Activity of deep abdominal muscles increases during submaximal flexion and extension efforts but antagonist co-contraction remains unchanged

Donna T. McCook, Bill Vicenzino, Paul W. Hodges *

NHMRC Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Science, University of Queensland, Brisbane, Qld 4072, Australia

Received 25 May 2007; received in revised form 1 November 2007; accepted 2 November 2007

Abstract

Lumbo-pelvic stability relies, amongst other factors, on co-contraction of the lumbo-pelvic muscles. However, during submaximal trunk flexion and extension efforts, co-contraction of antagonist muscles is limited. It was predicted that activity of the deeper lumbo-pelvic muscles that are often excluded from analysis (transversus abdominis (TrA) and the deep fascicles of multifidus (DM)), would increase with load in each direction. In eleven healthy subjects, electromyographic activity (EMG) was recorded from eight trunk muscles using surface and fine-wire electrodes. Subjects performed isometric flexion and extension efforts to submaximal loads of 50, 100, 150 and 200 N and a maximal voluntary contraction (MVC). Loading tasks were then repeated in trials in which subjects knew that the load would release at an unpredictable time. Compared to the starting position, EMG of all muscles, except DM, increased during MVC efforts in both directions. During the flexion and extension submaximal tasks, there was no increased co-contraction of antagonist muscles. However, TrA EMG increased in both directions. In the unpredictable trials, EMG of all lumbo-pelvic muscles except TrA was decreased. These findings provide further support for a contribution of TrA to lumbo-pelvic stability. In submaximal tasks, TrA activation may enhance stability as a strategy to improve trunk stiffness without requiring a concurrent increase in activity of the larger torque producing trunk muscles.

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Co-contraction; Trunk muscles; Lumbar spine; Stability

1. Introduction

Co-contraction of the lumbo-pelvic muscles is required even in neutral upright postures because the passive structures of the spine are inadequate to maintain stability of the lumbar spine (Cholewicki and McGill, 1996; Crisco and Panjabi, 1991; Gardner-Morse et al., 1995; Granata and Marras, 1995). Modelling studies predict that the level of co-contraction depends on the demands for spinal control, which are influenced by factors such as the nature and magnitude of applied loads and the stability of the task (Granata et al., 2005). However, co-contraction of antagonist muscles are not generally observed in tasks that involve submaximal isometric or isotonic flexion or extension efforts (Bartelink, 1957; Cresswell and Thorstensson, 1989; Granata and Marras, 1995; Granata et al., 2005; Silfies et al., 2005). It is unclear whether this suggests that no increase in co-contraction is required during isometric flexion or extension efforts, or whether the data are explained by lack of consideration of the redundancy in the motor system (i.e. many muscles are capable of contributing to spinal stability (Cholewicki and Van Vliet, 2002)) including the possible contribution of deeper trunk muscles. These muscles are often excluded from analysis of trunk muscle function.

It is possible, if not likely, that the strategy for increased muscle activity with increased demand for stability may
differ between tasks and individuals. Consistent with this proposal, recent data suggest that the stability of the spine is increased in individuals with low back pain (Van Dieen et al., 2003), but with considerable variation in muscle activation strategy (Hodges et al., 2006). Furthermore, despite evidence that the deeper muscles of the lumbo-pelvic region (e.g. transversus abdominis, lumbar multifidus) provide a contribution to the control of the spine (Barker et al., 2006; Hodges et al., 2003; Kaigle et al., 1995; Wilke et al., 1995) and pelvis (Richardson et al., 2002), few studies have considered the contribution of these muscles in progressive spinal loading (Cresswell, 1993). Activity of these deeper muscles with increased load may preclude or compliment increased co-contraction of the more superficial trunk muscles.

This study aimed to investigate the activity of the deep and superficial trunk muscles during submaximal and maximal flexion and extension efforts. The influence of reduced task predictability on the activation of deep and superficial trunk muscles was also examined.

