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Cross-correlations of center of mass and center of pressure displacements reveal multiple balance strategies in response to sinusoidal platform perturbations

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ABSTRACT

Compared to static balance, dynamic balance requires a more complex strategy that goes beyond keeping the center of mass (COM) within the base of support, as established by the range of foot center of pressure (COP) displacement. Instead, neuromechanics must accommodate changing support conditions and inertial effects. Therefore, because they represent body's position and changes in applied moments, relative COM and COP displacements may also reveal dynamic postural strategies. To investigate this concept, kinetics and kinematics were recorded during three 12 cm, 1.25 Hz, sagittal perturbations. Forty-one individual trials were classified according to averaged cross-correlation lag between COM and COP displacement ($lag_{COM:COP}$) and relative head-to-ankle displacement ($\Delta_{head}/\Delta_{ankle}$) using a k-means analysis. This process revealed two dominant patterns, one for which the $lag_{COM:COP}$ was positive (Group 1 ($n=6$)) and another for which it was negative (Group 2 ($n=5$)) . Group 1 (G1) absorbed power from the platform over most of the cycle, except during transitions in platform direction. Conversely, Group 2 (G2) participants applied power to the platform to maintain a larger margin between COM and COP position and also had larger knee flexion and ankle dorsiflexion, resulting in a lower stance. By the third repetition, the only kinematic differences were a slightly larger G2 linear knee displacement ($p=0.008$) and an antiphasic relationship of pelvis (linear) and trunk (angular) displacements. Therefore, it is likely that the strategy differences were detected by including COP in the initial screening method, because it reflects the pattern of force application that is not detectable by tracking body movements.

1. Introduction

Balance is critical for performing everyday tasks. However, as we grow older, this sense becomes less acute and the risk of falling increases (Horak et al., 1989). In fact, falls are the leading cause of accidental death for adults over 75 (Minino et al., 2006; Kung et al., 2008), many of which are related to performing simple daily activities. Beyond age-related degeneration, impaired balance is also a common outcome for many pathologies, including stroke, multiple sclerosis, Parkinson's disease, and traumatic brain injuries, leading to increased incidence of injuries and death (Horak et al., 1989; Newton, 1995; Rogers, 1996; Geurts et al., 2005). However, before new balance training and rehabilitation tools can be developed we must first develop a better understanding of the fundamental postural strategies used to maintain balance.

Unperturbed standing balance simply requires the body's center of mass (COM) to stay within the base of support (BoS) established by limits of center of pressure (COP) displacement (Creath et al., 2005). However, this task becomes more complicated in the presence of external perturbations that can move the COM outside of the standing BoS. The complexities presented by this scenario have led to dynamic representations such as the 'extrapolated' COM that incorporates COM velocity (Hof et al., 2005). Additionally, COP movement represents changes in plantarflexor moment about the ankles (Winter et al., 1996). Naturally, changes in these moments will require corresponding changes in the moments about other joints, resulting in additional changes in body position, which may also be controlled to attain another goal, such as the minimization of head displacement (Nashner, 1983; Dietz et al., 1993; Buchanan and Horak, 1999). Therefore, a synergistic relationship develops between COP and COM as the body responds to internal and external stimuli that challenge posture and balance. However, because of the body's multiple degrees of freedom and anthropometric heterogeneity

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