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The effects of short-term and long-term experiences on co-contraction of lower extremity postural control muscles during continuous, multi-directional support-surface perturbations

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ABSTRACT

While reactive balance control in response to single perturbations in quiet standing is relatively well understood, some occupational environments (e.g. maritime environments) expose workers to continuous, multi-directional challenges to balance and postural control, which require workers to respond to the current perturbation, as well as anticipate coming perturbations. Investigation of muscle activation patterns during continuous, multi-directional perturbations, and the role of previous experience, is warranted to better understand postural control strategies in these types of environments. This study aimed to identify changes in co-contraction in the lower extremity postural control muscles during multi-directional support-surface perturbations as a result of short-term and long-term experience. Twenty-five participants (12 with minimal experience (novice), 13 with ≥6 months experience working in moving maritime environments (experienced)) were exposed to five 5-minute trials of continuous support-surface perturbations. Muscle activity was recorded from six muscles bilaterally. Co-contraction indices were calculated for selected muscle pairings and compared between groups and trials. Co-contraction decreased across trials, and was lower in the experienced group relative to the novice group. These findings provide insight into the influence of previous experience on muscle activation during reactive balance control, and suggest that increased co-contraction may be a potential mechanism of the increased risk of workplace fatigue, falls, and injury in novice maritime workers. The development and refinement of training programs targeting novice workers may be a potential avenue to reduce fall and injury risk in maritime environments.

Introduction

A variety of occupational environments, such as maritime occupations, impose movement on workers. Challenges such as balance problems and physical fatigue are present to a greater extent in moving environments compared to stationary environments (Wertheim, 1998). These challenges may contribute to the higher incidence of both accidents (Hansen, 1996) and fatalities (Driscoll et al., 1994) in maritime workers compared to land-based occupations. In addition, the proportion of slip-, trip-, and fall-related injuries is much higher in maritime workers (43% of injuries; Jensen et al., 2005) compared to land-based occupations (17% of injuries; U.S. Bureau of Labor Statistics, 2015). Within maritime workers, inexperience may further increase the risk for fatal incidents (Driscoll et al., 1994). Similarly, greater proportions of falls and fall-related injuries have been observed in commercial fishermen < 20 years old, compared to those between the ages of 20–50 years (Jensen, 2000). Experience has also been found to influence fatigue levels in maritime workers on high-speed watercraft, with higher fatigue for less-experienced workers (Leung et al., 2006).

Workers in offshore environments are regularly exposed to external perturbations that are unpredictable, continually changing, and multi-directional (Duncan et al., 2014a). With these types of perturbations, the central nervous system must produce both feedforward responses for the oncoming perturbation, and feedback mechanisms for the perturbation at hand. Consequently, an adequate response must be produced for the current perturbation without compromising stability for the oncoming perturbation. These responses require complex patterns of muscle activity to meet these demands and prevent a loss of balance. Previous work has examined average muscle activation levels during postural control tasks in moving environments (Grover et al., 2013; Holmes et al., 2008; Matthews et al., 2007). Further, Ingram et al. (2016) found that individuals with previous experience on a laboratory

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motion platform demonstrated reduced lower extremity muscle activation compared to those who had no experience with the platform. However, examination of the patterns of muscle activation (i.e. co-contraction) is warranted to better understand how muscle activity is coordinated to maintain balance when responding to continuous multi-directional perturbations.

Co-contraction refers to the concurrent activation of two muscles (Lewek et al., 2004; Missenard et al., 2008; Rudolph et al., 2000; Silvestri et al., 2013), and provides a measure of the relationships between the activation patterns of pairings of muscles. Co-contraction contributes to increased joint stiffness, which is often used as a compensatory strategy to maintain or regain balance in response to balance challenges (Allum et al., 2002; Reynolds, 2010). As such, the study of co-contraction in postural control research has mainly focused on quiet standing (Benjuya et al., 2004; Laughton et al., 2003; Nagai et al., 2013; Sozzi et al., 2013); clinical tests of dynamic stability (Nagai et al., 2013); or discrete perturbations (Horak et al., 1989; Welch & Ting, 2014). Co-contraction has been quantified using ratios between antagonist pairs (Benjuya et al., 2004), or between the antagonist and total muscle activity (Nagai et al., 2013); and as the percentage of a trial that both muscles are active (Laughton et al., 2003). The former methods quantify the activation of one muscle relative to the other or to total activation; while the latter method focuses specifically on the timing of activation. However, neither of these methods account for the magnitude of muscle activation. Furthermore, the majority of studies focus solely on co-contraction levels between antagonist pairs, but have neglected the quantification of co-contraction between synergist pairs, which are necessary to obtain full representation of activation patterns within the lower extremity.