2. Methods

2.1. Subjects

Eleven males with a mean (SD) age, height and weight of 27 (7) years, 1.8 (0.9) m, 75.5 (10.5) kg, respectively, participated in the study. Subjects were excluded if they had any prior history of low back pain that was sufficient to require medical intervention or absence from their full time activities (work or study). Additional exclusion criteria included any major orthopaedic, neurological or cardiopulmonary disorders. Subjects were recruited via local advertising on notice boards and university web-based notices. Previous studies have reported differences in electromyographic activity (EMG) of the trunk muscles between males and females. This has been attributed to physical variations in body weight, centre of mass, muscle stiffness, muscle mass and skin impedance (Granata and Orishimo, 2001). For the purposes of this study male subjects were nominated for subject homogeneity; however, a subsequent study may be warranted to determine if there are any differences between genders for this specific task. The study was approved by the Institutional Medical Research Ethics Committee and was conducted in accordance with the Declaration of Helsinki.

2.2. Electromyography

EMG recordings were made from eight trunk muscles using a combination of surface and fine-wire electrodes. Disposable Ag/AgCl surface electrodes were placed on the right side over the thoracic erector spinae (TES: 5 cm lateral to T9 spinous process); the lumbar erector spinae (LES: 3 cm lateral to L3 spinous process); rectus abdominis (RA: 3 cm lateral to the umbilicus); lower abdominal wall, recording from obliquus internus and TrA (LA: midway between the anterior superior iliac spine and symphysis pubis, above the inguinal ligament); and upper abdominal wall measuring contributions from all of the abdominal muscle layers (UA: lateral abdominal wall over the 10th rib and immediately inferior to this) (Ng et al., 1998).

Recordings of EMG of transversus abdominis (TrA) and the superficial and deep fibres of the multifidus muscle (SM and DM), respectively, which have been shown to be differentially active in response to predictable and unpredictable perturbations (Moseley et al., 2002, 2003) were made using bipolar fine-wire intramuscular electrodes fabricated from two strands of Teflon-coated stainless steel wire (75 µm, A-Systems, USA). Wires were threaded through a hypodermic needle (0.7 × 32 mm, 0.7 × 38 mm or 0.7 × 50 mm), 1 mm of Teflon was removed from the end (to limit cross-talk) and the tips were bent back at 1 and 3 mm to form hooks. Electrodes were inserted into the right TrA (midway between the ribcage and the iliac crest) (Hodges et al., 1999), and right multifidus (Haig et al., 1991) to record from the DM and SM independently with electrodes inserted under the guidance of ultrasound imaging (Moseley et al., 2002). The ground electrode was placed over the lateral aspect of the right iliac crest.

EMG data were amplified 2000 times, band-pass filtered between 20 Hz and 1 kHz, and sampled at 2 kHz using Spike2 software and Power 1401 Data acquisition system (Cambridge Electronic Design, Cambridge, UK). Data were exported for analysis using Matlab 6.5 (The Mathworks, USA).

2.3. Procedure

Subjects were positioned in a semi-seated position on a tilted seat in a custom-built frame (Cholewicki et al., 2000) (Fig. 1). The position allowed subjects to maintain a natural lordosis while reducing the contribution of the hip and lower limb muscles to force generation. The lumbo-pelvic control system has considerable redundancy. That is, there are multiple ways to generate trunk force in standing with contributions possible from both the lower limb and trunk muscles. One advantage of the semi-seated position with the pelvis fixed was that it limits one of the sources of variation. A second advantage of this task was that it maintained the spine in its mid position (i.e., gentle lumbar lordosis) reducing the contribution of passive elements to spinal control. Although not necessarily functional, it is argued that this task allows a focused evaluation of neural strategies to control the spine, with less inherent variability in the redundant lumbo-pelvic system.

