, range, fractal dimension, and total power, but a lower DFA scaling exponent at all phases. The results suggest that both children and adults can quickly adapt their postural control system to WBV and maintain balance during and after vibration. Children display some adult-like postural control during and after WBV; however, their postural development continues into adolescence.

Keywords: Balance; time domain analysis; frequency domain analysis; detrended fluctuation analysis; long-range correlation.

1. Introduction

A short exposure of whole-body vibration (WBV) has been shown to increase lower leg muscle activity [1, 2] and peak torque [3] in young adults. Immediately after 4-minute WBV with an amplitude of 2 mm and an individualized frequency at 30-50 Hz, young adults were found to increase center of pressure (COP) velocity and excursion during standing [4]. Also, median frequency of the COP was found to increase immediately after the vibration but return to its baseline level 10 minutes after the vibration [5]. It was suggested that cutaneous receptors under the feet may become less active during vibration and experience a residual effect of reduced activity for about 15 minutes after vibration [6-8]. Furthermore, the vibration transmitted to the muscles and tendons of the lower extremities can activate muscle spindles and elicit a tonic vibration reflex [9, 10]. This reflex contraction together with reduced sensitivity in cutaneous receptors may change the sensory integration in the central nervous system [6, 10], resulting in increased postural sway after vibration.

Compared to the number of studies investigating postural control after WBV, little is known on postural sway during vibration. One reason is that most studies used a force plate to collect COP, which is unavailable while standing on a WBV platform. An alternative method is to collect center-of-mass (COM) data with a motion capture system. The COM has been found to be reliable in quantifying postural sway in standing tasks [11]. However, few studies have examined the COM movement before and after WBV [4, 7] in young adults, and none during WBV in both children and adults. In addition, young adults usually increase the COP range and area when closing their eyes during quiet standing [12]. In contrary, children do not achieve the adult-like visual function until the age of 15 years [13]. Previous postural studies manipulated various visual conditions during and after WBV in young adults [4, 5, 7, 8]. However, no study has examined both the visual and WBV effects on postural control in children.

When analyzing the COP/COM data, time-domain variables such as average velocity, range and sway area are usually reported to quantify the spatiotemporal characteristics [12]. Fractal dimension is another common variable, measuring the extent to which the COP/COM excursion fits the limiting area of its sway. Fractal dimension is considered to quantify the complexity of the COP/COM time series [12] and helps estimate instability in balance [14, 15] and the severity of injuries or diseases [14, 16]. Furthermore, frequency domain analysis is often used to examine the frequency characteristics of postural sway and assess the relative contributions of different sensory systems [17]. For instance, mean frequency of the COM was found to match that of soleus and gastrocnemius activation in young adults during quiet standing, whereas children displayed a higher mean frequency of the COM possibly due to different inertial properties of body segments and/or motor control strategies [18]. Additionally, nonlinear analysis such as detrended fluctuation analysis (DFA) has been applied on biological time series [19, 20] to assess the long-range correlation embedded in the data. The DFA scaling exponent estimates the correlation in which current COP/COM movement is affected by previous movements [21]. Young adults typically display the scaling exponent of the COP data between 1.0 and 1. 5 during quiet standing, demonstrating a persistence feature of postural control [21, 22]. A lower scaling exponent in that range implies a more direction-changing postural sway and a lesser persistent feature [20].

The purpose of this study was to investigate the effect of a short exposure of WBV on the COM movement before, during, immediately after, and 5 minutes after WBV in children aged 5-11 years and young adults. Our first hypothesis was that both children and adults would increase average velocity, fractal dimension and mean frequency, but decrease the range, sway area and DFA scaling exponent during WBV. Regarding the immediate and residual effects of WBV, our second hypothesis was that COM variables for both children and adults would maintain their values immediately after WBV but return to the baseline level 5 minutes after vibration. As children still are developing their postural control until adolescence [23], our third hypothesis was that children would exhibit higher values in time- and frequency-domain variables but a lower DFA scaling exponent than adults before, during, and after WBV.

2. Methods

2.1. Participants

Fourteen healthy young adults (6M/8F) and fourteen typically developing children (6M/8F) participated in this study (Table 1). This study was approved by the hosting university's institutional review board. We obtained a signed consent form from each adult participant, and a signed permission form from the parent and a verbal assent from each child participant.