The co-contraction index (CCI) (Lewek et al., 2004; Rudolph et al., 2000) incorporates both the magnitude and timing of activation for the muscles of interest (Rudolph et al., 2000; Schinkel-Ivy et al., 2013; Silvestri et al., 2013). In addition, it avoids divide-by-zero errors (Rudolph et al., 2000); and it does not require the assignment of agonist and antagonist roles to muscles, which is particularly useful for postural control tasks in which these roles can not always be clearly identified (Nelson-Wong et al., 2012). While this index has not been widespread in postural control research to date, previous work conducted in older adults has related high CCI values around the ankle during quiet standing to being identified as at-risk for falls, based on clinical tests of fall risk (Nelson-Wong et al., 2012). As balance is compromised in moving environments, thereby increasing fall risk, CCI may potentially represent an important measure for quantifying postural control in these environments. Previous experience may also influence co-contraction levels. For example, Welch and Ting (2014) found reductions in co-contraction around the ankle over repeated trials of discrete standing perturbations, while Freyler et al. (2016) observed reductions in lower extremity co-contraction due to perturbation training. Similarly, Sigward and Powers (2006) observed greater co-contraction around the knee during a side-step cutting task in novice athletes, compared to experienced athletes. These findings may suggest that if novice workers in a maritime environment exhibit higher levels of co-contraction, this may represent an underlying mechanism for the higher occurrence of falls in this group, compared to experienced workers. As such, there is a need to quantify the effects of both short-term and long-term experience in moving environments on co-contraction levels.

Therefore, the purpose of this study was to quantify the effects of short-term (one session with multiple 5-minute trials) and long-term (≥6 months) experience on muscle activation patterns in the lower extremities during postural responses to large, continuous, multi-directional support-surface perturbations. It was hypothesized that co-contraction would decrease with short-term experience, and would be lower for individuals with long-term experience (experienced group) compared to individuals with minimal experience (novice group).

Methods

Participants

This was a secondary analysis of previously collected and published data (Duncan et al., 2016). Twelve novice individuals (6 male and 6 female) with no maritime work experience (novice group) and 13 (10 male and 3 female) individuals with a minimum of 6 months of maritime work experience (experienced group) were recruited (Duncan et al., 2016). All participants were between 20- and 40 years old, to minimize age-related effects in postural response. Exclusion criteria for all participants were determined through a self-reported survey, and consisted of: susceptibility to motion sickness, presence of medical conditions that would adversely affect balance, and the presence of musculoskeletal injuries or other impairments that would prevent them from safely exercising (Duncan et al., 2016). Additional inclusion criteria for individuals in the novice group were: no experience working in offshore environments, and < 2 weeks of lifetime cumulative experience in recreational boating activities (Duncan et al., 2016). Inclusion criteria for individuals in the experienced group were: ≥6 months of experience working in moving maritime environments, and actively working in a moving maritime environment in the last year (Duncan et al., 2016). All participants provided informed consent prior to participation. The Interdisciplinary Committee on Ethics in Human Research at Memorial University of Newfoundland approved all data collection procedures (Duncan et al., 2016).

Instrumentation

All trials were performed on a Moog 6DOF2000E electric motion platform (Moog Inc., Elma, NY, USA) equipped with a 2 m-by-2 m metal platform with 1.02 m high railings along the perimeter (Duncan et al., 2016). A canopy enclosure eliminated external horizontal and vertical cues of the non-moving environment from the participant's field of vision. Platform motions were derived from captured wave-induced ship motions using linear wave theory to produce complex linear combinations of sine functions differing in amplitudes, frequencies, and phases (Lloyd, 1993). Five degrees of freedom were used (roll, pitch, heave, surge, and sway). The magnitude and frequency of the motion profile were modified to produce platform motions that were expected to induce instability while still assuring that the motions were realistic to those recorded *in situ* (Duncan et al., 2014a,b, 2016). Linear equations used to develop all motion profiles are detailed (Eqs. (1)–(5), with each equation calculating a position in time in degrees (pitch, roll) or meters (heave, surge, sway). The resultant 5-minute motion profiles were identical for all participants across all trials (Table 1). Motions about the z-axis (yaw) were not included due their minimal contribution to wave-induced platform motions.

$$Roll = 0.8(6\sin(1.050t) + 1.25\sin(0.11t + 0.5)) \quad (1)$$

$$Pitch = 0.8(2.5\sin(1.76t + 0.5) + \sin(t) - 1.5) \quad (2)$$

$$Heave = 0.1(5\sin(1.595t + 2) + 15\sin(1.21t)) \quad (3)$$

$$Surge = 0.1(7.8\sin(0.649t + 4.8) + 7.8\sin(0.825t + 3.8) + 0.5) \quad (4)$$

$$Sway = 0.1(18\sin(0.583t + 5) + 9\sin(1.122t + 5.4) - 0.25) \quad (5)$$

Muscle activation amplitudes of the tibialis anterior (TA), medial gastrocnemius (MG), peroni group (PER), vastus lateralis (VL), biceps femoris (HAM), and gluteus medius (GLUT) were measured bilaterally during all motion trials using surface electromyography (EMG). Electrode sites were shaved and cleaned with isopropanol prior to securing the electrodes to ensure optimal signal quality. Electrode placement (Table 2) was determined using guidelines provided by Criswell and Cram (2010). Signals were differentially amplified (frequency response 20–450 Hz, common mode rejection > 80 dB, EMG baseline noise of