A harness attached to an adjustable light rigid frame was placed over the subject’s shoulders and tensioned to comfort. The frame was positioned such that cables for application of load were attached to the harness at the T9 level. The cable was adjusted to run horizontally to a pulley and then vertically via a load cell to an electromagnet at the base of the frame. Subjects either isometrically flexed (posterior load) or extended (anterior load) the trunk against the resistance of the cable to four different force levels (50, 100, 150 and 200 N), consistent with forces used by other authors (Cholewicki et al., 2000, 2005; Reeves et al., 2005; Stokes et al., 2006; Vera-Garcia et al., 2006). Force output and target forces were shown to the subject on an oscilloscope. In the first set of trials, the electromagnet was energised throughout the trial so that the cable was not released (predictable trials). Subjects were instructed to steadily increase the force to the target level, maintain the force for 4–5 s and then release slowly. In the second set of trials, the magnet was released at an unexpected time during the force matching task (non-predictable trials) after the force had been maintained for 3–8 s. Although subjects anticipated that the load would be released, they could not predict its timing. Data was obtained up to the point of release and not subsequent. For both the predictable and non-predictable flexion and extension trials, three repetitions of each of the four target loads were presented in a randomised order. During each set of...
repetitions \((n = 12)\), subjects rested for 5–10 s between each repetition. Subjects also rested for 5 min between the four trials. Baseline EMG was recorded prior to the commencement of each task. Following completion of the submaximal loading trials three isometric MVC efforts were performed into flexion and extension with verbal encouragement to optimise contraction potential. The average difference from the mean for the MVC efforts was 6% for isometric flexion and 5% for isometric extension efforts.

2.4. Data analysis

Root mean square (RMS) EMG amplitude was calculated for 2 or 3 s during the isometric contractions for all loading conditions. Baseline EMG amplitudes were also calculated for 3 s prior to onset of force increase. EMG data were normalised as a percentage of the greatest activity recorded across the trials (generally during the MVC). Any data that deviated by more than 2 SD from the mean data were excluded as outlying data. This was generally due to the presence of a movement artefact. This was necessary in less than 5% of trials.

EMG data were compared between conditions (predictable versus non-predictable), directions (posterior load versus anterior load) and load levels (0, 50, 100, 150, 200 N and MVC) using repeated measures ANOVA. Post hoc analysis was undertaken with Duncan’s Multiple Range test. Significance was set at \( P < 0.05 \).

In order to take into account the individual variations in strategy between subjects during the submaximal loading tasks, the net amount of the normalised EMG amplitude of the trunk flexor and extensor muscles (excluding the deep muscles that have minimal torque generation capacity) was calculated. This analysis results in a single value for flexor and extensor activity for each subject that could be compared to the baseline level of activity, thus accounting for individual differences in strategy. Although this analysis did not take into account different muscle mass and moment arms, it allowed the estimation of net changes in agonist and antagonist muscle activity despite any variation in individual muscles between subjects. For this analysis the net change in EMG amplitude from the baseline taken in the upright starting position was compared to zero (i.e. no change) with \( t \)-tests for single samples \( (P < 0.05) \). Net EMG amplitude of the flexor and extensor muscles was compared between the predictable and unpredictable trials with paired \( t \)-tests.

3. Results

3.1. Predictable isometric trunk flexion and extension tasks

When subjects isometrically flexed the trunk to the target flexion forces, EMG of all abdominal muscles (RA, UA, LA and TrA) increased progressively from the baseline EMG amplitude that was recorded in the upright starting position (Force \( \times \) Direction, \( P < 0.0001 \)). UA was the only muscle with increased EMG at the 50 N interval \( (P = 0.03) \). Activity of other muscles was increased at the 100, 150 and 200 N increments (all: \( P < 0.03 \)) (Fig. 2). There was no change in EMG from the baseline amplitude for any of the individual antagonist paraspinal muscles (SM, DM, LES, TES) at any of the four loads for the isometric flexion tasks (all: \( P > 0.15 \)) (Fig. 3), and despite individual variability in responses, there was no significant change in the net EMG of the paraspinal muscles (DM excluded) at any of the load intervals (50 N, \( P = 0.059 \); all other increments \( P > 0.074 \)) (Fig. 4). In contrast to the
submaximal tasks, during MVC flexion efforts, EMG of the antagonist paraspinal muscles SM, LES and TES increased (all: $P < 0.04$). However, similar to the low load tasks, there was no change in DM EMG ($P = 0.225$).

