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Effects of increased anterior–posterior voluntary sway frequency on mechanical and perceived postural stability

Teresa Martin Lorenzo, Jos Vanrenterghem *

School of Sport and Exercise Sciences, Faculty of Science, Liverpool John Moores University, Liverpool, UK

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Despite a substantial number of studies, the interaction between mechanical indicators of stability and perception of instability remains unclear. The purpose of this study was to determine the effect of sway frequency and verbal restraint on mechanical and perceived postural stability. Fourteen participants underwent a series of standing voluntary anterior–posterior swaying trials at three frequencies (20, 40, and 60 bpm) and two levels of restraint (non restraint and verbally restraint to swaying at the ankle). Repeated measures ANOVA tests revealed greater mechanical stability defined though the margin of stability, and greater horizontal ground reaction forces, while the center of pressure excursions remained unchanged with increasing frequency. Furthermore, ground reaction forces were greater in the non-restraint condition. Moreover, a tendency toward greater perceived instability with increasing voluntary sway frequency was observed. Our results indicate that variations in sway frequency and verbal restraint resulted in noticeable alterations in mechanical indicators of stability, with no clear effect on perceived instability.

* Corresponding author at: School of Sport and Exercise Sciences, Faculty of Science, Liverpool John Moores University, Byrom Street Campus, Liverpool L3 3AF, UK. Tel.: +44 (0)1519046259.

E-mail address: j.vanrenterghem@ljmu.ac.uk (J. Vanrenterghem).

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1. Introduction

Subjects with impaired postural control are prone to falls, which are associated with considerable morbidity, suffering from reduced independence, and inability to perform activities of daily living. Research on postural control assessment has focused primarily on the diagnosis of balance disorders and rehabilitation of postural control, as well as understanding the pathophysiology of balance (Visser, Carpenter, Van der Kooij, & Bloem, 2008). However, this sometimes ignores the biomechanical bases of postural stability, which cannot be overlooked when trying to gain a better understanding of postural control.

The biomechanical bases of postural stability have been characterized by a number of variables that are widely used to describe balance in the scientific literature (Winter, Patla, Ishac, & Gage, 2003). These variables have been studied in relation to the functional base of support (FBoS) which is defined as the maximum excursion of the center of pressure (CoP) under the feet during a maximal sustained leaning task (King, Judge, & Wolfson, 1994). The dependency of the center of mass (CoM) control on FBoS has been established through dynamic models, which take into account CoM velocity (Hof, Gazendam, & Sinke, 2005; Pai & Patton, 1997) and even CoM acceleration (Hasson, Van Emmerik, & Caldwell, 2008; Slobounov, Slobounova, & Newell, 1997). These models have demonstrated that when the CoM is outside the FBoS, but is moving towards the FBoS, balance could still be regained. Similarly, when the CoM is inside the FBoS and apparently in a stable state, but is moving outwards, an unstable situation may arise. In order to describe stability under these circumstances, Hof et al. (2005) introduced the "extrapolated CoM" (XCoM) variable, which is based on the position and velocity of the CoM and is indicative of the future position of the CoM if it were to continue moving at that velocity. Therefore, this variable represents the ability to control momentum or the ability to withstand large variability (Granata & England, 2007). From this concept, a margin of stability (MoS) can be defined. The MoS is the distance between the XCoM and the limits of the FBoS in the direction of travel, and therefore represents a mechanical need to make postural adjustments in order to maintain stability (Hof et al., 2005).

An important assumption in the above is, however, that the body behaves in these circumstances as a one linked inverted pendulum (OLIP). The OLIP model assumes that the body moves as an inverted pendulum with movement limited to the ankle joint. As such, Hasson et al. (2008) confirmed that when the body moves under a physically restricted OLIP a critical MoS indicated a need for an alternative strategy such as stepping. A similar response may have been observed under a voluntary swaying task of increasing frequency (Murnaghan, Elston, Mackey, & Robinovitch, 2009). As the CoM has inertial properties, when frequency is higher, a higher CoM velocity would be expected and therefore it would be more difficult to stop its movement in terms of the control of momentum thus exerting critical MoS. Murnaghan et al. (2009) verbally restricted sway mode to a OLIP, but only CoM displacement and not XCoM was reported. The CoM displacement reduced with increased sway frequency, but it is not clear whether XCoM excursions would have remained constant under the two sway frequencies used, confirming MoS as a mechanical limit. Alternatively, voluntary sway at the higher frequency may have involved a forced change in strategy from a OLIP to a multi linked inverted pendulum (MLIP) (Hof et al., 2005; Ko, Challis, & Newell, 2001). Furthermore, a limit to the maximum frequency where a subject can move as a OLIP has been reported as 1 Hz (Murnaghan et al., 2009), and predominately mixed strategies would appear to control the XCoM movement.

Under real life situations, subjects are not restricted to the sole use of a OLIP. On the contrary, it has been reported that subjects use a whole continuum of strategies to control balance, not limited solely to the ankle strategy (Runge, Shupert, Horak, & Zajac, 1999). Slobounov et al. (1997) compared a verbally restricted OLIP to a free condition in which subjects were allowed to use a MLIP under voluntary sway and found in both conditions that increased horizontal ground reaction forces (GRF), were evident as the CoP approached the BoS. This would account for a possible change in strategy under critical MoS, yet this was not assessed.

An increased sway frequency may not only lead to a shift towards MLIP movement strategies, but also to an altered perception of stability and therefore potentially less XCoM motion than what would be mechanically possible (Murnaghan et al., 2009). Under quiet bipedal standing, increased postural