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The effects of initial movement dynamics on human responses to postural perturbations

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ABSTRACT

Falls are a major cause of injury, and often occur while turning, reaching, or bending. Yet, we have little understanding of how an ongoing feet-in place activity at the onset of imbalance, and its associated cognitive and biomechanical demands, influence our ability to recover balance. In the current study, we used an ankle-rocking paradigm to determine how the nature of the baseline task influences the balance recovery response to a backward support surface translation. Fourteen participants were instructed to "recover balance without stepping" and were perturbed at vertical while standing quietly ("S"), while ankle rocking and moving forward ("A_f"), or while ankle rocking and moving backward ("A_b"). The results showed that changes in rocking velocity at the time of the perturbation elicited changes in the incidence of stepping, magnitude of trunk angular displacements ($p < .01$), and the onset latencies of distal muscles (gastrocnemius and soleus, both $p < .01$) used to recover balance. In addition, plots of onset latencies across all muscles showed that onset latencies appeared to occur earlier in many muscles when participants held a static position compared to when they performed a dynamic task at the onset of the perturbation. The results suggest that muscle activities used to recover balance are tailored to the nature of the perturbation and the ongoing task, and that onset latencies are later when participants are performing a dynamic as opposed to static task at the time of a perturbation. These findings support previous research suggesting that automatic postural responses are highly adaptable to environmental, situational, and task demands.

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1. Introduction

In studies examining how the central nervous system (CNS) controls standing balance in response to postural perturbations, researchers have shown that automatic postural responses (that act to return the center of gravity (COG) to a position within the base of support) are altered by a variety of factors including stance width, body position, instruction, and emotional state (Carpenter, Frank, Adkin, Paton, & Allum, 2004; Henry, Fung, & Horak, 2001; Horak & Nashner, 1986; Jacobs & Horak, 2007; Tokuno, Carpenter, Thorstensson, & Cresswell, 2006). For example, Tokuno et al. (2006) showed that when participants stood quietly and there was baseline movement of the center of pressure (COP) in a direction opposite to the perturbation, participants showed more frequent stepping responses, earlier muscle onsets, and greater EMG amplitudes in antagonist muscles compared to neutral positions. In addition, postural anxiety has been shown to delay onset of the deltoid muscles in response to a perturbation. Furthermore, a change in the experimental instruction (i.e., fall versus recover balance or feet-in place versus change-in support) appears to influence the amplitude while preserving the sequence and onset latency of postural responses (Burleigh & Horak, 1996; Carpenter et al., 2004; Weerdesteyn, Laing, & Robinovitch, 2008). Collectively, these studies support the view that automatic postural responses are highly adaptable and are altered to meet the demands of the task as well as the context of the situation (Horak, Henry, & Shumway-Cook, 1997).

While these findings have advanced our understanding of the organization of postural responses, the vast majority of studies have perturbed participants during initial static states, such as quiet stance (Henry, Fung, & Horak, 1998; Horak & Nashner, 1986; Hsiao & Robinovitch, 1999; Keshner, Woollacott, & Debu, 1988; Mackey & Robinovitch, 2006; Nashner, 1977; Runge, Shupert, Horak, & Zajac, 1999). However, falls usually occur while performing whole body displacing (i.e., locomotion) and feet-in place (i.e., turning, reaching and bending) dynamic activities (Talbot, Musiol, Witham, & Metter, 2005), where the COG moves with substantial horizontal velocity. Recently, there has been greater emphasis on the impact of COG velocity on the limits of stability, and the threshold for protective stepping following manual waist pulls (Mille et al., 2003; Pai, Maki, Iqbal, McIlroy, & Perry, 2000; Pai & Patton, 1997; Pai, Rogers, Patton, Cain, & Hanke, 1998). While research has investigated the effects of dynamic activities such as locomotion on postural responses to a perturbation (Belanger & Patla, 1987; Marigold & Patla, 2002; Oddsson, Wall III, McPartland, Krebs, & Tucker, 2004), little research has investigated the effect of COG velocity associated with feet-in place dynamic activities on reactive balance control. More specifically, to our knowledge there is very little research on how the COG velocity during a feet-in place voluntary dynamic activity influences how we recover balance.

Research does however suggest that, when a postural perturbation is applied during an ongoing movement (as compared to an initial static state), there is a delay in the initiation of functionally relevant muscles that are fundamental to the appropriate balance correcting response. Researchers have suggested that this may be due to sensory discharge from the ongoing movement causing an attenuation in perturbation-specific afferent information (Quant, Maki, Verrier, & McIlroy, 2001; Staines, McIlroy, & Brooke, 2001). This has been manifested as late tibialis anterior onset when participants experienced a forward support translation during voluntary sway (Stelmach, Phillips, DiFabio, & Teasdale, 1989), delayed biceps femoris activation when participants marched in place prior to a backward perturbation (Maki, Quant, McIlroy, Perry, & Verrier, 1999), and delayed initiation of compensatory grasping in response to a support rotation when participants were seated and pedaling with the lower limbs (Quant et al., 2001). Although there appears to be a consistent delay in initiating a balance recovery response during the performance of an ongoing activity, the question remains whether this delay is dependent on the nature of the task (i.e., velocity) at the onset of the postural perturbation.

In the current study, we used a whole-body, feet-in place ankle rocking paradigm to determine how characteristics of the ongoing movement at the time of a postural perturbation affect specific features of the balance recovery strategy (incidence of stepping behavior, trunk segment kinematics and onset latencies of muscle activity). We were specifically interested in testing the hypothesis that,