During isometric extension efforts, EMG of DM, SM, and LES increased progressively at all 4 force increments: 50, 100, 150 and 200 N (all: $P < 0.006$) (Figs. 2 and 3). TES EMG increased with loads of 100 N and above ($P < 0.034$) but there was no change at 50 N ($P = 0.51$). EMG of the antagonist flexor muscles (RA, UA and LA) did not increase above baseline at any of the loading increments (all: $P > 0.53$) (Fig. 3). There was also no change in the net EMG of the abdominal muscles (TrA excluded) (200 N, $P = 0.054$; all other increments $P > 0.15$) (Fig. 4).

However, during maximal extension efforts, EMG of all flexor muscles increased above baseline to co-contract with the extensor muscles (all: $P < 0.02$) (Fig. 2).

TrA EMG behaved differently to the other abdominal muscles during extension efforts with increased EMG during trunk extension efforts of 150 and 200 N (both: $P < 0.028$) (Figs. 2 and 3). Thus, TrA EMG was increased in both directions of load. Although the amplitude of TrA EMG was greater during isometric flexion than extension at the 200 and 50 N intervals ($P < 0.033$) it did not differ between directions at the 100 and 150 N loads ($P > 0.25$) or during the MVC efforts ($P > 0.53$) (Figs. 2 and 3).

Consistent with the limited co-contraction observed in the submaximal loading task, EMG of UA, LA, SM,
DM and LES differed between directions at all loads ($P < 0.011$). RA and TES EMG differed between directions at loads of 100 N or more ($P < 0.011$) but not at 50 N (RA: $P = 0.153$, TES: $P = 0.22$). During the maximal efforts, EMG of all muscles, except TrA, differed between directions (all: $P < 0.03$) (Fig. 2).

### 3.2. Comparison between predictable and non-predictable trials

When subjects anticipated that the load would be released at an unpredictable time during sustained isometric flexion (i.e. non-predictable trials), EMG of the abdominal muscles was altered compared to that recorded when subjects matched an identical load during the predictable trials without release of the load (Force $\times$ Direction $\times$ Prediction $\times$ Muscle: $P = 0.05$). When the release of the posterior load of 200 N was anticipated (i.e. the non-predictable isometric flexion trials), EMG of UA, RA and LA was less than that identified in the predictable trials at the same load ($P < 0.0001$ for all muscles). UA EMG was also less in the unpredictable condition at the 100 N load ($P = 0.048$). TrA EMG did not differ between the predictable and non-predictable trials. However, there was a tendency for TrA EMG to be greater when there was reduced predictability, particularly at the 150 N ($P = 0.069$) and 200 N increments ($P = 0.058$) (Fig. 2). In the same unpredictable isometric flexion tasks, activity of the antagonist paraspinal muscles TES and SM was decreased at the 50 N load (TES by 2.9%, SM by 2.5% (both: $P < 0.045$)). There was no significant change in EMG for any of the individual paraspinal muscles at any of the other loads ($P > 0.109$). There was a net reduction in activity of the paraspinal muscles (DM excluded) at the 50 and 100 N loads ($P > 0.20$). Although this reduction differed from the predictable trials during which there was no reduction in net paraspinal EMG, there was no difference in net amplitude between these conditions (all: $P > 0.28$).

In trials in which the load was released from the front (i.e., the non-predictable isometric extension trials), compared to the predictable isometric extension trials, SM EMG was reduced at all force increments ($P > 0.0011$), DM EMG was less at 100 and 200 N ($P < 0.034$), LES EMG was less at 200 N ($P < 0.037$), but TES EMG was unchanged ($P > 0.155$) (Fig. 2). For the same non-predictable extension task, EMG of TrA and the individual antagonist muscles (RA, UA and LA) was not different to that measured in the predictable trials at any of the submaximal load intervals (all: $P > 0.34$). There was also no change in the net EMG of the antagonist abdominal muscles (TrA excluded) between the predictable and non-predictable trials (all: $P > 0.07$).

