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The effect of short-term changes in body mass distribution on feed-forward postural control

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Abstract

It was recently shown that short-term changes in the whole body mass and associated changes in the vertical position of the center of mass (COM) modify anticipatory postural adjustments (APAs) [Li X, Aruin AS. The effect of short-term changes in the body mass on anticipatory postural adjustments. Exp Brain Res 2007;181:333–46]. In this study, we investigated whether changes in the body mass distribution and related changes in the anterior–posterior COM position affect APA generation. Fourteen subjects were instructed to catch a 2.2 kg load with their arms extended while standing with no additional weight or while carrying a 9.08 kg weight. Adding weight to a backpack, front pack or belly pocket was associated with an increase of the whole body mass, but it also involved changes in the anterior–posterior (A/P) and vertical positions of the COM. Electromyographic activity of leg and trunk muscles, body kinematics, and ground reaction forces were recorded and quantified within the typical time intervals of APAs. APAs were modified in conditions with changed body mass distribution: increased magnitude of anticipatory EMG activity in leg and trunk muscles, as well as co-activation of leg muscles and decreased anticipatory displacement of the COM in the vertical direction, were seen in conditions with increased body mass. Changes in the COM position induced in both A/P and vertical directions were associated with increased anticipatory EMG activity. In addition, they were linked to a co-activation of muscles at the ankle joints and significant changes in the center of pressure (COP) position. Modifications of the COM position induced in the A/P direction were related to increased anticipatory EMG activity in the leg and trunk muscles. At the same time, no significant differences in anticipatory EMG activity or displacement of COP were observed when changes of COM position were induced in the vertical direction. The study outcome suggests that the CNS uses different strategies while generating APAs in conditions with changes in the COM position induced in the anterior–posterior and vertical directions.

Keywords: Anticipatory postural adjustments; Body mass; Center of mass; Principal component analysis; Backpack; Human

1. Introduction

Anticipatory postural adjustments (APAs) are initiated by the central nervous system (CNS) to maintain body equilibrium while dealing with a predictable perturbation (Massion, 1992). It is believed that the CNS uses APAs to generate forces and torques to stabilize the body's COM prior to a voluntary movement (Belen'kii et al., 1967; Bouisset and Zattara, 1981). However, this belief has been challenged in recent literature. For example, studies showed that APAs were not involved in the stabilization of the COM for the movements of trunk-bending, arm-raising or leg-lifting in microgravity conditions during parabolic flight or space mission (Clement et al., 1984; Massion et al., 1993, 1997; Pedrocchi et al., 2002). Moreover, it was suggested, based on simulation of voluntary arm movement in standing, that the initial control of the COM was passive, and the goal of APAs was to counteract hip and knee flexion or stabilize the joints (Pozzo et al., 2001; Patla et al., 2002). In other literature, anticipatory

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trunk muscle activity was found to mainly control the orientation of the trunk in space (Cresswell et al., 1994; Hodges et al., 1999) or move the whole body COM backward during performance of a lifting task (Kingma et al., 1999). Moreover, it was noted that instead of keeping the COM position unchanged, the anticipatory muscular activity in the lower limbs actually creates a forward COM displacement within the base of support during whole body reaching tasks (Stapley et al., 1999).

The body mass distribution varies substantially between humans due to the effects of age, pregnancy, surgical procedures (i.e. amputation or liposuction), etc. that induce changes of the vertical and horizontal locations of COM. Moreover, when humans carry loads, an additional load changes the position of the whole body-COM. However, the functional implications of these changes on feed-forward postural control remain largely unknown.

