Journal of Electromyography and Kinesiology 24 (2014) 144–152

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Support surface related changes in feedforward and feedback control of standing posture

Sambit Mohapatra, Komal K. Kukkar, Alexander S. Aruin *

University of Illinois at Chicago, Chicago, IL 60612, United States

ARTICLE INFO

Article history:
Received 18 November 2012
Received in revised form 9 October 2013
Accepted 26 October 2013

Keywords:
Postural control
Support surface
EMG

ABSTRACT

The aim of the study was to investigate the effect of different support surfaces on feedforward and feedback components of postural control. Nine healthy subjects were exposed to external perturbations applied to their shoulders while standing on a rigid platform, foam, and wobble board with eyes open or closed.

Electrical activity of nine trunk and leg muscles and displacements of the center of pressure were recorded and analyzed during the time frames typical of feedforward and feedback postural adjustments. Feedforward control of posture was characterized by earlier activation of anterior muscles when the subjects stood on foam compared to a wobble board or a firm surface. In addition, the magnitude of feedforward muscle activity was the largest when the foam was used. During the feedback control, anterior muscles were activated prior to posterior muscles irrespective of the nature of surface. Moreover, the largest muscle activity was seen when the supporting surface was foam. Maximum CoP displacement occurred when subjects were standing on a rigid surface.

Altering support surface affects both feedforward and feedback components of postural control. This information should be taken into consideration in planning rehabilitation interventions geared towards improvement of balance.

1. Introduction

Control of upright posture requires a unique integration of inputs from the three major sensory systems of the body: visual, vestibular, and somatosensory (Manchester et al., 1989; Nashner and Berthoz, 1978). It is believed that important afferent information that is necessary to maintain posture, comes from the two types of specialized mechanoreceptors located on the sole of the feet (Magnusson et al., 1990). Slowly adapting mechanoreceptors provide spatial information about the pressure distribution between the feet and the ground whereas rapidly adapting mechanoreceptors provide information about the amplitude and changes in the pressure distribution (Kavounoudias et al., 1999). Also, it is important to note that such mechanoreceptors not only supply information about surface contact pressure (Vallbo and Johansson, 1984), but they also help sense small continuous changes of posture.

Individuals with diabetic neuropathy, elderly individuals with peripheral neuropathy, or individuals with traumatic injury that involves one of the nerves of the lower extremity, commonly have diminished ability to utilize somatosensory information (Greene et al., 1990; van Deursen and Simoneau, 1999). Balance assessment techniques frequently involve standing on a rigid surface or foam, a more compliant supporting surface positioned on the top of the force platform (Allum et al., 2002; NeuroCom, 2010). It is also reported that wobble boards could be used in balance retraining (Burton, 1986).

Both foam and wobble board distort the normal proprioceptive inputs from the lower extremity. Standing on a compliant surface such as foam induces body instability in both the sagittal and frontal planes and also alters inputs to both joint receptors and cutaneous mechanoreceptors in the sole. However, the stimulation of stretched muscle is not affected while standing on foam (Chiang and Wu, 1997). Past studies have shown that standing on foam results in a significant challenge to postural control (Patel et al., 2011; Blackburn et al., 2003; Jeka et al., 2004; Vrancken et al., 2005). Moreover, standing on foam is considered to be an even more complex balance task than pitch controlled ankle-sway referencing (Allum et al., 2002).

Standing on wobble board induces body instability in one plane. Furthermore, due to the differences in the physical properties of the surface in contact with the sole (firm or soft), somatosensory inputs from the foot are different between standing on a wobble board versus standing on foam (Roll et al., 2002). Standing on a

* Corresponding author. Address: Department of Physical Therapy (MC 898), University of Illinois at Chicago, 1919W. Taylor St., Chicago, IL 60612, United States. Tel.: +1 (312) 355 0904; fax: +1 (312) 996 4583.

E-mail address: aaruin@uic.edu (A.S. Aruin).

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.10.015

wobble board stimulates activity of lower limb musculatures as well as lumbar erector spinae (Burton, 1986).

Maintenance of vertical posture is regulated by feedforward and feedback components of postural control. Feedforward control involves activation of leg and trunk muscles prior to an expected body perturbation also known as anticipatory postural adjustments (APA) (Belen'kii et al., 1967; Massion, 1992). Feedback control is initiated by the sensory feedback signals after the perturbation onset and is known as compensatory postural adjustments (CPA) (Alexandrov et al., 2005; Horak et al., 1996; Park et al., 2004). There are differences in the function between the two: APAs serve to minimize the displacement of the body's Center of Mass (CoM) prior to a perturbation (Aruin and Latash, 1995; Bouisset and Zattara, 1987) while CPAs serve as a mechanism of restoration of the position of CoM after a perturbation has already occurred (Macpherson et al., 1989; Maki et al., 1996).