### 4. Discussion

Results of this study demonstrate that although co-contraction of antagonist muscles is increased during maximal
flexion and extension efforts, antagonist co-contraction does not increase (above that recorded in the upright sitting position) during submaximal efforts of the magnitude used here or when predictability of the task is reduced. In contrast, in both task directions, the EMG of TrA increased at the higher load increments and did not decrease when task predictability was reduced. These data are consistent with the proposal that TrA contributes to stabilisation of the spine.

4.1. Effect of load level on co-contraction

Consistent with previous data, low level tonic EMG of the flexor and extensor muscles was evident to maintain the mechanical stability of the spine in the upright neutral posture (Cholewicki et al., 1997). During maximal efforts, co-contraction was enhanced with increased EMG of all muscles during both isometric flexion and extension tasks, except for DM which did not increase during flexion tasks. This increased co-contraction during strong efforts has been shown to be necessary to maintain intervertebral stability (Cholewicki et al., 1997; Granata and Marras, 1995, 2000; Stokes, 2005).

Despite the challenge to stability of the spine imposed by the progressive increase in loading (Bergmark, 1989; Cholewicki and McGill, 1996; Cholewicki et al., 1997; Gardiner-Morse et al., 1995; Thelen et al., 1995), EMG of muscles that were antagonists to those generating the force (i.e. the abdominal muscles during the trunk extension task, and paraspinal muscles during the flexion tasks) was not increased during the submaximal flexion and extension efforts in this task. Comparison of the net EMG response suggests that there was no increase in antagonist co-contraction that may have been obscured from the analysis of individual muscles by differences in strategy between subjects. In contrast, analysis of the net EMG amplitude of flexor and extensor muscles showed that the activity of muscles that were antagonist to the force direction could even be decreased relative to that recorded in the initial upright starting posture in some individuals.

Other studies that have investigated submaximal lifting (Dag grenfeldt and Thorstensson, 1997; El-Rich et al., 2004; Granata and Marras, 1995; Ross et al., 1993), dynamic flexion and extension (Silfies et al., 2005) or isometric tasks (El-Rich et al., 2004) have also reported no or minimal change in co-contraction despite increases in load. In contrast, co-contraction has been shown to increase when load is elevated by increased movement velocity (Bartelink, 1957; Floyd and Silver, 1950, 1955; Granata and Marras, 1995; Hemborg et al., 1983; Thelen et al., 1995), increased asymmetry of the load (Huang et al., 2001; McGill, 1991; Pope et al., 1986), positioning the load away from the body (Granata and Orishimo, 2001) and during vertical loading of the trunk (Cholewicki et al., 1997). These findings suggest that increases in co-contraction may be related to the task complexity, the loading site and loading velocity, but is not necessarily required for all tasks.

Unlike the activity of the lumbo-pelvic flexor and extensor muscles, activity of TrA was increased when submaximal force was generated in both directions. Taken together these data suggest that in tasks involving submaximal flexion or extension torque, either: the demands for stability are not increased; the amount of activity present in the lumbo-pelvic muscles during upright sitting is sufficient to meet the demands of lumbo-pelvic stability during submaximal efforts; or the increase in TrA EMG may be sufficient to maintain stability and there may be some benefit to the nervous system for selection of this strategy. As TrA does not have a significant moment arm for flexion or extension (McGill et al., 1988; Urquhart and Hodges, 2005) activity of this muscle may provide an optimal strategy to enhance stability during flexion and extension efforts (Hodges et al., 2003, 2005).

4.2. Effect of reduced predictability

Consistent with previous studies, it was anticipated that co-contraction would increase when the predictability of the task decreased (Cholewicki and McGill, 1996; Granata and Orishimo, 2001). When a perturbation is applied to the trunk by unexpectedly adding a load there is increased co-contraction prior to the time of loading in order to optimise the control of the impending event (Andersen et al., 2004; Chiang and Potvin, 2001; Cresswell et al., 1994; Granata and Orishimo, 2001; Krajcarski et al., 1999; Lavender and Marras, 1995; Lavender et al., 1989). Increased co-contraction stiffens the spine and reduces the displacement induced by the perturbation (Janevic et al., 1991; Lavender et al., 1989; Marras et al., 1987). Furthermore, the amplitude of any additional muscle activity in response to the perturbation is decreased (Vera-Garcia et al., 2006).

