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Center of mass control and multi-segment coordination in children during and after whole-body vibration

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Center-of-mass control and multi-segment coordination in children during and after whole-body vibration

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Introduction

Maintaining upright posture under external perturbations requires the coordination between the nervous system and the musculoskeletal system, and it is a milestone of motor development in early childhood [1]. Whole-body vibration (WBV) has acute effect on postural control and muscular activation during standing, resulting in an increased sway velocity and sway area of center-of-mass (COM), and the residual effect usually vanishes within 20 minutes after the vibration exposure [2].

In quiet standing, a human body can be considered as a multi-segment linked system, and an uncontrolled manifold (UCM) approach has been used to examine how this multi-joint motor redundancy is utilized to achieve postural control of the body [3]. The aim of this study was to compare the joint variance structure between children and adults while controlling the COM before, during, and after WBV disturbance.

Method

Participants: Fifteen children (6M/9F) and fourteen young adults (6M/8F) participated in the study. Mean (SD) age of the children (TD group) was 8.1 (1.8) years, height 1.32 (0.10) m, and mass 30.2 (6.7) kg. Mean (SD) age of the adults (YA group) was 24.5 (3.9) years, height 1.68 (0.12) m, and mass 70.6 (13.4) kg.

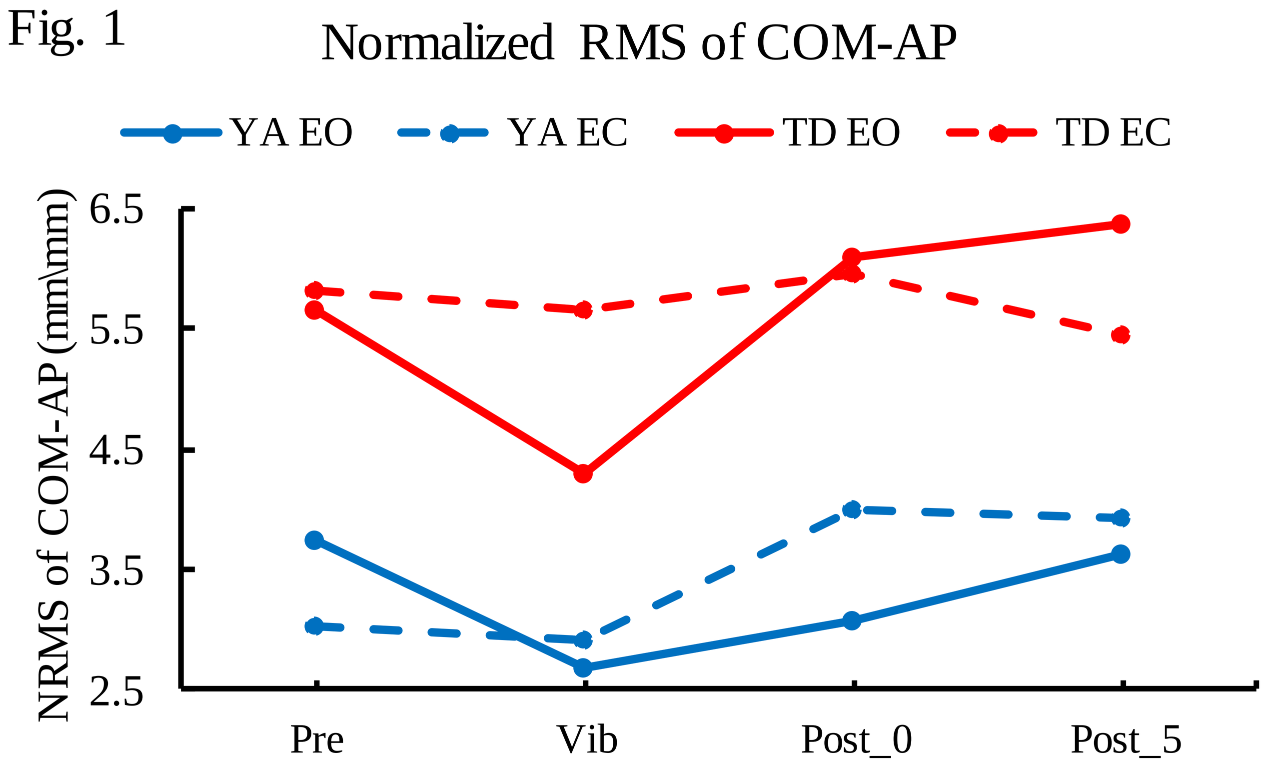
Experimental design: An 8-camera Vicon motion capture system and the Vicon full-body PSIS model were used for data collection. A Soloflex platform was used to provide WBV with the frequency of 28 Hz and the amplitude of <1mm, resulting in a vertical acceleration of 0.5*g* (*g*=9.81m/s^2). Participants were asked to stand upright for four 40-second trials: before vibration (*Pre*), during vibration (*Vib*), immediately after vibration (*Post_0*), and 5 minutes after vibration (*Post_5*). There were 2 visual conditions: eyes open (EO) and eyes closed (EC).

