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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 min after 40-s 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 min after WBV with an frequency of 28 Hz and an amplitude of <1 mm. 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.

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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-min 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 min 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 min 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

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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 min 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 min 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.

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)

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 100 Hz before, during and after WBV. A Soloflex WBV platform (Soloflex, Hillsboro, OR) was used to provide synchronous WBV with vertical amplitude of less than 1 mm. 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-s trials [26,27] were collected: before vibration (*Pre*), during vibration (*Vib*), immediately after vibration (*Post_0*), and 5 min 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 $0.4 \times g$ 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 toward 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-s 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].