2.2. Data collection

All participants came to the laboratory for one session. A 35-marker Vicon full-body plug-in-gait model [24, 25] was used to attach reflective markers to the participant's bone landmarks. An 8-camera MX T10 Vicon motion capture system (Vicon, Centennial, CO) was used to record the reflective markers at a sampling rate of 100Hz before, during and after WBV. A Soloflex WBV platform (Soloflex, Hillsboro, OR) was used to provide synchronous WBV with vertical amplitude of less than 1mm. Subjects stood on an AMTI Optima force plate (AMTI, Watertown, MA) before and after WBV and the COP data were collected but not presented here due to the primary focus of this study.

Participants stood barefoot as still as possible with feet hip width apart and hands on the hips. In each condition, four 40-second trials [26, 27] were collected: before vibration (*Pre*), during vibration (*Vib*), immediately after vibration (*Post_0*), and 5 minutes after vibration (*Post_5*). Participants were asked to sit down and rest between phases *Post_0* and *Post_5* to assess the residual effect of the vibration.

There were two visual conditions: eyes-open (EO) and eyes-closed (EC). Each visual condition was repeated twice for the adults, but was tested only once for children to minimize boredom and fatigue. Our preliminary results demonstrated consistency in adults between the two repetitions of each visual condition. Therefore, an average of two repetitions in each visual condition was used in adults for further analysis. There were two vibration conditions: 28 Hz and 40 Hz. The frequency of 28 Hz elicited about 0.4*g* vertical acceleration consistently in both groups, which was assessed with a reflective marker placed on the platform. However, the 40-Hz vibration did not elicit acceleration different from that of 28 Hz in children, and was thus determined unreliable and excluded from further data analysis. The order of the visual and vibration conditions was randomized across participants and adequate rest was provided between conditions.

2.3. Data analysis

The trajectories of the markers were processed through a Butterworth low-pass filter with a cut-off frequency of 6 Hz [28], and then a COM marker was generated in Vicon Nexus [25]. The anterior-posterior (AP) and medial-lateral (ML) time series of the COM data were exported from Vicon Nexus, and the means were removed for further calculation [12]. A custom-written MATLAB program (Mathworks, Natick, MA) was used to calculate all the COM variables. During standing, some children occasionally swung unexpectedly or moved their arms towards the end of a trial due to boredom. Several seconds of these trials were removed for less than 20% of the total trials in children and only ten trials were less than 35-second long.

2.3.1 Time domain analysis

Average velocity and range of COM movement were calculated in the AP and ML directions, separately. Average velocity was the total COM excursion divided by time. Range was the largest distance between any two points. Also, 95% confidence ellipse area was calculated as an elliptical area enclosing 95% of the COM trajectory combining the AP and ML directions (see Appendix). Average velocity and range were normalized by the participant's height, and 95% confidence ellipse area was normalized by the height squared. In addition, fractal dimension was calculated as the degree to which the COM trajectory fit the metric space that it encompassed (see Appendix). It usually has a value between 1 and 2 and a higher value suggests an increased tendency of postural instability [15].

2.3.2 Frequency domain analysis

The COM time series were transformed into power spectral density using a fast Fourier transform (FFT) algorithm in MATLAB [28] for the AP and ML time series, separately. Total power was the integrated area of the power spectrum. Median frequency was the frequency below which 50% of the total power was found.

2.3.3 Detrended fluctuation analysis

The scaling exponent α was calculated separately for the AP and ML time series [21]. The COM time series was first divided into consecutive intervals of length d and a regression line was calculated at each interval. Then, the COM data were detrended by subtracting the theoretical value $X_d[n]$ given by the regression from its original value $X[n]$. For a given interval length d, the size of fluctuation was calculated as:

$$F(d) = \sqrt{1/d \sum [X[n] - X_d[n]]^2} ,$$

The above computation was repeated for intervals from 10 to N/2. Normally, the F(d) value increases with interval length, and a power law is expected as:

$$F(d) = ad^{\alpha} ,$$

where a is a constant. The scaling exponent α indicates the long-range correlation of the original time series [20]. Scaling exponent α greater than 1 implies non-stationary and persistent series with α=1.0 representing a 1/f noise and α=1.5 representing a Brownian motion. A lower scaling exponent α denotes more roughness of the motion signal.

