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Standing on wedges modifies side-specific postural control in the presence of lateral external perturbations

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ABSTRACT

Standing on wedges changes the position in the ankle joints and affects postural stability in the medial-lateral direction. The objective of the study was to investigate the role of wedges and external lateral perturbations on anticipatory (APA) and compensatory postural adjustments (CPA). Ten healthy young participants were exposed to perturbations applied to the lateral part of their right shoulder when standing on a planar surface, on a medial or lateral wedges. Bilateral electromyographic activity of dorsal and ventral postural muscles and the center of pressure (COP) displacement were recorded and analyzed during the APA and CPA phases. When exposed to the lateral perturbation, reciprocal activation of shank muscles was seen on the side of the perturbation while co-contraction of shank muscles was seen on the contralateral side during the APA and CPA phases. Standing on a wedge was associated with decreased magnitudes of co-contraction and reciprocal activation of shank muscles. The COP displacements were smaller in the APA phase and larger in the CPA phase while standing on wedges compared to standing on the planar surface. The outcome of the study provides a basis for future investigations of incorporating wedges in balance re-training paradigms for the elderly or individuals with neurological impairment.

1. Introduction

The ability to maintain a stable, upright stance is an essential component of daily activities. In order to achieve that, the central nervous system (CNS) integrates information from different sensory systems (vestibular, visual, and somatosensory) and modulates commands to the muscles continuously. When maintaining and restoring balance in the presence of internal or external perturbations, the CNS utilizes anticipatory and compensatory postural adjustments. Anticipatory postural adjustments (APAs) control the position of the center of mass (COM) of the body by activating the trunk and leg muscles prior to a forthcoming body perturbation (Massion, 1992), while compensatory postural adjustments (CPAs) serve as a mechanism of restoration of the position of the COM after perturbation has already occurred (Alexandrov et al., 2005).

A number of factors affect the generation and utilization of APAs and CPAs for postural control. Among them are changes in the body configuration (Aruin, 2003) and in the dimensions of the base of support (Aruin et al., 1998), changes in the direction and magnitude of the forthcoming perturbations (de Azevedo et al., 2016; Santos et al., 2010) and fear of falling (Adkin et al., 2002). In order to overcome the perturbations while maintaining balance, the CNS uses reciprocal and co-contraction patterns of activation of leg and trunk muscles (Slijper and Latash, 2004). Reciprocal activation involves sequential activation of the ventral and dorsal muscles, for example, reciprocal activation of the hamstrings/quadriceps muscle pairs has been reported during unilateral arm movements performed by healthy individuals (van der Fits et al., 1998). On the other hand, co-contraction of ventral and dorsal muscles has been reported in individuals with Parkinson's disease (Latash et al., 1995) and Down syndrome (Aruin and Almeida, 1997) during task involving bilateral arm flexion movement. Moreover, reciprocal and co-contraction activation patterns could occur simultaneously on the left and right side of the body, depending on functional roles the side of the body plays while maintaining balance in response to the perturbation (Santos

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and Aruin, 2009). Thus, it was reported that reciprocal activation of muscles on the target side and co-contraction of muscles on the contralateral side was observed when standing in asymmetrical posture and being subjected to a symmetrical external perturbation (Chen et al., 2015).

While maintenance of posture in response to anterior-posterior perturbations has been examined extensively, less attention was paid to the investigation of postural control associated with lateral perturbations. The diminished medial-lateral postural stability has been recognized as an important factor falls in older adults (Hilliard et al., 2008; Lord and Sturnieks, 2005). Older adults have been observed to use higher compensatory activity of postural muscles and COP displacements compared to young adults (Claudino et al., 2013). Moreover, when exposed to lateral external perturbations induced at the shoulder level, older fallers exhibit a delay in muscle activation during compensatory postural adjustments (Santos et al., 2016). Additionally, individuals with Parkinson's disease have limited flexibility to respond to perturbations as a result of reduced amplitude of COP and increased passive stiffness in the leg and pelvis (de Azevedo et al., 2016). These prior studies described the organization of postural control in response to external lateral perturbations (Claudino et al., 2013; de Azevedo et al., 2016; Santos and Aruin, 2009; Santos et al., 2016). However, the role of side-specific reciprocal and co-contraction patterns of activation of muscles on anticipatory and compensatory postural adjustments when exposed to the external lateral perturbations has yet to be examined.

