Activation amplitude patterns do not change for back muscles but are altered for abdominal muscles between dominant and non-dominant hands during one handed lifts

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Abstract

It is assumed when lifting with the dominant hand that the relationship between contralateral and ipsilateral trunk muscle responses are similar to when lifting with the non-dominant hand. The purpose of this study was to quantify trunk muscle activation amplitude patterns during right- and left-handed lifts. Surface electromyography (EMG) and kinematic variables were recorded from 29 healthy subjects. Minimal trunk and pelvis motion was observed. Three principal patterns accounted for 95% of the variation in the EMG data indicating minimal variation in the pattern. Significant differences in scores captured different recruitment strategies for reach and hand. Selective and differential recruitment of back sites characterized lifts at greater distances from the body, whereas co-activation between internal oblique and back sites characterized lifts closer to the body. While the results showed no handedness effect for back muscles, the external oblique responded differently between right- and left-handed lifts. Specific recruitment strategies were used to account for subtle changes in reach and asymmetrical demands.

Key words: Electromyography; Pattern recognition; Asymmetrical lifting, Trunk muscles; Amplitude recruitment strategies, Handedness

Introduction

In many ergonomic studies, it is assumed when lifting with the dominant hand that the contralateral trunk muscle responses are similar to when lifting with the non-dominant hand (Huang et al. 2001, 2003; McGill et al. 1996). How- ever, evidence suggests that preferential use of the dominant hand (handedness) may change mechanical and physiological properties of skeletal muscles (McGill et al.

1988; Farina et al. 2003; Diederichsen et al. 2007; Merletti et al. 1994; Sung et al. 2004; Marras and Davis 1998). Presently, the affect of handedness on trunk muscle amplitude recruitment strategies during work related tasks has not been fully explored.

During work tasks it is commonly observed that workers handle loads with one hand creating asymmetrical loads on the spine. The motor control system coordinates trunk muscle activation strategies in response to coupled external moment and spinal stability challenges due to asymmetrical loading. It has been shown that co-activation (simultaneous activation between agonist and antagonist muscles) increases during asymmetrical postures to account for the reduced mechanical stability of the spine (Granata and Wilson 2001). In addition, different regions within a muscle are differentially activated in response to asymmetrical moment demands (Brown et al. 2006; Butler et al. 2007a; Mirka et al. 1997; Vink et al. 1988). For instance, during symmetrical lifting and axial torque production different regions of the external oblique muscle responded to changes in external moment demands and trunk posture (Butler et al. 2007a; Mirka et al. 1997). The motor control system also has been shown to selectively recruit the lateral portions of the erector spinae to higher activation amplitudes compared to the medial muscle sites during asymmetrical loading (Seroussi and Pope 1987; Thelen et al. 1995). Despite these findings, the relationship between motor control strategies and handedness is a relatively unexplored scenario in the area of spine research.

Handedness has been shown to influence muscle properties such as cross-sectional area (McGill et al. 1988), Fibre type (Farina et al. 2003) and neural drive (Diederichsen et al. 2007), which in turn affects muscle fatigue (Merletti et al. 1994; Sung et al. 2004) and spinal loading variables (Marras and Davis 1998). For example, higher normalized muscle activation and decreased muscular strength have been observed in muscles of the non-dominant hand during motor control tasks (Bagesteiro and Sainburg 2002; Brouwer et al. 2001; Diederichsen et al. 2007). Similarly, studies that have examined the effect of hand dominance on trunk muscle activation found that when hand dominance was not accounted for there were no differences in fatigue variables between the right and left sides of back muscle sites (Merletti et al. 1994; Sung et al. 2004). However, when the variability associated with hand dominance was accounted for, the non-dominant side of longissimus muscle demonstrated less fatigue (Merletti et al. 1994). Marras and colleagues observed greater spinal loading during dynamic lifting with the left hand on the left side of the body com- pared to lifting with the right hand on the right side of the body (Marras and Davis 1998). The higher spinal loads were linked to the higher contralateral activation amplitudes observed when lifting with the left hand in comparison to right-handed lifts. This suggests that left-handed lifts may be related to a greater injury risk to the low back than when lifting with the right hand. Since these findings may be related to how lifts are performed, it is necessary to examine trunk muscle response during a task that constrains the motion of the trunk, thereby reducing confounding variables related to dynamic lifting technique.