2.4. Statistical Analysis

A series of three-way mixed ANOVAs (2 group × 2 visual × 4 phase) with repeated measures on the last two factors were conducted for statistical analysis. Dependent variables included: (1) time-domain measures including normalized average velocity, range, 95% confidence ellipse area and fractal dimension; (2) frequency-domain measures including total power and median frequency; and (3) DFA scaling exponent α. Post-hoc pairwise comparisons with Bonferroni adjustments were conducted when appropriate. SAS 9.4 software (SAS, Cary, NC) was used to conduct statistical analysis. A significant level was set at alpha=0.05.

3. Results

3.1. Time domain analysis

The children group displayed a faster COM average velocity but a different trend across phases compared to the adult group (Table 2). There was a group by phase interaction in both AP (p=0.020) and ML (p=0.040) directions. In the AP direction, both groups increased average velocity from *Pre* to *Vib,* and then reduced to *Pre* level at both *Post_0* and *Post_5*. However, children had a greater increase in velocity from *Pre* to *Vib* than adults. In the ML direction, while adults maintained COM velocity across the phases, children increased velocity from *Pre* to *Vib* and then reduced to *Pre* level only at *Post_5*. Both groups also showed a greater velocity in the EC than in the EO condition (visual effect, p=0.031).

The children group showed a larger COM range but a different trend across phases compared to the adult group (Table 2). In the AP direction, both groups displayed a trend such that range at *Vib* was smaller than that at both *Post_0* and *Post_5* (group effect, p<0.001; phase effect, p=0.018). In the ML direction, a group by phase interaction was found (p=0.001) such that while adults maintained their range across phases, children had a greater range at *Post_0* compared to the other three phases.

The children group displayed a greater 95% confidence ellipse area but a different trend across phases compared to the adult group, (Table 2). There was a group by phase interaction (p=0.003) such that while adults maintained the area across phases, children decreased the area from *Pre* to *Vib*, increased it to above *Pre* level at *Post_0*, and reduced it to *Pre* level at *Post_5*. Also, both groups showed a similar fractal dimension at each phase and increased it from *Pre* to *Vib* and then returned to *Pre* level at both *Post_0* and *Post_5* (phase effect, p<0.001).

3.2. Frequency domain analysis

The children group showed a larger total power but a different trend across phases compared to the adult group (Table 3). In the AP direction, both groups maintained their total power across all phases (group effect, $p<0.001$). In the ML direction, there was a group by phase interaction ($p=0.009$) such that while adults maintained their total power across phases, children showed a larger total power at *Post_0* than the other three phases.

Both groups showed a similar trend in both directions such that median frequency increased from *Pre* to *Vib*, and then returned to *Pre* level at *Post_0* and *Post_5*. There was a group by phase interaction ($p=0.002$) showing that children exhibited a higher median frequency than adults only during *Vib* in the AP direction. Also, both groups displayed a higher median frequency at EC compared to the EO condition in both AP and ML directions (visual effect, $p<0.05$).

3.3. DFA method

Scaling exponent α was mostly in the range of 1.0-1.5 across conditions and was generally smaller in children than in adults (Figure 1). In the AP direction, both groups decreased scaling exponent from *Pre* to *Vib* and returned to *Pre* level only at *Post_5* (phase effect, $p<0.001$). A group by visual interaction ($p=0.032$) revealed that only adults displayed a smaller scaling exponent value at EC than EO condition. In the ML direction, both groups decreased scaling exponent from *Pre* to *Vib* and returned to *Pre* level at *Post_0* and *Post_5* (phase effect, $p<0.001$). Moreover, both groups showed a smaller scaling exponent value at EC compared to EO condition (visual effect, $p=0.037$).

4. Discussion

The generally increased COM velocity, fractal dimension and mean frequency, and decreased range, sway area and DFA scaling exponent during WBV in children and to a lesser extent in adults mostly supports our first hypothesis. It suggested that both children and adults may have to constrain their range of sway during vibration disturbance, but sway at a faster COM velocity and a more direction-changing trajectory. In the frequency domain, both children and adults increased median frequency of the COM and probably recruited additional sensory receptors and/or modified sensory integration to accommodate vibration disturbance. In terms of fractal geometry and long-range correlation, both children and adults increased roughness of the COM trajectory with a higher fractal dimension and a lower DFA scaling exponent during WBV. The vibration basically elicited less persistent COM movements, i.e., a higher probability of changing its movement direction at each time increment [20, 21].