The importance of the ankle joints in postural control has been established in the literature. Healthy individuals use ankle musculature to control posture in the sagittal plane very effectively (Horak, 2006; Robinovitch et al., 2002). Moreover, cutaneous and somatosensory information from the feet and ankle joints play an important role in maintaining balance in response to anterior and posterior surface translations (Horak et al., 1990). It was even suggested that ankle joints serve as the first responders to the induced balance disturbance of a certain magnitude (Balasubramaniam et al., 2000; Ntousis et al., 2013). As such, a number of approaches have been used to enhance the contribution of ankle joints in postural control. Four weeks of balance training involving dynamic body stabilization while standing on one leg enhanced dynamic balance control in individuals with chronic ankle instability (McKeon et al., 2008). Moreover, it was reported that individuals with chronic ankle instability improved their postural control after a single session of exercises involving kicking a ball (Conceicao et al., 2016). Alternatively, stabilization of ankle joints using orthotic devices appears to be a useful strategy in reducing postural sway and increasing stability in individuals with ankle instability (Guskiewicz and Perrin, 1996). Standing on wedges is another approach that could be beneficial for postural control as it increases ankle joint stiffness, thus enhancing the performance of precision tasks (Balasubramaniam et al., 2000). Medial wedges are used to promote supination or pronation, based on their medial or lateral design. For example, lateral sole wedges placed under the entire lateral aspect (outside) of the foot are used to limit supination. Also heel wedges are used to promote inversion (turning inward) or eversion (turning outward). It is reported in the literature that lateral wedges could be beneficial for treatment of pain and improving the quality of life for the patients suffering from knee joint osteoarthritis (Rafiaee and Karimi, 2012; Rodrigues et al., 2008). It was also reported that wedges could reduce postural sway during quiet standing with and without visual feedback (Ganesan et al., 2014).

The objective of the present study was to investigate how standing on wedges affects the anticipatory and compensatory postural adjustments associated with maintenance and restoration of balance when exposed to external lateral perturbations applied at the shoulder. We hypothesized that following a lateral perturbation, activation of leg and trunk muscles will be associated with side-specific patterns seen as co-contraction of muscles on the side of the perturbation impact and reciprocal activation of muscles on the contralateral side of the body. We also hypothesized that larger COP displacements prior to the forthcoming perturbation and smaller COP displacements after the perturbation will be observed when standing on wedges as compared to standing on a horizontal planar surface.

2. Methods

2.1. Participants

Ten young adults (6 males and 4 females) without any neurological or musculoskeletal disorders participated in the study. All participants had normal or corrected to normal vision. The mean age of the study participants was 28.8 ± 1.3 years, the mean height was 1.68 ± 0.03 m and the mean body mass was 70.9 ± 7.19 kg. All subjects signed a written informed consent approved by the Institutional Review Board of the University of Illinois at Chicago.

2.2. Procedure

Participants were instructed to stand barefoot on three different surfaces placed on top of a force platform: a horizontal planar surface (PS), two 10º lateral wedges (LW) and two 10° medial wedges (MW). The participants were instructed to stand still with even body weight distribution between the left and right foot to the best of their effort. An aluminum pendulum was used to induce perturbations at the shoulder level on the right side of the body (Fig. 1). A 30 cm long wooden stick with a flag was attached to the pendulum, allowing the participants to see the approaching pendulum via peripheral vision, without a need for head rotation. The length of the central rod of the pendulum was adjusted to each individual's shoulder height. A load (5% of the individual's body mass) was attached to the pendulum next to its distal end. The pendulum was positioned at an initial angle of 30° to the vertical (0.8 m from the body) and was released by an experimenter 1–2 s after the start of each data collection trial. Perturbation consisted of unidirectional force applied by the pendulum to the lateral side of the right shoulder. The participants were instructed to look forward and maintain their balance after the perturbation. Two practice trials were performed prior to data collection and five trails were recorded in each experimental condition. The order of the conditions was randomized across subjects.

2.3. Data collection

Ground reaction forces and moments of forces were recorded using the force platform (Model OR-5, AMTI, USA). An accelerometer (Model 333B42, PCB Piezotronics, USA; mass 7.5 mg, sensitivity 51.0 mv/(m/s^2) and measurement range ±98 m/s^2 pk) was attached to the pendulum and its signal was used to determine the timing of the pendulum impact (T0). EMG of muscles were recorded using disposable surface electrodes (3 M Red Dot™, USA). After cleaning the skin with alcohol prep pads, electrodes were attached to the bellies of the following muscles: tibialis anterior, TA (at one-third on the line between the tip of the fibula and the tip of the medial malleolus), medial gastrocnemius, MG (on the most prominent bulge of the muscle), rectus femoris, RF (at 50% on the line from the anterior superior iliac spine to the superior part of the patella), biceps femoris, BF (half way between the ischial tuberosity and the lateral epicondyle of the tibia), rectus abdominis, RA (3 cm lateral to the umbilicus), and erector spinae, ES (3 cm lateral to L1). The