However, a different strategy was observed. When the perturbation of the trunk was generated by a sudden reduction of the load (i.e., unloading of muscle contraction) at an unpredictable time, there was no increase in co-contraction in advance of the perturbation. Instead there was reduced activity of the individual lumbo-pelvic agonist muscles (muscles generating force against the load prior to perturbation) and, in some cases, also reduced activity of the antagonist muscles.

Although agonist activity has been shown to be reduced immediately prior to predictable unloading of the trunk (Aruin et al., 1998; Brown et al., 2003) and limbs (Hugon et al., 1982), little change in agonist muscle activity has been observed in other studies (Brown et al., 2003) with unpredictable unloading. However, Brown et al. (2003) used lighter loads (less than 100 N) and found no change in LES or TES EMG. In the current study, the activity of LES was significantly decreased at higher loads (200 N). Furthermore, activity of DM and SM was reduced during the extension tasks at several loads and these muscles were not recorded by Brown et al. (2003). Although increased co-contraction may be predicted to be an ideal strategy to prepare the spine for the impending
perturbation to a sudden loading task, there are a number of reasons why this may not occur in preparation for a rapid unloading of the trunk muscles.

In unloading tasks, regardless of the amplitude of co-contraction that preceded the load release, the position of the trunk to the upright state cannot be restored until the activity of the agonist muscles is reduced and/or the activity of the antagonist muscles are rapidly increased. This contrasts with the response to a suddenly applied load, which requires a rapid increase in activity of the muscles that oppose the newly applied load (Cresswell et al., 1994; Stokes et al., 2000; Thomas et al., 1998). Preliminary data comparing a load release with the trunk stiffened by co-contraction and to a load release with the trunk muscles relaxed prior to unloading suggest that the acceleration, displacement and rate of recovery profiles are distinctly different for the two states. The functional ramifications of either strategy are currently unclear and warrant further investigation.

4.3. Activation of the deep lumbo-pelvic muscles during flexion and extension tasks

Activity of TrA responded to changes in load direction and magnitude in a manner that was different to other lumbo-pelvic muscles. TrA EMG increased in both directions of loading during submaximal and MVC efforts. This is consistent with previous studies (Cresswell et al., 1992) in which subjects generated flexion and extension torques in side lying. Similarly, TrA activity is not affected by force direction during arm movements in different directions (Hodges et al., 1999; Hodges and Richardson, 1996, 1997). These data suggest that TrA may provide a contribution to spinal control when challenged by forces over a range of directions.

In the present study, TrA was also the only lumbo-pelvic muscle with no reduction of EMG amplitude during tasks with unpredictable unloading. As this muscle has minimal ability to generate torque (Hodges et al., 2005; McGill et al., 1988; Urquhart and Hodges, 2005) but potential to contribute to spinal stability (see below), this may provide an ideal strategy to optimise control in this task. These findings support the suggestion that TrA provides a contribution to stabilisation of the spine in a manner that differs from the other lumbo-pelvic muscles (Hodges et al., 2003). TrA has the capacity to increase spinal stability via its contribution to IAP (Cresswell et al., 1994; Cresswell and Thorstensson, 1994; Daggfeldt and Thorstensson, 1997; Hodges, 1999), and via modulation of tension in the thoraco-lumbar fascia (Barker et al., 2006; Hodges et al., 2003, 2005; Tesh et al., 1987). Increased IAP, to which TrA is closely related, decreases intervertebral motion (Hodges et al., 2003) and increases stiffness of the spine (Hodges et al., 2005). Increased tension in the thoraco-lumbar fascia contributes to the control of intervertebral motion (Hodges et al., 2003), counteracts flexion moments (Barker et al., 2006) and controls shear in both directions (Guggenheimer et al., 2006, unpublished data). Via these mechanisms, increased TrA activity may contribute to the maintenance of stability during both isometric flexion and extension efforts. As TrA makes only a minor contribution to torque production, activation of this muscle may provide a simple solution to enhance spine stability without the need to control associated torques generated by the muscle.