In order to understand how the trunk musculature responds to different task demands, there is a need to sample from both back extensor and abdominal muscle sites on both sides of the body. Many studies have shown the importance of different trunk muscles for the maintenance of the stability of the spine (Brown et al. 2006; Cholewicki and VanVliet IV 2002; Kavcic et al. 2004). Therefore there is a need for data reduction techniques and while a variety of techniques exist, the utility of the approach used in this study has been demonstrated (Butler et al. 2008; Hubley-Kozey and Smits 1998). The purpose of this study was to quantify how activation amplitude patterns from a comprehensive set of abdominal and back extensor muscles (consisting of 24 trunk muscle sites) during a one-handed asymmetrical lift were altered by different work conditions (lifting with the right or left hand) and whether the patterns changed during different task demands (horizontal distance to the load) using pattern recognition techniques.

Methods

Twenty-nine healthy, right-hand dominant individuals (15 males and 14 females) with a mean age of 30.9 § 9.1 years and mean body mass index 23.5 § 3.6 kg/m2 with no his- tory of low back pain were included in this study. Hand dominance was determined by the hand they used for writ-ing (Corey et al. 2001). Subjects reported no cardiovascular, neurological or orthopaedic conditions, previous abdominal surgeries and no previous shoulder or elbow injury or pain that would limit them to lift items. Also, the subjects reported that they did not have extensive experience with manual material handling tasks. The subjects provided writ- ten consent prior to participation in the study, which was approved by the governing ethics board at Dalhousie University.

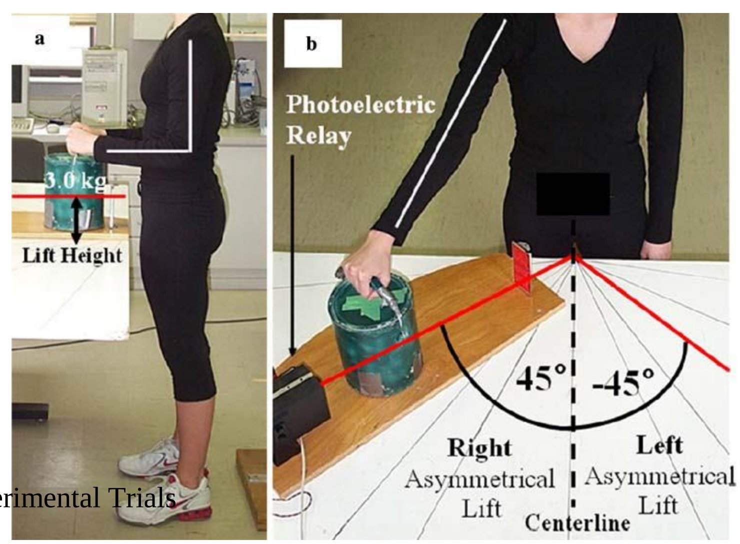
Motion Measurement

The linear and angular positions of the trunk and pelvis were monitored using the Flock of Birds™ (FOB) motion system (Ascension Technology Inc., Burlington, VT, USA). Two electromagnetic sensors were placed on the subject, one over the spinous process of the seventh thoracic vertebrae and one on the left iliac crest. Each sensor provided 6 *df* (*x*,*y*,*z* displacement, yaw, pitch and roll rotations) with respect to a global coordinate axis system located at the source. These measures were used primarily to ensure that subjects did not produce significant trunk motion during the lifting trials.

Surface Electromyography **(EMG)**

Surface electromyography (EMG) collection and processing protocols were in accordance with published standards (Merletti 1999). Surface electrodes, with 30 mm inter-electrode distance (Ag/Ag Cl Meditrace, Graphics Control Canada Ltd.) were placed in a bipolar configuration along the orientation of the muscle fibres. Detailed descriptions of the individual sites have been previously described (Butler et al. 2008). However, in brief, the 24 trunk muscle sites included the right (R) and left (L) sides of the body with two sites over the rectus abdominis lower and upper, three sites over the external oblique representing the anterior (EO1), lateral (EO2) and posterior fibres (EO3), one site over the internal oblique (IO) and six sites for the back extensors at different lumbar levels; L1, L3, L4 and L5. For L1 and L3 lumbar levels, electrodes were placed at 3 and,6 cm from the midline to record from the longissimus and iliocostalis muscles, respectively (L13, L16, L33, L36). The quadratus lumborum and multifidus muscles were represented at the L4 and L5 lumbar levels with electrodes placed at approximately 8.5 and 1–2 cm from the midline, respectively (L48, L52). Although all sites were based on standard placements, minor adjustments were made based on individual anthropometric differences and a series of resisted movements aimed at isolating each muscle site.

