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The effect of elbow flexor fatigue on spine kinematics and muscle activation in response to sudden loading at the hands

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ABSTRACT

Sudden loads, originating at either the hands or the feet, can cause injury to spine structures. As muscles are primarily responsible for stabilization following a perturbation, the effect of spine muscle fatigue in this context has been well investigated. However, the effect of fatigue of arm muscles, which can help control perturbations originating at the hands, on the spine is unknown. The purpose of this study was to determine if the magnitude of spine flexion or the pre-activation, reflex amplitude, and reflex latency of spine muscles were altered by elbow flexor fatigue during a sudden loading (6.8 kg) perturbation at the hands. Elbow flexor fatigue was induced by an isometric 30% maximal elbow flexion moment until failure. Results demonstrate that spine kinematics were not altered in the presence of elbow flexor fatigue. Small magnitude differences in trunk muscle pre- and peak activation indicate that the presence of elbow flexor fatigue does not necessitate substantially greater spine muscle action under the tested conditions. Despite fatigued elbow flexors, the arm muscles were sufficiently able to control the perturbation. Interestingly, 5/14 participants demonstrated altered reflex latencies in all observed muscles that lasted up to 10 min after the fatiguing task.

1. Introduction

The spine can be vulnerable to perturbations that arise at either the feet or the hands and travel through the kinetic chain. The spine, an inherently unstable structure (Crisco and Panjabi, 1992), relies on muscular responses to maintain stability (Cholewicki and McGill, 1996). When the spine is perturbed, muscle reflex responses are required to minimize spine motion, as intrinsic stiffness is not sufficient to prevent large rotations (Brown and McGill, 2009). Further, poorly coordinated muscle activations can overload or destabilize the spine, increasing the risk of injury (Magora, 1973; Cholewicki and McGill, 1992; Brown et al., 2006). Therefore, optimal functioning of spine muscles is important for minimizing risk of injury during perturbations.

To better understand how spine muscles respond to perturbations, many studies have been performed investigating the effects of pre-activation (e.g. Granata et al., 2001), anticipatory adjustments (Brown et al., 2003; Grondin and Potvin, 2009), or the presence of low back pain (Wilder et al., 1996; Gregory et al., 2008; Mok et al., 2011). As muscles are largely responsible for controlling perturbations, the effect of spine and abdominal muscle fatigue has also been well investigated (Wilder et al., 1996; Granata et al., 2001; Chow et al., 2004; Grondin and Potvin, 2009; Dupeyron et al., 2010). Herrmann et al. (2006) and Dupeyron et al., 2010 both reported increases in reflex amplitude of erector spinae muscles after spine muscle fatigue when the trunk was suddenly perturbed. Grondin and Potvin (2009) found that prior to perturbation at the hands, spine muscle pre-activation and co-contraction increased when the spine muscles were fatigued. Increased pre-activation and co-contraction is a common strategy to help maintain spine stiffness (van Dieën et al., 2003). The effect of spine muscle fatigue on reflex latency remains unclear with studies reporting increases (Hagbarth et al., 1995; Wilder et al., 1996) or no changes (Granata et al., 2004; Herrmann et al., 2006; Dupeyron et al., 2010) in latencies.

Spine perturbations are often elicited experimentally by either suddenly loading (Gregory et al., 2008; Grondin and Potvin, 2009) or unloading the hands (Brown et al., 2003; Chow et al., 2004). When perturbed through the hands, upper limb muscles are able to modulate the perturbation before it is transmitted to the spine. The elastic storage and dissipation of energy are determined by elbow stiffness and damping, respectively; both stiffness and damping are heavily influenced by the surrounding muscles.

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Muscle stiffness is relatively proportional to the generated force (Morgan, 1977; Bergmark, 1989) and therefore increases from pre-activation (intrinsic stiffness) to peak activation levels (reflexive stiffness) (Brown and McGill, 2009). The overall stiffness of the elbow will determine the maximum angular displacement following the perturbation. Muscles are also going to influence elbow damping, as eccentric contractions along with stretch of viscoelastic tissues are largely responsible for energy dissipation. Any impairment in force production, such as during local muscle fatigue, has the potential to affect the elastic storage and dissipation of energy at the elbow. It remains unknown whether elbow flexor fatigue affects the transmission of energy to the lumbar spine.

The purpose of this study was to determine the effect of elbow flexor fatigue on spine kinematics and muscle activation following a moderate perturbation to the hands. It was hypothesized that the effective perturbation to the spine would be increased resulting in greater spine angular displacement following elbow flexor fatigue. Pre- and peak activation of spine muscles were also expected to increase in order to maintain spine stiffness in preparation for the perturbation and reflexively control spine movement, respectively.