Our second hypothesis was partially supported by the results that both children and adults somewhat increased the COM range immediately after WBV, but showed *Pre*-level values for most of the variables immediately (*Post_0)* and 5-minute after vibration (*Post_5*). This suggested that both children and adults can modify postural sway characteristics to adapt to 40-second WBV (28 Hz and <1 mm amplitude) and maintain balance. Moreover, both children and adults quickly re-calibrated their postural control system to the *Pre*-level when the vibration was terminated. However, our results disagree with previous studies [4, 8], which showed an immediate, and a residual effect of WBV (10-20 minutes) on postural control variables. This discrepancy may be due to a longer WBV duration and a higher frequency and amplitude [4], as well as challenging standing tasks [8] in other studies.

Our third hypothesis was mostly supported by the results that the children group displayed a higher COM velocity, range, sway area, fractal dimension, and total power, but a lower DFA scaling exponent than adults at all phases. Our *Pre*-vibration results are consistent with previous findings from quiet standing in children [18, 29], suggesting that children aged 5-11 years have not achieved adult-like balance control ability during quiet standing. During WBV, our children group followed the adult-like trend in manipulating the COM variables primarily in the AP direction, but not in the ML direction. This implies that the development of postural control in children may not occur in both AP and ML directions at the same time; rather, balance control in the AP direction may be prioritized. Furthermore, the results of the DFA scaling exponent demonstrated that the adult exponent value was close to 1.5 (Brownian motion) while the children exponent value was lower than 1.5 but still markedly higher than 1.0 ($1/f$ noise). Our results suggest that children displayed more frequent corrections of COM movement, causing a more fractal geometrical structure in the COM trajectory. Furthermore, in contrary to our hypothesis and previous studies [18, 28], our children group did not show a higher median frequency than adults except during vibration in the AP direction. This suggests that children aged 5-11 years may have developed somewhat adult-like sensory contribution and integration [30] for quiet standing but not for WBV disturbance.

Our results demonstrated a visual effect of WBV on frequency-domain and DFA variables, but not on time-domain measures in both children and adults. This suggests that both frequency-domain analysis and DFA may be more sensitive to the removal of visual input. Further, compared to fractal dimension, the DFA scaling exponent showed a significant group and/or visual effect. This suggests that this DFA variable may be more sensitive than fractal dimension and shall be included in future postural studies with WBV. In addition, a different posture was often observed in children in the EC condition such that they flexed the knees and trunk more, particularly during WBV. This change in posture may warrant further research on joint angles and muscle activation to explore the kinematic and neuromuscular mechanisms while adapting to WBV. One limitation of this study was the intensity and duration of WBV. WBV of 0.4*g* used in this study was considerably lower than that of previous studies and might not elicit substantial biomechanical and neuromuscular modifications. Furthermore, 40-second WBV may not be long enough to accumulate WBV effect on the postural control system. However, our selection of WBV intensity and duration was mainly to accommodate children and minimize boredom and maximize compliance. Future studies may use an alternating instead of a synchronous WBV with a higher amplitude and frequency to further examine the effects of WBV in children.

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Appendix:

(1) 95% confidence ellipse area [12]:

$\text{Area} = \pi ab$

where radii for the ellipse, major *a* and minor *b* are:

$$a = [F_{0.05[2,n-2]}(S_{AP}^2 + S_{ML}^2 + D)]^{1/2}$$

$$b = [F_{0.05[2,n-2]}(S_{AP}^2 + S_{ML}^2 - D)]^{1/2}$$

$$D = [(S_{AP}^2 + S_{ML}^2) - 4(S_{AP}^2 S_{ML}^2 – S_{APML}^2)]^{1/2}$$

where $F_{0.05[2,n-2]}$ is the *F* distribution for a bivariate data with *n* points. For a large sample size (n>120) and at a 95% confidence level, $F_{0.05[2,\infty]}$ is 3.00. S_{AP} and S_{ML} are the standard deviations of AP and ML time series respectively. S_{APML} is the covariance:

$$S_{APML} = 1/N \sum AP[n]ML[n]$$

So the calculation of Area can be reduced as:

$$\text{Area} = \pi ab = 2\pi F_{0.05[2,n-2]}[S_{AP}^2 S_{ML}^2 – S_{APML}^2]^{1/2}$$