Fig. 1 Experimental set up for **a** normal and **b** maximum reaches



Experimental Trials

The subjects performed a ‘lift and replace’ movement with the left hand on the left side of the body and with the right hand on the right side of the body using a 3.0-kg load located at 45° to body midline in both normal and maxi- mum reaches (Fig. 1). Both hand and reach conditions were randomized with three trials performed in succession. The subjects were instructed to stand with their body midline in front of the centreline of the table height adjusted to the subject’s elbow height and lift the load vertically 4–5 cm and replace it in its original position in a slow and con- trolled manner while minimizing trunk and pelvis motion. The movement was separated into lift, transition and replace phases by event markers triggered by a pressure transducer and a photoelectric relay system. In the present study only the activation amplitude pattern corresponding to the lift phase was examined since our previous work has shown relatively small back extensor amplitude changes [<2% maximum voluntary isometric contraction (MVIC)] across lift phases (Butler et al. 2008).

EMG Normalization

Detailed description of the normalization protocol and exercises used has been previously described (Butler et al. 2008). Briefly, two trials of nine exercises requiring MVIC’s were performed following the lifting trials. These exercises included; supine sit-up and V-sit-up; sitting axial rotations (right and left); side-lying lateral flexions (right and left with contralateral hip hike); prone back extensions and prone back extension coupled with axial rotations (right and left). At the end of the normalization trials, with the subject lying supine, baseline muscle activity was recorded followed by system bias measurement for 0.5-s at 1,000 Hz.

Data Acquisition

Separate data collection systems were used to record the EMG and the motion data from the FOB sensors. The two systems were synchronized using the event marker sys- tem. The raw EMG signal was preamplified (500£) close to the electrode site and was further amplified (Bandpass 10–1,000 Hz; CMRR = 115 db, input impedance 10 GQ) with three AMT-8 EMG systems (Bortec Inc., Calgary, AB, Canada). The raw EMG and event signals were sampled at 1,000 Hz using two 16-bit analogue to digital (A/D) converters (National Instruments, CA-1000) and stored on a personal computer using LABVIEW™. Motion data and event markers were collected using LABVIEW on a second computer. The output from the FOB was connected to the computer via a serial port (RS232) and the raw signal was sampled at 50 Hz using a 12-bit analogue to digital converter (National Instruments, CA-1000). The EMG and FOB data collection systems both used IBM Pentium computers for collection, storage and subsequent off-line processing.

Data Processing

Customized programs in Matlab® (MathWorks, Inc., Natick, MA, USA. version 7.3) were used to process the EMG and motion data separately. To remove ECG artefact the raw EMG signal was first filtered using a recursive fifth-order Butterworth high pass filter at a cut-off frequency of 30 Hz (Butler et al. 2007b; Drake and Callaghan 2006; Zhou et al.2007). For each muscle site, the root mean square (RMS) amplitude was calculated during the lift phase. Within each normalization trial a 500-ms moving window was used to identify the maximum RMS amplitude for each muscle site (Vezina and Hubley-Kozey 2000), which was then used to normalize the activation amplitude from the test trials as a percentage of MVIC (% MVIC). The mean normalized activation amplitude across the trials was used.

For the motion data, the three-dimensional angular positions were low-pass filtered at 1 Hz with a recursive second-order Butterworth filter. The maximum angular displacement for yaw, pitch and roll were calculated as the difference in degrees between the maximum and minimum value for the lift phase of the movement for each trial.

EMG Data Analysis

Previous studies have described pattern recognition techniques in detail (Butler et al. 2008; Hubley-Kozey and Smits 1998; Jackson 2003). For the present study, the data matrix **X**[116 £ 24] consisted of *n* observations (29 subjects, 2 reaches and 2 hands) and *P* variables (24 normalized activation amplitudes) that represented the activation amplitude pattern. This pattern is unique to the order that the muscle sites were entered into the pattern recognition technique and this order was standardized. Essentially the order grouped the 12 abdominals together and the 12 back extensor together with left and right sites for a given muscle being adjacent pairs.