DM activity is also argued to contribute to intervertebral stability (Kaigle et al., 1995; Moseley et al., 2003; Wilke et al., 1995) and EMG of this muscle has been reported to be independent of the direction of force during rapid arm movements (Moseley et al., 2002). However, contrary to our prediction, DM EMG only increased during isometric extension tasks. In the flexion task, consistent with the other posterior lumbo-pelvic muscles, there was negligible change in activity. This finding suggests that either DM EMG recorded in upright sitting was sufficient to maintain stability, or activity of this muscle was not required to maintain control during the isometric flexion efforts.

It is interesting to note that TES differed little between directions and was not affected by predictability. With the harness attached at T9, the task may have been more of a lumbar extension task requiring less contribution from the TES during the tasks – irrespective of predictability. However, the possibility that the activity of TES was more related to the maintenance of stability and the upright posture than generating torque also cannot be excluded.

5. Conclusion

This study shows that healthy individuals do not increase co-contraction of antagonist muscles during submaximal flexion and extension efforts beyond that which is required in the upright posture. Instead, activity of the deep muscle TrA increased with torque generation in both directions, potentially providing an alternative strategy to simple co-contraction of antagonist muscles to increase spine stability during this task.

Acknowledgements

The authors thank David MacDonald, Michel Coppieters and Henry Tsao for assistance with data collection. Financial support was provided by the University of Queensland and Paul Hodges was supported by the National Health and Medical Research Council of Australia.

References


Hodges P, Richardson C. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exp Brain Res 1997;114:362–70.


Hodges PW, Cholewicki J, Coppieters MW, MacDonald D. Trunk muscle activity is increased during experimental back pain, but the pattern varies between individuals. In: Proceedings of the XVI congress of the international society of electrophysiology and kinesiology; 2006. p. 204.


Donna T. McCook MHSci, PGD (Manipulative Physio), GD (Clinically Applied Exercise Science) is a lecturer in the Physiotherapy Division at the University of Queensland where she teaches undergraduate and postgraduate courses in musculoskeletal physiotherapy and exercise prescription. She completed her undergraduate degree in Physiotherapy (1990), and her Post-Graduate Diploma in Manipulative Physiotherapy and Masters in Health Science (Physiotherapy) (2000) at Auckland University of Technology (New Zealand). In 2003, she completed a Post-Graduate Diploma in Clinically Applied Exercise Science (Human Movement Studies) at the University of Queensland (2003). Currently, she is a PhD student at the University of Queensland with the Centre for Clinical Research Excellence in Spinal Pain, Injury and Health. Her current doctorate research is investigating the muscular contribution to spinal stability and motor control in people with and without low back pain and the neurophysiological effect that spinal manipulation may have on the motor system.

Bill Vicenzino is a Professor in Sports Physiotherapy and Head of Division of Physiotherapy in the School of Health and Rehabilitation Sciences at The University of Queensland, Australia. Initially graduating with a Bachelor of Physiotherapy (1980) from the University of Queensland, he subsequently completed a Graduate Diploma in Sports Physiotherapy and Masters in Science from Curtin University before completing his PhD (2000). He leads the Musculoskeletal Pain and Injury Research Unit and his research focus is on the clinical efficacy and underlying mechanisms of a range of physical therapies, such as manipulation, exercise, taping and foot orthoses.

Paul W. Hodges PhD, MedDr, BPhty (Hons) is a Principal Research Fellow (National Health and Medical Research Council) at the University of Queensland where he heads the Centre for Clinical Research Excellence in Spinal Pain, Injury and Health. He has doctorates in both physiotherapy and neuroscience and his work blends neurophysiological and biomechanical methods to study the control of movement and stability of the spine and limbs and how this changes in pain. He was awarded the 2006 ISSLS Prize for spinal research from the International Society for the Study of the Lumbar Spine. His primary research interests include investigation the relationship between pain and motor control; the coordination of the multiple functions of the trunk muscles; pain rehabilitation; and the biomechanical mechanisms for control of the spine.