Changes in the stability of the supporting surface and associated changes in the available somatosensory information could affect both of the components of postural control. Thus, APAs are reduced when body posture is unstable (Nouillot et al., 1992) or very stable (Nardone and Schieppati, 1988). In addition, APAs were also reduced when subjects performed backward bending while standing on a narrow support (Pedotti et al., 1989). Moreover, earlier and smaller APAs were observed in experiments involving fast arm movements while standing on a wobble board as compared to standing on a stationary surface (Gantchev and Dimitrova, 1996). Instability of the supporting surface also affects the feedback component of postural control. Thus, standing on a narrow beam (Gatev et al., 1999; Horak and Nashner, 1986) or on one leg (Tropp and Odenrick, 1988) results in subjects utilizing primarily the hip strategy when recovering from a perturbation induced by a moving support. Moreover, an increase in the amplitude of compensatory EMG activity of the leg and trunk muscles was observed while subjects wore unstable foot wear (Sousa et al., 2010), while standing on foam (Fransson et al., 2007) or while standing on a wobble board (Burton, 1986).

While the effect of standing on foam or a wobble board was investigated individually, to the best of our knowledge there are no studies that evaluate the effect of both of these supports in the control of vertical posture in the presence of an external perturbation.

Thus, the current experiment was designed to study the role of different support surfaces upon APAs and CPAs. The subjects were exposed to similar perturbations induced at the shoulder level while standing either on stable or unstable surfaces (foam, wobble board). We hypothesized that: (a) APAs will be reduced in conditions with diminished stability induced by foam (that causes instability in both sagittal and frontal planes) or wobble board (that induces instability in sagittal plane) and (b) CPAs will be different between the two unstable conditions with greater EMG activity in the foam condition, which is the most unstable.

2. Materials and methods

2.1. Participants

Nine healthy participants (4 males and 5 females) with no history of lower extremity injury, chronic ankle instability or clinically diagnosed balance disorders within last 6 month participated in the study. Mean age, height and weight of the participants were 23 ± 0.5 years, 1.7 ± 0.02 m and 67 ± 5.8 kg respectively. The right side was the dominant side for all subjects. The protocol was approved by the University's Institutional Review Board prior to participant recruitment, and all participants provided written informed consent before taking part in the experimental procedures.

2.2. Procedure

The subjects were instructed to stand on the different surfaces and maintain standing balance while being subjected to external perturbations at the shoulder level induced by an aluminum pendulum attached to the ceiling. An additional load (mass = 5% of subject's body weight) was fixed to the pendulum at its lower end. The width of the padded hitting surface of the pendulum was adjusted to match the subject's shoulder width. The pendulum was positioned at an initial angle of 30° to the vertical (distance of 0.6 m from the body) and released by an experimenter. Perturbations consisted of unidirectional forces applied by the pendulum on the shoulders of the subjects. The subjects were instructed to look straight towards a target attached to the pendulum at eye level and maintain their balance after the perturbation (Mohapatra et al., 2011, 2012). The supporting surface was either stationary (RIGID) as the subjects stood on the force platform or unstable. Instability was induced by a piece of foam, 12.7 cm thickness (FOAM) or a wooden wobble board, 7.6 cm in height, (WOBBLE) positioned on the top of the force platform. The subjects stood barefoot on these surfaces while keeping eyes open or closed. Thus the eyes open conditions were REO (Rigid-Eyes Open), FEO (Foam-Eyes Open) and WEO (Wobble-Eyes Open), and the eyes closed conditions were REC (Rigid-Eyes Closed), FEC (Foam-Eyes Closed) and WEC (Wobble-Eyes Closed). Accordingly, when their eyes were open, the subjects were able to see the upcoming pendulum and generate anticipatory postural adjustments, while in the conditions with their eyes closed only compensatory adjustments were generated (Santos et al., 2010a). The experimenter made sure that the feet position in relation to the center of the force platform was the same across all the conditions.

The subjects wore wireless headphones playing music throughout all of the conditions to mask any kind of auditory information. For safety, the participants remained in a harness with two straps attached to the ceiling and wore protective glasses during the experiment. The subjects performed two to three practice trials in each experimental condition prior to the start of data collection. Five trials, each of 5 s in duration, were collected in each experimental condition and the order of the conditions was randomized across subjects.

2.3. Instrumentation and data processing

Ground reaction forces and moments were recorded using a force platform (Model OR-5, AMTI, USA). An accelerometer (Model 208CO3, PCB Piezotronics Inc., USA) was attached to the subject's proximal clavicle to record the moment of pendulum impact (defined as T_0). Electrical activity of muscles (EMGs) was recorded unilaterally (right side) from 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), lateral gastrocnemius (GL, at one third line from lateral side of the popliteus cavity to the lateral side of the Achilles tendon insertion), rectus femoris (RF, at 50% on the line from the anterior superior iliac spine (ASIS) to the superior part of the patella), vastus lateralis (VL, lower 25% between ASIS and Gerdy prominence), vastus medialis (VM, lower 25% between ASIS and knee joint space), biceps femoris (BF, half way between the ischial tuberosity and the lateral epicondyle of the tibia), semitendinosus (ST, 5 cm above the posterior knee joint medially), rectus abdominis (RA, 3 cm lateral to the umbilicus), and erector spinae lumborum (ESL, 3 cm lateral to the first lumbar vertebra) by disposable surface electrodes (Red Dot 3 M). These specific leg and trunk muscles were selected because of their involvement in control of vertical