The primary features were extracted using eigenvector decomposition of the cross-product matrix. The eigenvectors of the cross-product matrix are uncorrelated and capture the key features and are referred to as principal patterns (PP). The number (*k*) of eigenvectors or PP that accounted for 95% of the total variance in the activation amplitude patterns was retained. Essentially if that number is <24 then data reduction has occurred. A *PPi score* was calculated for each observation, which provides a measure of how close the activation amplitude pattern corresponds to the features captured in each PP. The *PPi scores* were then statistically tested to identify the differences associated with reach and hand conditions during the lift phase of the movement. To assist with the interpretation of these PP, (1) the location where the greatest variation occurred within each principal pattern was determined (scaled percent variation explained) and (2) the mean from a subsample of activation amplitude patterns that corresponded to high and low *PPi scores* (Jackson 2003).

Statistical Analysis

To test for differences due to reach and hand on the activation amplitude patterns, separate two-factor ANOVAs with repeated measures were performed on the *PPi scores* for each retained principal pattern. All statistical analyses were performed using Minitab™ at a level of significance of 0.05 (Minitab Inc., State College, PA, USA, version 14). Significant pairwise differences were tested using a Bonferroni test that corrected for multiple comparisons.

Results

Figure 2 shows the mean activation amplitude patterns for normal and maximum reaches when lifting with the right or left hand. While the RA sites were activated to similar amplitudes across the experimental conditions, the oblique sites slightly increased close to 2% MVIC during maximum reach compared to normal reach. In general, the contralateral back sites responded to the external Flexion and lateral Flexion moments with higher activation amplitudes com- pared to the ipsilateral sites and appear to be similar for right- and left-handed lifts.

Motion Assessment

Yaw and roll produced the greatest mean angular displacement for the pelvis (0.8°), whereas the yaw was the greatest change for the trunk (1.1°). Based on these results it could be suggested that the activation amplitude patterns were in response to the lifting perturbation and not due to changes in inertial forces on the trunk, muscle length or velocity that are associated with dynamic (unrestricted) trunk motion.

EMG Activation Amplitude Patterns

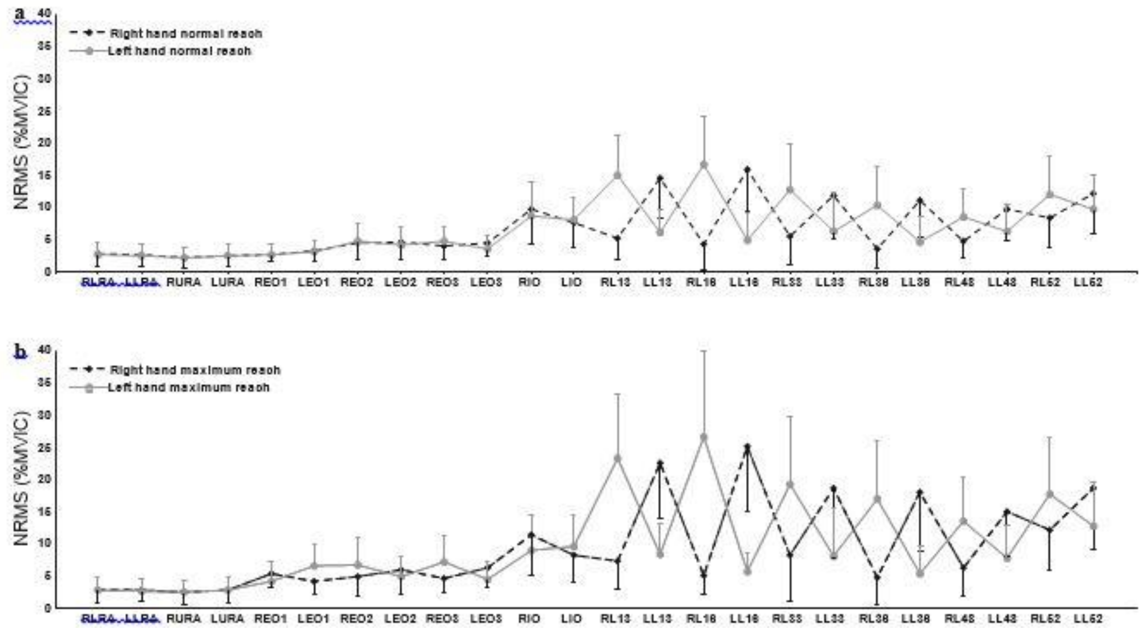


Fig. 2 Mean and standard deviation bars of the normalized activation amplitude pattern (% MVIC) for the right- and left-handed lifts in **a** normal and **b** maximum reaches

Using pattern recognition, four principal patterns explained 95.7% of the total variance for the asymmetrical lift data. The variance explained by each principal pattern was 78.0, 14.0, 2.2 and 1.5% for PP-one, PP-two, PP-three and PP-four, respectively. However, for PP-four, statistical results indicated no main or interaction effects among the experimental conditions, and thus did not contribute to the interpretation. As a result, only the first three PP, which explained 94.2% of the total variance, were used to interpret the activation amplitude patterns in biomechanical terms.

