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ANTICIPATORY POSTURAL ACTIVITY OF THE DEEP TRUNK MUSCLES DIFFERS BETWEEN ANATOMICAL REGIONS BASED ON THEIR MECHANICAL ADVANTAGE

R. J. PARK, [a,b] **H. TSAO,** [a] **A. G. CRESSWELL** [a,b] **AND P. W. HODGES** [a]*

[a] *The University of Queensland, NHMRC Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Sciences, Brisbane, Queensland, Australia*

[b] *The University of Queensland, Centre for Sensorimotor Neuroscience, School of Human Movement Studies, Brisbane, Queensland, Australia*

Abstract—The functional differentiation between regions of psoas major (PM) and quadratus lumborum (QL) may underlie a mechanical basis for recruitment of motor units across the muscle. These mechanically unique fascicle regions of these complex multifascicular muscles, PM and QL, are likely to be controlled independently by the central nervous system (CNS). Fine-wire electrodes recorded the electromyographic activity of the PM fascicles arising from the transverse process (PM-t) and vertebral body (PM-v) and the anterior (QL-a) and posterior (QL-p) layers of QL on the right side during a postural perturbation associated with rapid arm movements. The findings of this study indicate that the CNS coordinates the activity of specific regions of PM and QL independently as a component of the anticipatory postural adjustments that precedes the predictable challenge to the spine associated with limb movements. The spatial and temporal features of discrete activity of different regions within PM and QL matched their differing mechanical advantage predicted from their anatomy. These findings suggest that the CNS differentially activates individual regions within complex spine muscles to control the three-dimensional forces applied to the spine. The data also point to a sophisticated control of muscle activation that appears based on mechanical advantage.

Key words: lumbar spine, trunk muscles, fine-wire electromyography, postural control.

INTRODUCTION

Trunk muscles have complex biomechanics, and regions within a single trunk muscle can have discrete mechanical actions on the spine and pelvis. Motor units dispersed across mechanically unique regions within a single muscle may be selectively controlled by the nervous system to meet task demands based on their mechanical efficiency (Gandevia et al., 2006) rather than recruitment based on the simple 'size principle' that implies smaller motor units will be recruited before larger units (Henneman, 1957). There is a clear evidence for functional differentiation between the fascicle bundles of the psoas major (PM) and quadratus lumborum (QL) muscles that may underlie a mechanical basis for recruitment of motor units across the muscle. For instance, PM fascicles can generate flexor or extensor moments at the trunk based on their orientation relative to the instantaneous axis of rotation (IAR) of the lumbar segments (Park et al., 2013). Complicating this relationship is the potential for this mechanical difference in function of PM fascicles to vary as the IAR changes with alteration of spinal curvature and fibers can change from having a relative flexion to extension moment (Bogduk et al., 1992). Thus, difference in posture would require modification of recruitment of muscle activity between muscle regions for an otherwise identical task. Such complexity suggests a high degree of sophistication of control of the discrete fascicles in these complex muscles. One method to test the degree to which the higher centers plan control of the discrete muscle fascicles is to investigate anticipatory postural adjustments (APAs). These adjustments are pre-planned by the central nervous system (CNS), based on the predicted demands of a future predictable task, such as the challenge to the spine resulting from the reactive moments associated with voluntary limb movements. It is unknown whether the CNS discretely controls the mechanically unique fascicle regions of complex multifascicular muscles such as PM and QL as a component of the APAs.

On the other hand, the potential functional advantage of discrete control of mechanically unique regions within one muscle during the APAs may be limited by lateral transmission of force. Such lateral transmission of force would limit the potential for discrete fascicles to generate unique forces (Street, 1983) as much of the longitudinal force generated by a single muscle fiber is

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*Corresponding author. Address: The University of Queensland, NHMRC Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Sciences, Brisbane, Queensland 4072, Australia. Tel: +61-7-3365-2008; fax: +61-7-3365-1284.

E-mail address: p.hodges@uq.edu.au (P. W. Hodges).

Abbreviations: ANOVA, analysis of variance; APAs, anticipatory postural adjustments; CNS, central nervous system; EMG, electromyography; ES, erector spinae; IAR, instantaneous axis of rotation; OE, obliquus externus abdominis; OI, obliquus internus abdominis; PM, psoas major; QL, quadratus lumborum; RMS, root mean square; SD, standard deviation; TrA, transversus abdominis.

