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SHIFTING THE BALANCE: EVIDENCE OF AN EXPLORATORY ROLE FOR POSTURAL SWAY

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Abstract—Humans and other species are unable to stand perfectly still; their bodies continuously sway during stance even during concentrated efforts to avoid such movement. Traditionally, this phenomenon has been viewed as an inability of the central nervous system (CNS) to maintain perfect equilibrium because of its reliance on feedback from sensory signals to control corrective ground-reaction forces. Using a novel method to minimize movements of the body during stance without subject awareness, we have made the unique discovery that ground-reaction forces are generated independent of body sway, as evidenced by observations of increased centre of pressure variability when postural sway is minimized experimentally. Contrary to traditional views, our results suggest that postural sway may be used by the CNS as an exploratory mechanism to ensure that continuous dynamic inputs are provided by multiple sensory systems. This novel paradigm has the potential to significantly shift long-standing views on balance, and questions the theoretical basis behind conventional treatment strategies for balance deficits associated with age and disease. © 2010 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: posture, stability, kinetics, EMG, neural control, sensori-motor.

Postural sway, the seemingly random oscillation of a body during stance, is a common characteristic among bipedal and quadrupedal species, including humans, dogs, cats, and horses (Winter et al., 1998; Brookhart et al., 1965; Thomson et al., 1991; Clayton et al., 2003). Postural sway is observable primarily during periods of quiet stance and persists despite concentrated efforts to minimize such movement (Vuillerme and Nafati, 2007). However, the exact cause or purpose of postural sway is currently unknown.

Balance is maintained during stance if the gravitational line through the body's centre of mass (COM) stays within the base of support. Human balance is typically modelled as an inverted pendulum, where the body is controlled as a single rigid segment, supporting a single point mass (i.e. the COM), which rotates about the ankle joint (Winter et al., 1998). The inverted pendulum is controlled through the development of ground-reaction forces which can be recorded using a forceplate. The vector sum of all of the ground-reaction forces under the feet is called the centre of pressure (COP), which is comprised of two different components: (1) the gravitational projection of the COM; and (2) torques generated at the ankle joint (dorsi-flexion/plantar-flexion) in the anterior–posterior (AP) plane and the hip joint (abduction/adduction) in the medial–lateral (ML) plane (Winter et al., 1996). As a result, displacements of the COM and COP can be viewed as a game of cat and mouse where the movements of one are chased or tracked by movements of the other.

The majority of currently-held theories assume that the goal of the central nervous system (CNS) is to maintain equilibrium of the COM around a set-point; a goal which is under constant challenge by continuous perturbations to the COM caused by factors such as breathing, heart-rate, and muscle activity (Soames and Atha, 1981, 1982; Jeong, 1991). Thus, the COP is considered to be constantly reacting to the estimated position of the COM, via feedback from multiple sources of sensory information (Ishida and Miyazaki, 1987; Johansson et al., 1988; Peterka, 2000), and the residual sway that persists is due, in part, to inherent delays or errors within the feedback control system.

Assuming that such theories are correct, and balance is controlled using corrective ground reaction forces (COP) to minimize movement of the COM, we hypothesized that an artificial stabilization of the COM would lead to a decrease in the displacement of the COP. To test this hypothesis, we have devised a unique apparatus (Fig. 1A) to minimize or "lock" movements of the COM in the sagittal plane and compare the resultant changes in COP displacement during the locked and unlocked conditions. The unique aspect of this apparatus is that COM can be locked and unlocked without the subject being aware that sway in the sagittal plane has been artificially minimized. Since COM displacement in the sagittal and frontal planes are known to be controlled by the CNS independently (Winter et al., 1996), we further hypothesized that any changes in COP displacements due to locking the COM would be restricted to the sagittal plane. Subjects performed the experiment with their eyes open or closed, to test the hypothesis that the effects of locking the COM on COP displacements would be independent of vision.

EXPERIMENTAL PROCEDURES

Participants

47 healthy young adults volunteered to participate in the study and were randomly assigned to one of three groups: the Eyes Open group (19 subjects (7 males, 12 females); mean±sd for

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Abbreviations: AP, anterior–posterior; CNS, central nervous system; COM, centre of mass; COP, centre of pressure; EMG, electromyography; ML, medial–lateral; RMS, root mean square.