Principal pattern one consistently accounted for 70-92% of the variation across the muscle sites (Figure 3a). The results from the statistical analysis (Figure 3**d**) revealed a significant main effect for reach ($p<0.000$). Examination of the sign and magnitude of the PP_1 *scores* revealed that maximum reach PP_1 *score* was significantly higher than the normal reach condition ($p<0.000$). PP-one represented the difference in physical demands between the normal and maximum reaches and showed that the overall demand is similar between the right and left hands during the lifts as shown in Fig. 2. Figure 3g illustrates the mean measured activation amplitude patterns that corresponded to high and low PP_1 *scores*.

Principal pattern-two characterized the differences due to the asymmetrical loading conditions. The back sites accounted for 10–30% of the variability in this pattern, with 1–3% of the variance explained by the external oblique muscle sites (Fig. 3b). Results from the ANOVA showed that there was a significant reach-by-hand interaction effect ($P < 0.000$) for PP-two (Fig. 3e). The multiple comparisons revealed that the PP2 scores were significantly higher in maximum reach for right ($P < 0.000$) and left ($P < 0.000$) handed lifts compared to the normal reach. The PP2 scores for right and left hands were significantly different for both normal ($P < 0.000$) and maximum ($P < 0.000$) reaches. Note, that the sign of the PP2 scores within a reach condition were opposite, however, the absolute values of the PP2 scores between the right and left hands were similar in magnitude. This indicated that PP-two captured the opposite pattern between the right and left asymmetrical tasks, but was similar in magnitude between hands. Examination of the sign and magnitude of PP2 scores, together with PP- two, revealed that positive PP2 scores were associated with left-handed lifts resulting in higher activations of the contralateral back, EO2 and EO3 sites compared to their corresponding ipsilateral sites. While negative PP2 scores were associated with right-handed lifts and resulted in similar but opposite pattern of activations for the contralateral back sites, the bilateral external oblique sites were similarly activated. Figure 3h presents two subsamples of activation amplitude patterns that corresponded to high positive and high negative PP2 scores.

Principal pattern-three accounted for 2–14% of the variation across the abdominal sites and 1–3% for the L3 sites (Fig. 3c). Results from the ANOVA revealed a significant interaction between reach and hand ($P = 0.019$; Fig. 3f).Pairwise comparisons showed that PP_3 *scores* for normal reach were significantly higher compared to maximum reach for right ($P < 0.000$) and left ($P = 0.005$) handed lifts. For maximum reach, *PP3 scores* associated with left- handed lifts were significantly greater than right-handed lifts ($P = 0.047$). The mean positive *PP3 score*, together with PP-three, captured similar activation levels of the IO and L3 back sites during normal reach for both hands, but was less apparent for the left-handed lift in maximum reach. Since *PP3 score* associated with the right-handed lift in maximum reach was close to 0, there was less change as a result of this feature. Although PP-three accounted for a relatively small portion of the total variation, subtle changes occurred in the abdominal and back muscle sites between the right- and left-handed lifts and the magnitude of these changes depended on the reach conditions. Two subsamples of activation amplitude patterns (that corresponded to high positive and negative *PP3 scores* illustrates this feature in Fig. 3i.

