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Posture-movement responses to stance perturbations and upper limb fatigue during a repetitive pointing task

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ABSTRACT

Localized muscle fatigue and postural perturbation have separately been shown to alter whole-body movement but little is known about how humans respond when subjected to both factors combined. Here we sought to quantify the kinematics of postural control and repetitive upper limb movement during standing surface perturbations and in the presence of fatigue. Subjects stood on a motion-based platform and repetitively reached between two shoulder-height targets until noticeably fatigued (rating of perceived exertion = 8/10). Every minute, subjects experienced a posterior and an anterior platform translation while reaching to the distal target. Outcomes were compared prior to and with fatigue (first vs. final minute data). When fatigued, regardless of the perturbation condition, subjects decreased their shoulder abduction and increased contralateral trunk flexion, a strategy that may relieve the load on the fatiguing upper limb musculature. During perturbations, kinematic adaptations emerged across the trunk and arm to preserve task performance. In contrast to our expectation, the kinematic response to the perturbations did not alter in the presence of fatigue. Kinematic adaptations in response to the perturbation predominantly occurred in the direction of the reach whereas fatigue adaptations occurred orthogonal to the reach. These findings suggest that during repetitive reaching, fatigue and postural perturbation compensations organize so as to minimize interaction with each other and preserve the global task characteristics of endpoint motion.

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1. Introduction

In order for humans to perform a reaching movement while standing, the control system must coordinate the body so as to ensure successful movement of the hand to the desired target while maintaining an upright, balanced posture. When performing such a task repetitively, as is the case in many occupations (e.g., manufacturing, carpentry) and leisure activities (sport, playing musical instruments), fatigue development can occur, reducing the capacity of some muscles. Faced with this intrinsic perturbation, the control system can maintain performance not just by adapting arm biomechanics but also by adapting whole-body postural control (Fuller, Lomond, Fung, & Côté, 2009). While it is clear that posture-movement control is adapted when fatigued, it remains unknown how the body is controlled when faced with an additional, extrinsic challenge such as a stance perturbation. In addition to a fundamental interest in better understanding the control underlying this dual task, the study of this condition is also practically relevant as it is similar to conditions experienced by individuals performing manual work on boats, trains, planes and other unstable surfaces.

Muscle fatigue, that can result from repetitive movements, is typically defined as a gradual phenomenon that leads to both the inability to maintain a certain level of force and to an increased perception of task difficulty (Enoka & Stuart, 1992). During submaximal tasks, fatigue is a developing phenomenon which may not lead to a decrease in target force but is typically associated with an increase in perceived effort (Jones & Hunter, 1983) and a reduced maximal force generating capability (Vøllestad, 1997).

In addition to reduced muscular capacity, fatigue may also affect movement quality due to altered afferent feedback arising from fatigued areas (Pedersen, Ljubisavljevic, Bergenheim, & Johansson, 1998; Pettorossi, Torre, Bortolami, & Brunetti, 1999; Windhorst & Kokkoroyiannis, 1991) and/or to altered central integration of sensory information (Allen & Proske, 2006). Since afferent feedback is utilized to maintain postural control (Bloem, Allum, Carpenter, Verschuuren, & Honegger, 2002; Horak, Nashner, & Diener, 1990; Kavounoudias, Gilhodes, Roll, & Roll, 1999; Nardone & Schieppati, 2004; Thompson, Bélanger, & Fung, 2011), it is not surprising that the presence of lower limb and trunk muscle fatigue has been shown to be associated with increased postural sway during quiet stance (Caron, 2003; Corbeil, Blouin, Bégin, Nougier, & Teasdale, 2003; Madigan, Davidson, & Nussbaum, 2006; Vuillerme, Pinsault, & Vaillant, 2005). The presence of localized fatigue has also been shown to be associated with significantly altered movement coordination during tasks spanning multiple joints (Bonnard, Sirin, Oddsson, & Thorstensson, 1994; Côté, Feldman, Mathieu, & Levin, 2008; Côté, Mathieu, Levin, & Feldman, 2002; Côté, Raymond, Mathieu, Feldman, & Levin, 2005; Forestier & Nougier, 1998; Gates & Dingwell, 2011), but not necessarily to poorer overall task performance (Gates & Dingwell, 2008). Indeed, during the performance of fatiguing, multi-joint movements the system can compensate for proprioceptive deficits (Emery & Côté, 2012; Vafadar, Côté, & Archambault, 2012) and reduced muscle capacity by increasing the contribution of non-fatigue areas while reducing the contribution of fatigued areas in order to maintain task performance (Boyas, Maisetti, & Guevel, 2009; Côté et al., 2002; Fuller et al., 2009; Strang, Berg, & Hieronymus, 2009).

Although previous studies have demonstrated the association of muscular fatigue with changes in both postural and movement control, the ways in which the system deals with both fatigue and postural perturbations at the same time remain poorly understood. Schmid, Schieppati, and Pozzo (2006) have shown postural sway measures to decrease in amplitude while endpoint (EP) precision remained unchanged during a repetitive bend-to-reach task which induced fatigue in the hip flexors. In contrast, Nussbaum (2003) and Sparto, Parnianpour, Reinsel, and Simon (1997) have both reported increased postural sway during a repetitive lifting task and a repetitive pointing task, respectively. In a study examining postural perturbations to the trunk following fatiguing of lumbar back extensions, Wilson, Madigan, Davidson, and Nussbaum (2006) found postural reaction strategies change with the development of fatigue and that these adaptations occur across several joints. Research from our group has shown that fatigue alters both postural and movement kinematics of the upper limb during a repetitive pointing task in what appears to be a task-specific manner (Côté et al., 2002, 2005, 2008; Fuller