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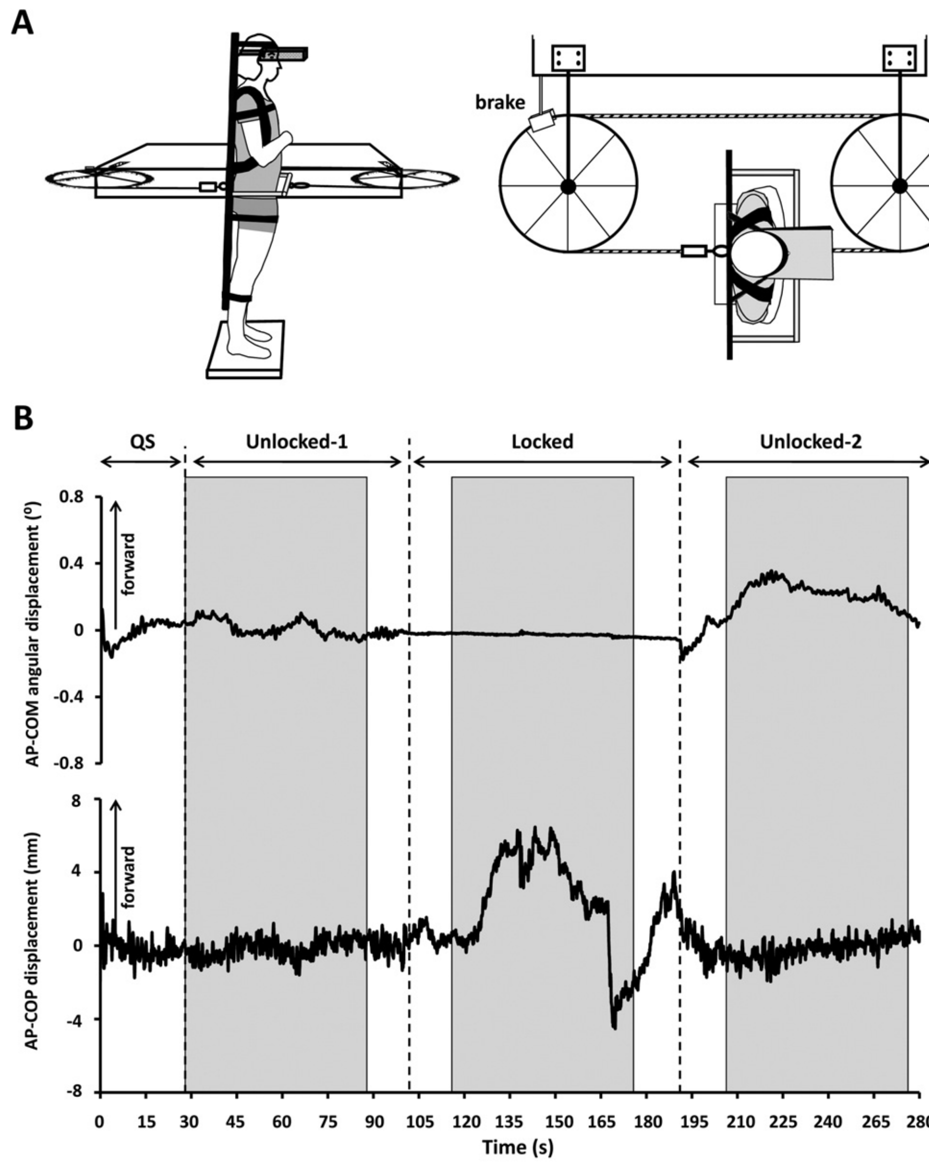

Fig. 1. Illustration of apparatus and experimental procedures: (A) sagittal and transverse views of the apparatus used to minimize or "lock" AP movements of the COM without the subject's awareness; (B) raw traces of the AP-COM angular displacement (top trace) and AP-COP displacement (bottom trace) from a representative subject in the Eyes Open group. Dashed vertical lines indicate the boundaries between quiet standing (QS—which was used to calculate the threshold for locking), Unlocked-1, Locked, and Unlocked-2 conditions. Grey boxes indicate the 60 s time periods used for data analysis. Zero on the y-axis represents the mean COP and COM position calculated during the initial 30 s quiet stance period.

age=24.5±2.8 years; height=170.9±8.2 cm; weight=66.1±9.9 kg), the Eyes Closed group (18 subjects (6 males, 12 females); age=25.1±3.8 years; height=172.6±11.7 cm; weight=70.1±11.9 kg) and the Control group (10 subjects (3 males, 7 females), age=21.3±2.7 years; height=167.8±7.4 cm; weight=60.7±6.7 kg). Each participant provided informed written consent, and the experimental protocol was approved by the Clinical Research Ethics Board at The University of British Columbia. All subjects were completely naive to the goals of the experiment and the intended effect of the apparatus on postural sway.

Apparatus

In all conditions (except the Control condition—see section *Experiment 2* under Experimental protocol) subjects were firmly braced with their back against a rigid board with adjustable straps tightened firmly around the head, both shoulders, chest, waist, hips, and lower legs. The board was used to ensure that sway was controlled as an inverted pendulum by allowing sway in the sagittal plane to occur only about the ankle joints.

The board was 1.66 m high (including head rest)×0.61 m wide and had a total mass of 12.5 kg. Despite the added mass, the average total body mass (including the mass of the board) for all subjects was 78.1 kg, which is still within a normal range for subjects of this age and height.

The board (not the person) was attached to a closed-loop pulley system that allowed the subject to stand and experience "normal postural sway" about the ankle joint unless the experimenter applied a brake, which would discretely lock the board (and thus COM) in place in the sagittal plane without the subject's knowledge (Fig. 1A). To eliminate any chance that the participant