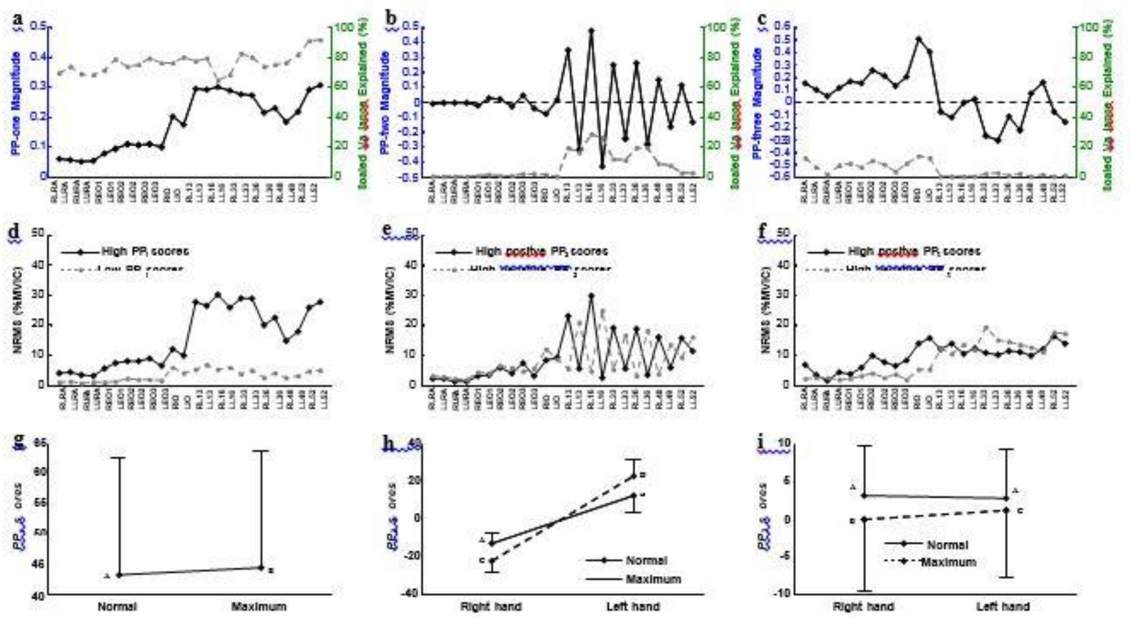


Fig. 3 Principal pattern (*solid*) and scaled variance explained (*dashed*) across the muscle sites for **a** principal pattern one (*PP-one*), **b** principal pattern two (*PP-two*) and **c** principal pattern three (*PP-three*). Mean normalized activation amplitude pattern for high PP_i *scores* and low PP_i *scores* for **d** PP-one, **e** PP-two and **f** PP-three. Mean and standard deviation for **g** PP_1 *scores* **h** PP_2 *scores* **i** PP_3 *scores* with signiWcant pair wise comparisons indicated with diVerent *capital letters*

Discussion

Three PP quantified the key trunk muscle recruitment strategies in response to asymmetrical lifting for right-hand dominant individuals. PP-one captured the majority of the variation in the data and characterized the general shape and amplitude differences for the main experimental condition of horizontal reach. PP-two and PP-three featured muscle recruitment strategies that responded to the other experimental conditions (hand); and demonstrated asymmetrical activation between bilateral back sites, selective recruitment of iliocostalis muscle sites, differential recruitment within back and external oblique sites, specific co- activation strategies between abdominal and back muscle sites.

When lifting with the right or left hand the recruitment of trunk muscle activation must balance the coupled Flexor and lateral bending moments generated by the asymmetrical loads (Danneels et al. 2001; Marras and Davis 1998; Thelen et al. 1995). Consistent with previous studies examining asymmetrical efforts (Jonsson 1970; Marras and Davis 1998; McGill 1991; Thelen et al. 1995), higher activations were observed for the back extensor sites contralateral to the load compared to the ipsilateral back sites for right- and left-handed lifts (PP-two). Furthermore, the PP2 scores were similar in magnitude but opposite in direction for the right- and left-handed lifts showing that the back extensor response to asymmetric loading to the left is associated with bilateral activation patterns similar in magnitude, but opposite in direction to loading to the right. This indicates that no handedness effect was observed for the agonists back extensor sites. In contrast to our findings, Marras and colleagues observed higher activation (>5% MVIC) in the contralateral erector spinae and IO sites when lifting with the left hand compared to right-handed lifts (Marras and Davis 1998). The dynamic motion of the trunk, unrestricted lifting technique and use of heavier loads (13.7 kg) in their study would influence the recruitment strategies and may account for the differences observed. For instance the free-style lifts may have facilitated different lifting techniques, and thus provide a possible explanation for the difference between studies. The results from our study suggest that by constraining trunk motion the back site activation amplitudes were mirror images between the right- and left-handed lifts for individuals who were right- hand dominant handling low loads.