(2) Fractal dimension [12]:

$$FD = \log(N) / \log(Nd / \text{Excursion});$$

where N is the number of data points and *d* is the diameter of the 95% confidence ellipse area enclosed:

$$d = [2a\ 2b]^{1/2} = [8 F_{.05[2,n-2]}(S_{AP}^2 S_{ML}^2 – S_{APML}^2]^{1/2}$$

Table 1: Mean (SD) of physical characteristics of the participants

Group	Gender	Age (years)	Height (m)	Body mass (kg)
YA	6M / 8F	24.5 (3.9)	1.68 (0.12)	70.6 (13.4)
TD	6M / 8F	8.1 (1.8)	1.32 (0.10)	30.2 (6.7)

Table 2: Mean (SD) of the COM variables in the time domain

Variable	Group	EO				EC				Statistics Results
		Pre	Vib	Post_0	Post_5	Pre	Vib	Post_0	Post_5	
Velocity-AP (mm/m/s)	YA	2.57 (0.52)	4.16 (1.21)	2.74 (0.59)	2.78 (0.57)	2.78 (0.51)	4.72 (0.79)	3.06 (0.84)	3.05 (0.77)	G*P: F(3,78) = 3.48, $p = 0.020$ G: F(1,26) = 27.91, $p < 0.001$ P: F(3,78) = 25.15, $p < 0.001$
	TD	8.34 (5.19)	11.76 (6.11)	8.53 (5.75)	8.27 (4.65)	8.10 (3.10)	12.24 (5.74)	8.94 (4.90)	7.44 (2.87)	
Velocity-ML (mm/m/s)	YA	1.50 (0.19)	1.79 (0.20)	1.56 (0.31)	1.65 (0.31)	1.61 (0.26)	1.94 (0.25)	1.57 (0.26)	1.66 (0.32)	V: F(1,25) = 5.26, $p = 0.031$ G*P: F(3,78) = 2.91, $p = 0.040$ G: F(1,26) = 58.69, $p < 0.001$ P: F(3,78) = 3.82, $p = 0.013$
	TD	4.91 (1.66)	5.35 (1.89)	5.72 (2.38)	5.73 (3.37)	5.41 (2.11)	6.70 (2.85)	6.97 (2.84)	5.37 (1.99)	
Range-AP (mm/m)	YA	14.85 (6.43)	11.98 (2.82)	13.98 (3.86)	16.11 (5.84)	13.87 (6.68)	13.79 (3.10)	18.10 (7.00)	17.57 (8.39)	G: F(1,26) = 28.82, $p < 0.001$ P: F(3,78) = 3.57, $p = 0.018$
	TD	28.50 (12.55)	22.83 (9.32)	30.09 (21.80)	34.04 (15.26)	26.58 (8.42)	27.57 (14.33)	30.20 (11.94)	27.80 (14.67)	
Range-ML (mm/m)	YA	5.43 (1.77)	5.73 (1.59)	6.48 (3.81)	7.01 (3.47)	5.67 (1.97)	5.02 (1.26)	7.38 (2.90)	6.84 (2.56)	G*P: F(3,78) = 5.95, $p = 0.001$ G: F(1,26) = 59.86, $p < 0.001$ P: F(3,78) = 9.28, $p < 0.001$
	TD	22.21 (11.55)	16.51 (7.54)	30.00 (23.23)	28.71 (20.01)	22.27 (9.54)	21.04 (11.03)	38.84 (20.77)	24.34 (8.81)	
95% confidence ellipse area (mm^2/m^2)	YA	72.0 (47.2)	57.8 (29.5)	64.5 (31.8)	95.3 (61.6)	66.3 (32.7)	49.8 (18.8)	92.4 (48.9)	99.5 (83.1)	G*P: F(3,78) = 5.01, $p = 0.003$ G: F(1,26) = 26.00, $p < 0.001$ P: F(3,78) = 6.92, $p < 0.001$
	TD	441.3 (306.8)	261.3 (166.8)	644.1 (578.4)	634.3 (559.4)	525.7 (309.4)	410.5 (410.4)	790.4 (705.3)	504.8 (421.9)	
Fractal dimension	YA	1.49 (0.08)	1.64 (0.12)	1.51 (0.06)	1.48 (0.08)	1.52 (0.07)	1.68 (0.09)	1.49 (0.07)	1.49 (0.05)	P: F(3,78) = 99.52, $p < 0.001$
	TD	1.54 (0.09)	1.70 (0.13)	1.51 (0.06)	1.50 (0.09)	1.52 (0.08)	1.68 (0.11)	1.53 (0.08)	1.52 (0.05)	