2. Methods

2.1. Participant characteristics

Fourteen healthy males (mean ± SD; age: 22 ± 1.7 years; mass: 75 ± 8.1 kg; height: 179 ± 6.3 cm) with no history of upper limb, shoulder, neck, or back injury participated in this study. Participants were recruited from the student population at the university and were asked to abstain from any strenuous arm or back exertions for three days prior to data collection. The Research Ethics Board at the university approved this study.

2.2. Protocol

Participants completed three isometric maximal voluntary elbow flexor moment contractions for each arm. Instructions were to slowly ramp up to maximal contraction against a force transducer (Vernier, Beaverton, OR) over three seconds and hold the maximal contraction for a further two seconds. Force data, collected at 100 Hz, were not provided as feedback to the participants. Maximum elbow flexion force was calculated as the average force over 500 ms centered at the peak force.

Three maximal voluntary contractions (MVC) were also performed for each of bilateral biceps brachii (BB) and triceps brachii (TB) and unilateral latissimus dorsi (LD), thoracic erector spinae (TES), lumbar erector spinae (LES), and external oblique (EO), as per McGill (1991) and Frost et al. (2012). Instructions were the same as above and manual resistance was applied to ensure all contractions were isometric. MVCs for BB and TB were completed while standing with 0° and 90° of shoulder and elbow flexion, respectively. Participants generated maximal elbow flexion moments with forearms fully supinated and extension moments with forearms mid-supinated for BB and TB MVCs, respectively. LD MVCs were completed while standing with 90° each of shoulder abduction and elbow flexion. Participants generated maximal shoulder adduction moments. For TES and LES MVCs, participants lay prone with anterior superior iliac crests at the edge of a bench with the upper body unsupported. Participants generated maximal back extension moments from an approximate neutral spine position. For EO MVCs, participants sat with knees, hips, and spine flexed in a mid-sit up position. Participants generated maximal flexion, left lateral bend, and right axial twist moments.

Participants completed a fatiguing isometric elbow flexion task to failure and four blocks of five sudden hand loading perturbations. Perturbation blocks were performed before the fatigue task (Pre), and zero (0-Post), five (5-Post) and ten (10-Post) minutes after the fatigue task. Before each block of perturbations, participants were asked to rate their perceived exertion (RPE), with zero being not fatigued at all and ten being completely fatigued.

2.3. Perturbations

Participants stood comfortably holding a box, with handles, anterior to their body with shoulders and elbows at 0° and 90°, respectively (Fig. 1). A 6.8 kg mass was dropped into the box from a height of ~2 cm (Gregory et al., 2008). This perturbation has been shown to elicit spine flexion and reflexive activation of spine muscles. The same researcher dropped the mass for every participant and care was taken to ensure that the drop height was consistent.

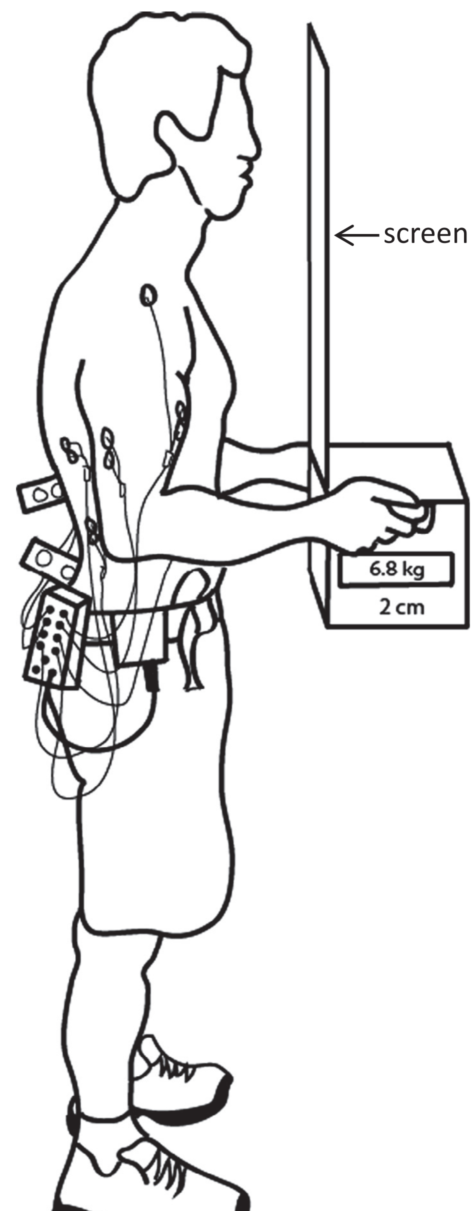

Fig. 1. Sagittal view of participant during perturbation.