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transmitted laterally via the adjacent complex intramuscular connective tissue (Street, 1983; Huijing, 1999). Although lateral transmission could limit the generation of discrete forces by discrete muscle fascicles, previous studies have shown differences in the timing of activity between fascicle regions in other muscles such as multifidus (Moseley et al., 2002) and transversus abdominis (TrA) (Urquhart and Hodges, 2005). A major difference is that in those muscles the discrete fascicles generate force in a similar direction, but with different vectors. Thus, variation in temporal aspects of control of those two fascicles would be unlikely to be limited by lateral transmission of force. In contrast, for PM the functions are potentially opposite (flexion vs. extension) and the effects of lateral transmission of force may be more problematic. The CNS could take advantage of the lateral transmission of force and co-contract the muscle fascicles as a mechanism to enhance spine stiffness.

The first aim of this study was to investigate whether regions within PM with opposite functions are controlled independently in advance of a predictable challenge to the spine as a component of the APA. Two alternatives were considered: the CNS may coordinate differential activation of the fascicles within PM based on the direction of reactive moments at the spine, or the CNS may co-contract the fascicles to augment spine stiffness. If discrete activity was identified, a second aim of the study was to determine whether such activity (timing and/or amplitude) of regions within a single muscle with opposite function was consistent with that predicted by the mechanical demands of the postural task.

To address these aims, an established paradigm (Cordo and Nashner, 1982; Bouisset and Zattara, 1987; Hodges and Richardson, 1997) that challenges equilibrium of the trunk during a rapid voluntary arm movement is used. The reactive forces from arm movement provide a predictable perturbation to the spine and the CNS initiates APAs that include preparatory movements of the trunk and pelvis (Zattara and Bouisset, 1988; Aruin and Latash, 1995; Hodges et al., 1999, 2000). These movements are matched to the mechanical demands and occur in all planes (i.e. in the sagittal, frontal and transverse planes) according to the direction and side of the unilateral arm movement (Hodges et al., 2000).

EXPERIMENTAL PROCEDURES

Participants

Thirteen healthy individuals (nine males and four females) with a mean (standard deviation, SD) age, height and weight of 24 (2) years, 170 (6) m, and 64 (13) kg, participated in this study. Participants were excluded if they had any major circulatory, orthopedic, neurological or cardiorespiratory conditions, recent or current pregnancies, any history of back pain, or previous surgery to the abdomen or back. All procedures were approved by the Institutional Medical Research Ethics Committee at The University of Queensland, and conformed to the Declaration of Helsinki. Participants provided written informed consent and few participants were also involved in another studies (Park et al., 2012, 2013).

Electromyography

A previously established protocol (Park et al., 2012, 2013) was used to record electromyographic (EMG) activity of PM-t, PM-v, QL-a and QL-p on the right side at the L3/4 spinal level. Two Teflon-coated 75-μm stainless steel wires (1 mm of Teflon removed and bent back to form 1- and 2-mm hooks) were threaded into a hypodermic needle (0.70 × 150 mm for PM and 0.65 × 70 mm for QL), and inserted into each muscle with ultrasound guidance (5–10 MHz, Logiq9, GE Healthcare, Wauwatosa, WI). Preliminary investigation was conducted on cadavers and ultrasound examination of healthy volunteers to confirm the anatomy of different regions of each muscle. As the fibers of the middle layer of QL were difficult to isolate from the other layers, it was not investigated.

Pairs of surface electrodes (Ag/AgCl disks, 10 mm in diameter, Noraxon, USA) were placed over the anterior and posterior regions of the deltoid muscles of both arms. Recordings of typical trunk extensor (erector spinae [ES]) and flexor/rotator muscles (obliquus externus abdominis [OE] and obliquus internus abdominis [OI]) were also made for comparison to assist interpretation of the function of the regions of PM and QL. To record from these muscles, surface electrodes were placed over right ES (2 cm lateral to the L4 spinous process) and over right OE and OI using electrode orientations described by Ng et al. (1998). A ground electrode was placed over the right anterolateral aspect of the caudal rib cage.

EMG data were amplified 2000 times, band pass filtered between 10 Hz and 1.5 kHz using a TeleMyo telemetered EMG system (Noraxon, Scottsdale, AZ) and sampled at 2 kHz using a Power1401 Data Acquisition System with Signal 3 software (Cambridge Electronic Design, Cambridge, United Kingdom).

Arm movement

Angular displacement of the arm was recorded using a potentiometer fixed to an upright support. A lightweight bar was attached to the shaft of the potentiometer and strapped to the wrist. The axis of rotation of the potentiometer was aligned with the estimated axis of rotation for flexion and extension of the glenohumeral joint. For bilateral arm movements, the bar was attached to the left arm.

Procedure

Participants stood with feet shoulder-width apart and arms by their sides in a relaxed manner. They were instructed to flex or extend the shoulder(s) to ~45° from the horizontal as quickly as possible with the elbow extended in response to a stimulus light. Red and green lights were used to cue flexion and extension movements, respectively. The direction of movement