Data analysis: The root-mean-square (RMS) of the COM data in the anterior-posterior (AP) direction was calculated and normalized by each subject's height. Markers on the right side of the body were used for the UCM analysis in the sagittal plane. A geometric model was established that associated the COM position with 8 segment angles (respect to the horizontal): foot, shank, thigh, pelvis, trunk, head, upper-arm, and forearm [1]. The variability of the segment angles can be partitioned into two subspaces: the UCM subspace (V_{UCM}) within which the variability helps maintain the mean COM position, and the orthogonal (ORT) subspace (V_{ORT}) within which the variability causes the deviation of the COM [3, 4]. To stabilize the COM, the variability in the UCM subspace should be greater than that in the ORT subspace [1, 3]. Customized MATLAB program was used to calculate V_{UCM} and V_{ORT}. The UCM ratio was further calculated as: $UCM\ ratio = \ln(V_{UCM} / V_{ORT})$

Statistical analysis: A 4-way (2 group x 2 visual x 4 phase x 2 component) ANOVA with repeated measures were conducted on variance in the two subspaces. A series of 3-way (2 group x 2 visual x 4 phase) ANOVA with repeated measures were conducted on RMS of COM-AP and UCM ratio. Post-hoc pairwise comparisons with Bonferroni adjustments were conducted when appropriate. Statistical significance was set at $\alpha = 0.05$.