YA: young adults; TD: typical development children. AP: anterior-posterior; ML: medial-lateral. EO: eyes-open; EC: eyes-closed. In statistics results, G: group effect; P: phase effect; V: visual effect; G*P: group by phase interaction; G*V: group by visual interaction at $p < 0.05$.

Table 3: Mean (SD) of the COM variables in the frequency domain

Variable	Group	EO				EC				Statistics Results
		Pre	Vib	Post_0	Post_5	Pre	Vib	Post_0	Post_5	
Total power-AP (mm^2)	YA	29.79 (9.68)	29.88 (9.82)	33.12 (9.72)	37.33 (13.48)	32.61 (13.37)	32.63 (5.71)	39.22 (12.68)	34.16 (13.36)	G: F(1,26) = 16.36, $p < 0.001$
	TD	45.32 (17.53)	41.95 (18.85)	49.59 (34.39)	52.05 (18.86)	44.74 (12.14)	51.79 (23.39)	51.16 (16.02)	46.08 (19.71)	
Total power-ML(mm^2)	YA	12.36 (5.38)	13.24 (3.56)	14.79 (7.43)	15.57 (5.94)	14.34 (6.57)	12.59 (3.13)	18.21 (7.70)	15.54 (4.59)	G*P: F(3,78) = 4.12, $p = 0.009$ G: F(1,26) = 53.93, $p < 0.001$ P: F(3,78) = 9.42, $p < 0.001$
	TD	37.80 (17.93)	30.79 (11.61)	47.70 (25.23)	43.53 (25.22)	38.94 (16.42)	37.67 (17.59)	58.52 (29.07)	42.55 (12.95)	
Median frequency-AP (Hz)	YA	0.20 (0.08)	0.25 (0.06)	0.23 (0.06)	0.22 (0.08)	0.24 (0.05)	0.29 (0.04)	0.23 (0.08)	0.20 (0.07)	V: F(1,25) = 4.26, $p < 0.050$ G*P: F(3,78) = 5.52, $p = 0.002$ G: F(1,26) = 8.61, $p = 0.007$ P: F(3,78) = 25.48, $p < 0.001$
	TD	0.22 (0.06)	0.35 (0.09)	0.23 (0.05)	0.23 (0.09)	0.22 (0.06)	0.39 (0.12)	0.26 (0.06)	0.25 (0.05)	
Median frequency–ML (Hz)	YA	0.30 (0.11)	0.33 (0.09)	0.29 (0.06)	0.23 (0.06)	0.28 (0.07)	0.41 (0.08)	0.32 (0.11)	0.31 (0.10)	P: F(3,78) = 15.12, $p < 0.001$ V: F(1,25) = 12.98, $p = 0.001$
	TD	0.26 (0.08)	0.34 (0.07)	0.25 (0.07)	0.25 (0.07)	0.26 (0.05)	0.43 (0.14)	0.30 (0.15)	0.31 (0.13)	

YA: young adults; TD: typical development children. AP: anterior-posterior; ML: medial-lateral. EO: eyes-open; EC: eyes-closed. In statistics results, G: group effect; P: phase effect; V: visual effect; G*P: group by phase interaction; G*V: group by visual interaction at $p < 0.05$.

Figure caption

Figure 1: Mean and standard deviation of the DFA scaling exponent α in children and adults. (a) AP, EO condition; (b) ML, EO condition; (c) AP, EC condition; and (d) ML, EC condition. A symbol * denotes a significant difference between children and adults at that phase. A symbol † indicates a significant difference between phases across the two groups.