One practical way to investigate the effect of changes in the COM position on APAs is to introduce an initial displacement of the COM and investigate how this experimentally induced COM change affects the generation of APAs. In our previous study, we modulated COM displacements in the vertical plane by adding weights symmetrically along the vertical axis of the body. Based on the results of the study, we argued that APAs are affected by changes in the body mass distribution and associated changes in the vertical position of the COM (Li and Aruin, 2007). The current study extends to the investigation of the effects of changes in the body mass distribution and changes in the COM position in the anterior–posterior (A/P) and vertical directions on feed-forward postural control. We hypothesized that the CNS would modify APAs differently depending on whether shift of the COM position is induced in anterior–posterior or vertical directions. We also hypothesized that changes in the body mass distribution would be associated with increased anticipatory co-activation of trunk and leg muscles. However, anticipatory involvement of particular trunk or leg muscles will depend on the actual modification of the COM position. To test these hypotheses, we designed an experimental paradigm in which changes of the COM position in the anterior–posterior or vertical directions were induced by having the subjects carry a backpack, a front pack, or a belly pocket. Throughout the experiments, participants were required to catch the same load released by the experimenter. This kept the magnitude and predictability of the perturbation constant and only the whole body mass and the location of the COM were altered.

2. Methods

2.1. Subjects

Fourteen subjects (eight males and six females) without any known neurological or musculoskeletal disorders participated in the experiments. The mean age of subjects was 27 ± 4 years, mean body mass was 59.08 ± 7.98 kg, and mean height was 1.65 ± 0.08 m. Subjects gave their written informed consent approved by the Institutional Review Board of the University of Illinois at Chicago.

2.2. Procedure

Subjects stood on a force platform (AMTI, Model: OR6-5, Newton, MA, dimensions $50.8\ \text{cm} \times 46.4\ \text{cm} \times 8.3\ \text{cm}$, length $\times$ width $\times$ height), which was utilized to measure three components of ground reaction forces (in the anterior–posterior (F_x), medial–lateral (F_y), and vertical (F_z) directions) and three moments (M_x, M_y, and M_z). The subjects were standing with their feet shoulder width apart and the outline of the feet position was marked on the surface of the platform with chalk. Participants were instructed to extend their arms in front of their chest with palms facing up. The desired hand position was marked with chalk on a metal frame positioned in front of the subject. Another line drawn 10 cm above the hand position indicated the initial position of the load to be released. Subjects were then instructed to catch a load released by the experimenter. The weight of the load was 2.27 kg, and its dimensions were $20\ \text{cm} \times 13\ \text{cm} \times 10\ \text{cm}$. Once the load was caught, subjects were told to hold it for about 2 s before releasing the load, which would be arrested by a cord attached to a metal frame overhead. After completion of each trial, subjects were directed to put their hands back to the starting position described above and wait for the next load release. The initial position of the load prior to its release was restored by the experimenter before each trial. The total time needed to perform one trial was 5 s, and there was a 2 s interval between trials.

Four experimental series were implemented. In the first series, the subjects performed the task of catching the load with no additional weight attached to their body; this series was used as the baseline for comparison. In the remaining three series, subjects repeated the similar task of catching the same 2.27 kg load while carrying 9.08 kg in a backpack, front pack or belly pocket. A selection of this particular weight was based on (1) common recommendations that the weight of the backpack should be within the range of 15–30% of the body weight (BW) (Goh et al., 1998; Quesada et al., 2000; Hong and Cheung, 2003; Chow et al., 2006) and (2) the average increase of body mass during pregnancy is about 11 kg (Chesley, 1944). Pieces of lead were inserted into the customized fabric containers and evenly distributed in the nylon bag or belly pocket. The nylon bag ($20\ \text{cm} \times 12\ \text{cm} \times 14\ \text{cm}$) and belly pocket ($18\ \text{cm} \times 14\ \text{cm} \times 12\ \text{cm}$) were located symmetrically to the left and right side of the body so that the position of the weight did not affect the body symmetry in the frontal plane. Velcro straps were used to fasten the bag or belly pocket to the body and restrict relative movements between the body and the additional weight. Six trials were recorded in each series. Subjects completed between one and three practice trials in each experimental series prior to start of data collection. The order of presentation of the series was randomized across subjects.

An accelerometer (Model 332B32, Piezeotronics, Inc.) was taped to the subject's dominant hand to record the moment of load impact. The dominant hand and leg were determined by asking subjects which hand and leg they preferred to use when catching or kicking a ball. All subjects' dominant hands and legs were of the same side (12 right and 2 left-sided). After the skin was wiped down with alcohol, disposable pediatric electrodes with 15 mm skin contact area (Red Dot 3M) were attached to the