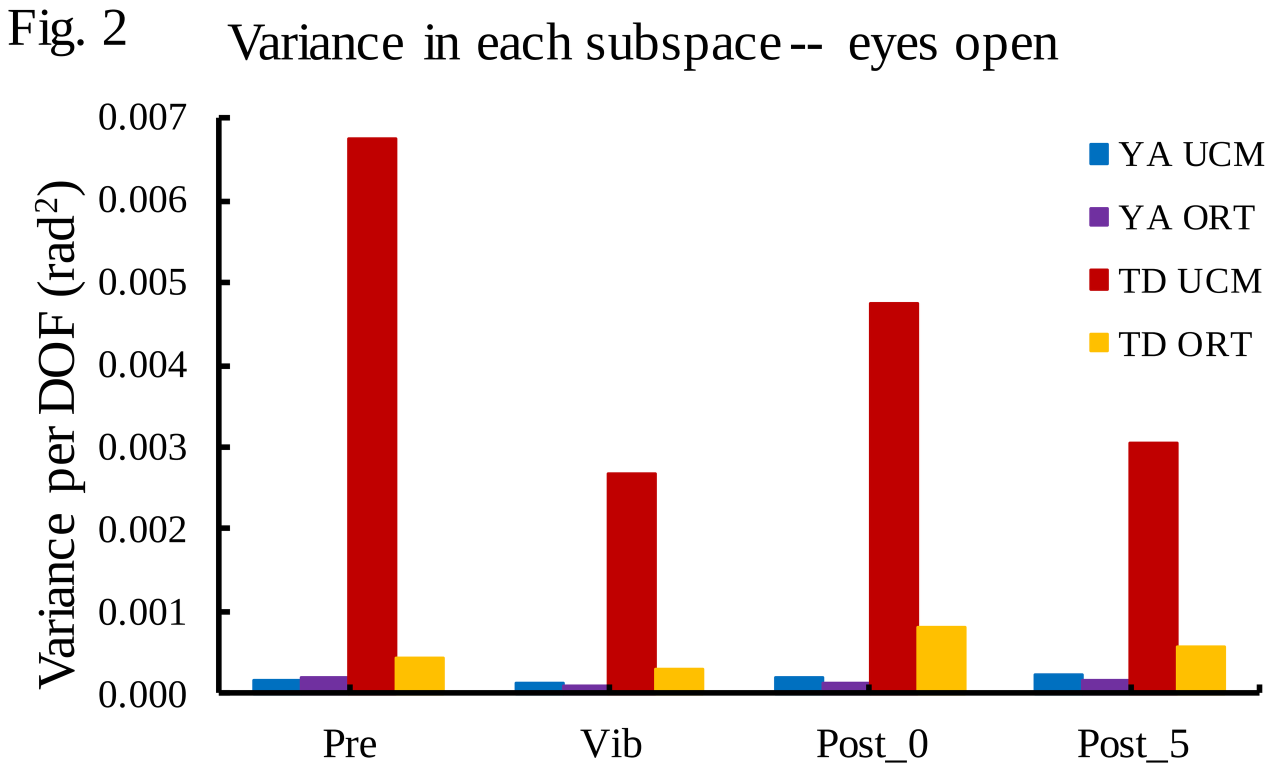
Results and Discussion

Fig. 1



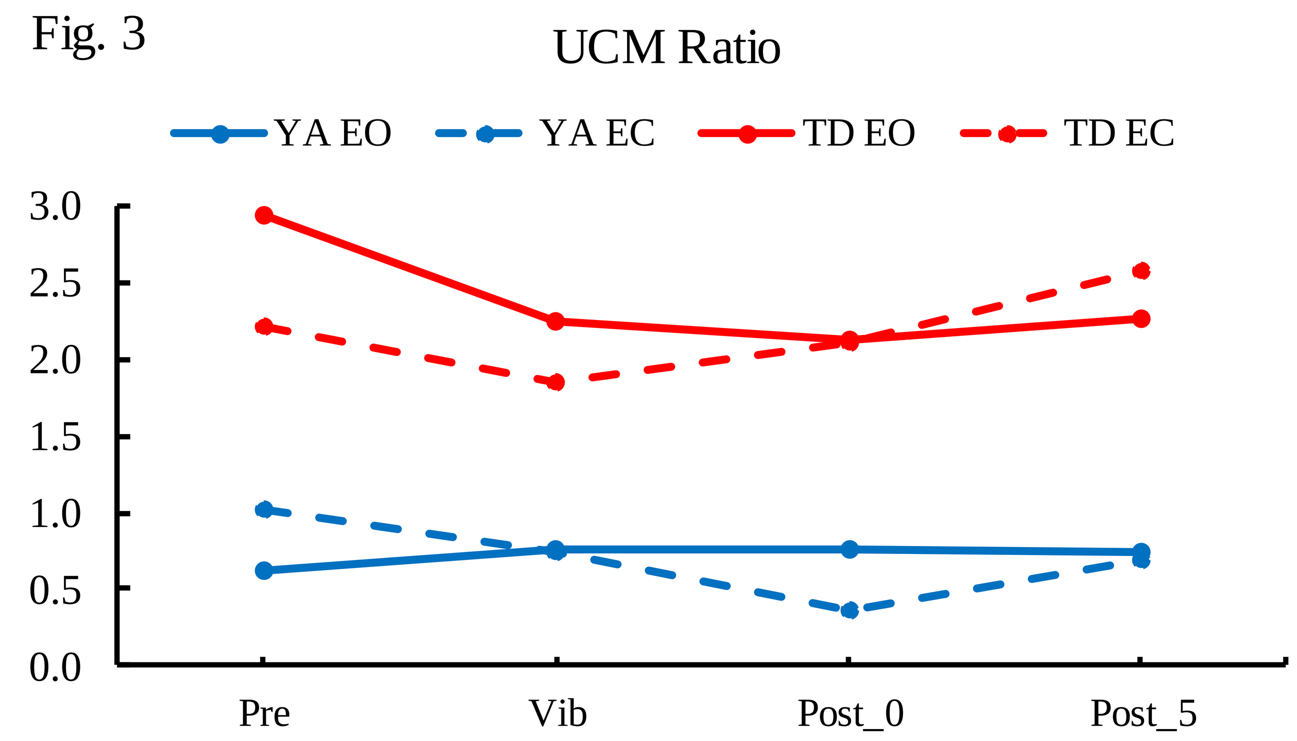
The TD group showed a larger RMS of COM than the YA group in the AP direction. Both groups decreased RMS from *Pre* to *Vib* phase, but increased to *Pre*-level immediately after vibration (Fig. 1).

Fig. 2



The TD group had greater UCM and ORT variances, and a greater difference between the two subspace variances compared to the YA group, (Fig. 2).

Fig. 3



The TD group showed a larger UCM ratio than the YA group across all phases (Fig. 3). Both groups displayed the UCM ratio greater than 0, indicating that more variance was allocated into the UCM subspace to help the stabilization of the COM.

Conclusions

Both groups displayed a decrease in COM-AP variance during WBV, but returned to the baseline level immediately after the cessation of vibration. In terms of the structure of variance partition, both groups distributed more variability in the UCM rather than the ORT subspace across all phases. Although the TD group had a greater variance than the YA group and the total variance for both groups decreased and increased at different phases, the structure of variance partition is similar between YA and TD. This suggests that the TD group may have developed an adult-like postural control strategy to compensate for greater joint variances while stabilizing the COM.

References

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