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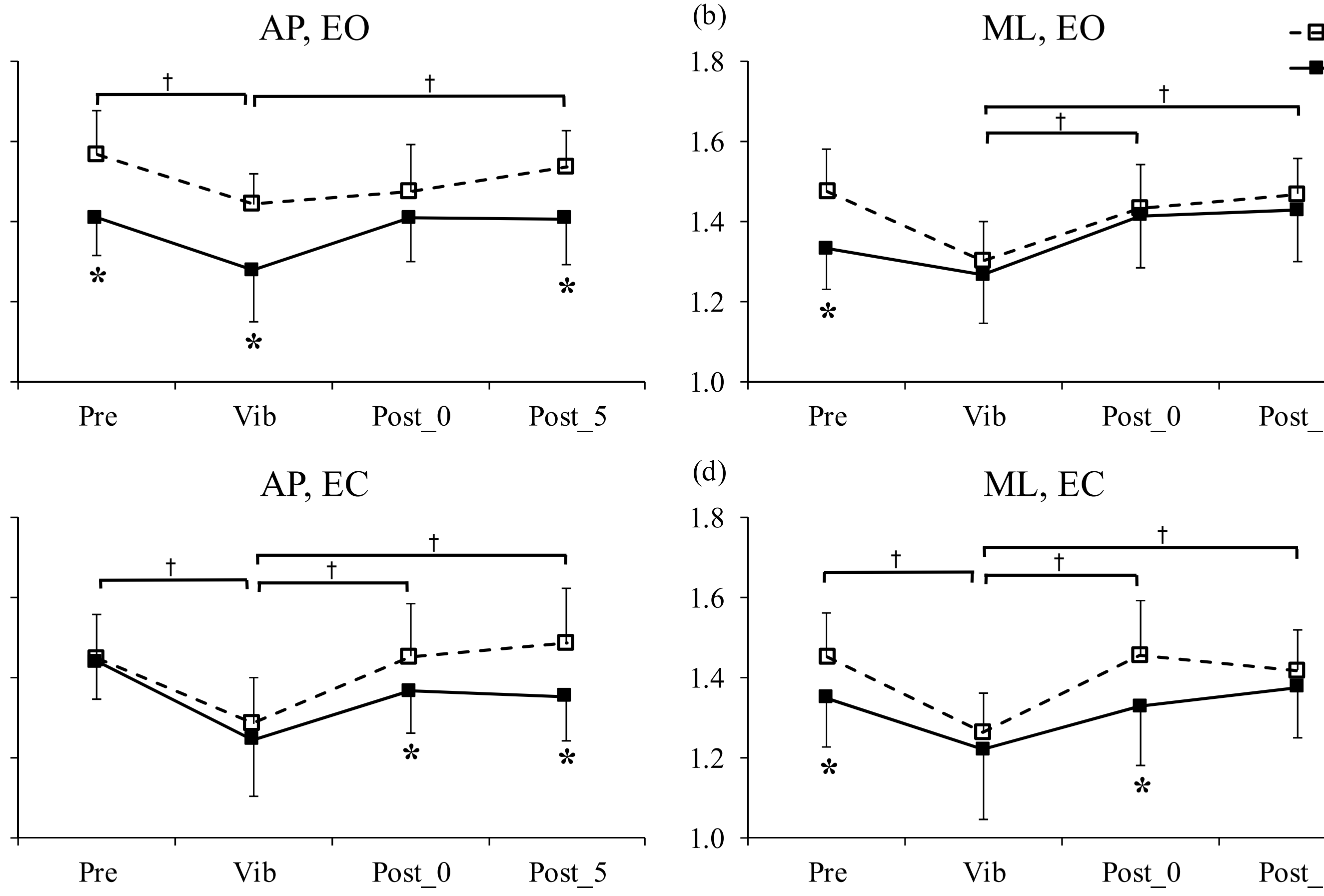
AP, EO
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Pre
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ML, EO
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Pre
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Highlights (3 to 5 bullet points with no more than 85 characters per bullet point):

- During WBV children and adults increase COM average velocity but decrease range
- During WBV children and adults increase median frequency but decrease DFA α
- After WBV children and adults show pre-vibration values for most COM variables
- Children show a higher COM velocity and range, but a lower DFA α than adults