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Activation amplitude and temporal synchrony among back extensor and abdominal muscles during a controlled transfer task: Comparison of men and women

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ABSTRACT

Muscle synergies are important for spinal stability, but few studies examine temporal responses of spinal muscles to dynamic perturbations. This study examined activation amplitudes and temporal synergies among compartments of the back extensor and among abdominal wall muscles in response to dynamic bidirectional moments of force. We further examined whether responses were different between men and women. 19 women and 18 men performed a controlled transfer task. Surface electromyograms from bilateral sites over 6 back extensor compartments and 6 abdominal wall muscle sites were analyzed using principal component analysis. Key features were extracted from the measured electromyographic waveforms capturing amplitude and temporal variations among muscle sites. Three features explained 97% of the variance. *Scores* for each feature were computed for each measured waveform and analysis of variance found significant ($p < .05$) muscle main effects and a sex by muscle interaction. For the back extensors, post hoc analysis revealed that upper and more medial sites were recruited to higher amplitudes, medial sites responded to flexion moments, and the more lateral sites responded to lateral flexion moments. Women had more differences among muscle sites than men for the lateral flexion moment feature. For the abdominal wall muscles the oblique muscles responded with synergies related to fiber orientation, with women having higher amplitudes and more responsiveness to the lateral flexion moment

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than men. Synergies between the abdominal and back extensor sites as the moment demands change are discussed. These findings illustrate differential activation among erector spinae compartments and abdominal wall muscle sites supporting a highly organized pattern of response to bidirectional external moments with asynchronies more apparent in women.

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1. Introduction

Neuromuscular control of spinal motion and stability relies on the integration of responses from all of the trunk muscles (Cholewicki & McGill, 1996; Panjabi, 2006). Modeling and empirical studies of the trunk suggest muscle activation patterns must be coordinated within tight tolerances to maintain dynamic stability of the spine while at the same time minimizing joint loads and risk of a low back injury (Bergmark, 1989; Brown, Vera-Garcia, & McGill, 2006; Cholewicki & McGill, 1996; Gardner-Morse & Stokes, 1998; Granata & Orishimo, 2001). Typically considered a single muscle unit, the erector spinae group, together with the abdominal wall muscles is an important spinal stabilizer (Bergmark, 1989). However, the erector spinae is separated morphologically into fascicles that span different vertebral levels and into separate muscles suggesting differential central nervous system (CNS) control (Bustami, 1986; Macintosh & Bogduk, 1987). In fact, a recent study using transcranial magnetic stimulation showed discrete organization of the motor cortex consistent with differential activation of the paraspinal muscle fascicles (Tsao, Danneels, & Hodges, 2011). Similarly, the abdominal wall is made up of distinct muscles that have different fiber orientations with separate innervations (Dumas, Poulin, Roy, Gagnon, & Jovanovic, 1991; Kondo & Bishop, 1987; Miyauchi, 1983; Ng, Kippers, & Richardson, 1998). Together this evidence supports the capability of independent CNS control of the trunk musculature.

Early studies of independent CNS spinal control show amplitude differences among back muscle sites at different spinal levels during trunk flexion–extension (Jonsson, 1970, 1973) with onset time differences reported during spinal rotations (Morris, Benner, & Lucas, 1962). More recent studies confirm differential amplitude responses for back muscles such as the medial verses lateral erector spinae sites based on the direction of the applied external moment during static planar efforts (Butler, Hubley-Kozey, & Kozey, 2009a, 2009b; Thelen, Schultz, & Ashton-Miller, 1995; Vink, van der Velde, & Verbout, 1988). When the task becomes dynamic, representing more functional demands, the erector spinae responds in a systematic fashion by increasing or decreasing activation amplitudes that correspond to the consecutive levels of the spinal column (de Seze, Falgairolle, Viel, Assaiante, & Cazalets, 2008). Segments within abdominal muscles have been shown to have diverse activations with their relative muscle responses related to the magnitude (Lavender, Tsuang, Andersson, Hafezi, & Shin, 1992; Perez & Nussbaum, 2002) and direction of the external forces acting on the spine (Butler, Hubley-Kozey, & Kozey, 2010) as well as whether the task is static or dynamic (Butler et al., 2009a, 2009b; de Looze, Groen, Horemans, Kingma, & van Dieën, 1999; Mirka, Kelaher, Baker, Harrison, & Davis, 1997; Moreside, Vera-Garcia, & McGill, 2008). Despite the stated importance of muscle synergies to respond to dynamically changing moments in an appropriate manner for protecting the spine from potentially damaging forces (Cholewicki & McGill, 1996; Panjabi, 2006), only a few studies have examined synergistic responses to dynamic perturbations by exploring the temporal patterns of the trunk musculature (Butler, Lariviere, Hubley-Kozey, & Sullivan, 2010; Hubley-Kozey, Hatfield, & Davidson, 2010; Hubley-Kozey & Vezina, 2002a; Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006; van der Hulst, Vollenbroek-Hutten, Rietman, & Hermens, 2010).

In studies of muscle co-activation, coordination or synergies, the experimental task is often unconstrained resulting in kinematic and kinetic influences on muscle responses (Anders, Wagner, Puta, Grassme, & Scholle, 2009) confounding the assessment of basic CNS control. In addition, often only discrete measures such as activation amplitudes (Anders, Brose, Hofmann, & Scholle, 2007), co-activation indices (Kellis, Arabatzi, & Papadopoulos, 2003; Lewek, Rudolph, & Snyder-Mackler, 2004), onset and offset times (MacDonald, Moseley, & Hodges, 2010; Radebold, Cholewicki, Polzhofer, & Greene,

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