While no differences were found between the right- and left-handed lift for the back extensor sites, the activation amplitudes from the external oblique muscle sites changed dependent on the hand that performed the lift. Selective recruitment of the ipsilateral anterior fibres and contralateral lateral and posterior fibres of the external oblique to higher amplitudes was observed during the left-handed lifts and was magnified in maximum reach conditions (PP-two). This indicates that a handedness effect was observed for the external oblique muscle. Given the different fibre orientations and innervations (Dumas et al. 1991; Ng et al. 1998) within the external oblique muscle, different regions of the external oblique muscle can be recruited differently depending on the moment demands of the task when acting as an agonist (Mirka et al. 1997). Thus, the contralateral lateral and posterior fibres of the external oblique were selectively recruited to oppose the lateral Flexion moment during the left-handed lift. However, during the right-handed lift the sites within the external oblique muscle were recruited to similar amplitudes. These differences between the right- and left-handed lifts may be related to different neuromuscular characteristics due to long-term preferential use of one hand. Interestingly, Moritani (Moritani 1996) observed that practice resulted in significant reductions in the neural output variability during a novel motor task. In this context, differential recruitment observed in the present study also may be associated with compensating for increased neural output in response to performing a new motor task with the left, non-dominant hand. Why this effect was observed in the antagonist muscles and not for the agonist muscles is unclear, however, it appears that a complex relationship exists between hand dominance, the side of the body the muscle is located, the muscle itself and task requirements.

Since insignificant trunk and pelvis motion was found in this study, we believe that the external oblique (antagonist) amplitude changes observed is mechanically and physiologically important. McGill and colleagues found that 7–13% MVIC changes in low level abdominal muscle activations resulted in increases in spinal compression by 1,000 N (McGill et al. 1995). Though the changes observed in our study was 2–3% MVIC, it is reasonable to suggest that these changes will influence the mechanical environment by increasing the compression force on the spine. Secondly physiological effects related to fatigue, if maintained over a period of time (8-h work day), will influence spinal stability (Granata et al. 2004). Thirdly Cholewicki and colleagues has shown that 2–3% MVIC changes improve spinal stability (Cholewicki et al. 1997). Given this information small amplitude changes from the abdominals (antagonist muscles) have potential impact for the mechanical stability of the spine and muscle fatigue associated with repetitive lifting tasks.

Several unique back extensor muscle recruitment strategies were observed in response to the asymmetrical loading conditions. Differential recruitment occurred within the back muscles at different lumbar levels during both the right- and left-handed lifts (PP-two). Higher activation amplitudes were observed for the longissimus and iliocostalis muscle sites at the lumbar level L1 compared to muscle sites at L3 for both reaches, but was more apparent for the maximum reach conditions. This finding is similar to previous work during a symmetrical lifting task (Butler et al. 2008). However, during tasks that combines lateral and forward Flexion moment demands, as required in the present study, a different back extensor recruitment strategy emerged. The selective recruitment of the lateral back extensor sites, in particular the iliocostalis muscle at lumbar level L1 was observed in response to the asymmetrical demands (PP-two). Similarly, the iliocostalis muscle has been shown to be recruited to higher amplitudes during asymmetrical static trunk exertions compared to the longissimus and multifodus sites (Jonsson 1970; Thelen et al.1995; Vink et al. 1988). Thelen et al. (1995) suggested that the central nervous system (CNS) may take into account the muscles' mechanical advantage when executing recruit- ment strategies for asymmetrical exertions. Specifically, the larger lateral muscle moment arm associated with the iliocostalis site would be well suited to counterbalance the lateral Flexion moment created during the one-handed lift. In contrast, the multifidus site exhibited more symmetrical activation between the contralateral and ipsilateral sites compared to the other back sites and is consistent with other studies examining bilateral activation of the multifidus (Butler et al. 2008; Danneels et al. 2002). The anatomical uniqueness of the multifidus muscle, which spans only two to three vertebrae, has been suggested to play an important role in intervertebral stability (Hodges and Moseley 2003; MacDonald et al. 2006). Together these findings suggest that the motor control strategies of the back muscle sites are coordinated to selectively recruit muscles based on anatomical arrangement and mechanical advantages that are best suited to respond to the asymmetrical loads when lifting with one hand.

Co-activation is well documented to be an important neuromuscular response (Cholewicki and McGill 1996; Granata and Orishimo 2001). While the term co-activation is commonly used to represent a general motor strategy between agonist and antagonist muscles, PP-three featured a specific co-activation strategy between the IO and L3 sites. This recruitment strategy called bracing, reflected similar activation amplitudes between the IO and back extensor sites. Interestingly, higher scores were associated with lifting in normal reach for the present study and for a symmetrical lifting task (Butler et al. 2008). It is likely that the lower physical demands associated with lifting in the normal reach conditions resulted in IO and back extensor co-activation to prevent unstable spinal behaviour since studies found that bracing is important for spinal stability (Brown et al. 2006; Grenier and McGill 2007; Vera-Garcia et al. 2006). In fact, the IO muscle has been shown to be the most important abdominal muscle in improving spinal stability while at the same time generating smaller spinal loads (Arjmand et al. 2008; Grenier and McGill 2007). The evidence from the present study indicates that it is important to characterize specific co-activation strategies to understand how the neuromuscular response changes to different physical demands and task characteristics.

The results from the present study must be interpreted within the limitations of surface EMG recording and the experimental design. First, while changes in muscle activation can indicate relative changes in loads experienced by the spine, it does not quantify the biomechanical risk associated with a back injury. Additional work needs to examine the compressive and shear forces associated with asymmetrical lifting and handedness to determine risk at work. Second, for the normalization protocol if the muscle did not produce a ‘true’ maximum voluntary contraction then the resulting normalized amplitudes would provide an overestimation of muscle activation. However, numerous studies provide evidence that the MVIC is a reproducible standard for comparison despite criticisms of its limitations (Burden and Bartlett 1999; Dankaerts et al. 2004;

Knutson et al. 1994). Furthermore, the evidence-based procedures employed in the present study, which included using a series of exercises (McGill 1991), feedback and motivation (Baratta et al. 1998; McNair 1996) as well as motor learning principles (Moritani 1996) increased the probability that the maximum voluntary activation was achieved. Third, despite the reported small pick up area of surface electrodes (Fuglevand et al. 1992) and low activation levels observed in this study, it should be acknowledged that there is the possibility that recorded activity from an electrode site may be contaminated with electrical activity from adjacent muscles. However, in the present study, appropriately sized electrodes and manual resistance tests were used to reduce the chance of cross-talk (Winter et al. 1994).

Finally, only right-hand dominant subjects were used in the present study. Further work to determine whether the same strategies are used for left-handed participants is needed.

While sex was not a specific objective in the present study, it has been shown that women have different muscle anatomy (Marras et al. 2001), greater Xexor co-activation (Granata et al. 2001; Granata et al. 2005) and greater relative spinal loads (Marras et al. 2000; Marras et al. 2002), which may put them at greater risk for pain-related disability than men. Thus, future research should consider male and female differences in activation patterns with particular focus given to temporal activation patterns since time varying information is provided in addition to amplitude changes.

Conclusions

The present study demonstrated unique patterns of activation amplitudes in response to the asymmetrical perturbation when lifting with one hand for right hand dominant individuals. The pattern showed low activation amplitudes for the abdominal sites, however, the external oblique sites (antagonists) were more sensitive to the Flexion and lateral bending moments and responded differently between the right- and left-handed lifts. For the back extensors, an asymmetrical activation pattern between the bilateral sites was observed and was similar in magnitude, but opposite in direction for the right- and left-handed lifts indicating no handedness effect for the agonist muscles. Selective recruitment of the lateral back sites, symmetrical activation for the bilateral multifidus sites and differential recruitment between the L1 and L3 sites suggests that the CNS may control different regions of the back musculature to optimally account for the biomechanical demands of the task. In addition, antagonistic co-activation of the IO and back extensor sites indicates a specific recruitment strategy that is important when performing lighter tasks with one hand.

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Legends

Figure 1: Experimental set up for (a) normal and (b) maximum reaches

Figure 2: Mean and standard deviation bars of the normalized activation amplitude pattern (%MVIC) for the right and left handed lifts in (a) normal and (b) maximum reaches.

Figure 3: Principal pattern (solid) and scaled variance explained (dashed) across the muscle sites for (a) principal pattern one (PP-one), (b) principal pattern two (PP-two), and (c) principal pattern three (PP-three). Mean and standard deviation for (d) PP_1 *scores* (e) PP_2 *scores* (f) PP_3 *scores* with significant pair wise comparisons indicated with different capital letters. Mean normalized activation amplitude pattern for high PP_i *scores* and low PP_i *scores* for (g) PP-one, (h) PP-two, and (i) PP-three.

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