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Altered trunk muscle recruitment patterns during lifting in individuals in remission from recurrent low back pain

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ABSTRACT

Changes in the recruitment pattern of trunk muscles may contribute to the development of recurrent or chronic symptoms in people with low back pain (LBP). However, the recruitment pattern of trunk muscles during lifting tasks associated with a high risk of LBP has not been clearly determined in recurrent LBP. The present study aimed to investigate potential differences in trunk muscles recruitment patterns between individuals with recurrent LBP and asymptomatic individuals during lifting. The subjects were 25 individuals with recurrent LBP and 20 asymptomatic individuals. Electromyography (EMG) was used to measure onset time, EMG amplitude, overall activity of abdominal muscles, and overall activity of back muscles during a lifting task. The onsets of the transversus abdominis/internal abdominal oblique and multifidus were delayed in the recurrent LBP group despite remission from symptoms. Additionally, the EMG amplitudes of the erector spinae, as well as the overall activity of abdominal muscles or back muscles, were greater in the recurrent LBP group. No differences in EMG amplitude of the external oblique, transversus abdominis/internal abdominal oblique, and multifidus were found between the groups. Our findings indicate the presence of an altered trunk muscle recruitment pattern in individuals with recurrent LBP during lifting.

1. Introduction

Low back pain (LBP) continues to be a disabling health problem, with a lifetime prevalence of 70–85% (Andersson, 1999) and a huge financial burden related to direct and indirect costs (Dagenais et al., 2008). Individuals with recurrent LBP have a higher total length of work disability, resulting in higher medical and insurance costs (Wasiak et al., 2006). Although most people will recover within 1 month (Pengel et al., 2003), up to 62% will experience episodes of LBP recurrence within a year (Hestbaek et al., 2003).

Bergmark (1989) has categorized trunk muscles into local muscles and global muscles. Local muscles such as the transverse abdominal (TrA), internal oblique (IO), and lumbar multifidus (MF) muscles are directly attached to the lumbar vertebrae and are capable of controlling intersegmental motion (Richardson et al., 1999). Global muscles include more superficial muscles, such as the rectus abdominis, external oblique (EO) muscle, and lumbar erector spinae (ES), and are capable of generating large torque for spinal movement, controlling spinal orientation, and balancing external loads (Panjabi, 1992; Richardson et al., 2004). It has been reported that individuals with LBP display alterations in their trunk muscle recruitment patterns related to onset timing of local muscle and electromyographic (EMG) amplitude of global muscles (Hodges et al., 2003; Kim et al., 2014; Suehiro et al., 2015). MacDonald et al. (2009) found that the onset of deep back muscles was delayed in people with recurrent LBP, despite the resolution of symptoms. The authors suggested that this alteration is responsible for the recurrence of LBP (MacDonald et al., 2009). However, these studies investigating changes in the activity pattern of trunk muscles have targeted limb movements, which are typically associated with a relatively light load (Hodges et al., 2003; Kim et al., 2014; MacDonald et al., 2009; Suehiro et al., 2015). Although changes in muscle activity patterns in LBP have been reported to be dependent on the task (Hodges et al., 2013), activity patterns of trunk muscles during lifting tasks associated with a high risk of LBP (Heuch et al., 2017) have not been fully elucidated in recurrent LBP. Butler et al. (2013) reported that individuals in remission from LBP have a greater overall EMG amplitude of trunk muscles than healthy control subjects during lifting. However, Haddas et al. (2016) reported that individuals with recurrent LBP have a higher EMG amplitude of ES and MF and a smaller EMG amplitude of EO than healthy subjects. Thus, changes in EMG amplitudes in patients with LBP during lifting are a matter of controversy.

Although Ferguson et al. (2004) investigated EMG onset time of trunk muscles during lifting in patients with LBP, EMG onsets of local muscles were not determined. In addition, EMG onset times of trunk

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muscles during lifting have not been studied in individuals in remission from recurrent LBP.

The aims of the present study were to compare the muscle recruitment patterns in individuals with recurrent LBP and asymptomatic individuals and to identify alterations in onset time and EMG amplitude of trunk muscles during lifting associated with recurrent LBP.

2. Methods

2.1. Subjects

Twenty-five participants with recurrent LBP and 20 control participants with no history of back pain were recruited for this study. The inclusion criterion for the recurrent LBP group was a history of at least two episodes of pain that interfered with functional activities such as work or sports (MacDonald et al., 2011). The exclusion criteria included orthopedic or neurological disorders, previous spinal surgery, and pregnancy in the last two years. At the time of testing, subjects with recurrent LBP were in remission, with no LBP symptoms. The study was approved by the Ethics Committee of the Kawasaki University of Medical Welfare. Informed consent was obtained from all subjects.

2.2. Electromyography

Muscle activity was recorded using a wireless electromyograph (Vital Recorder 2; Kissei Comtec, Nagano, Japan) with bipolar surface electrodes (Blue Sensor; Ambu Inc., Ballerup, Denmark) during a lifting task. After shaving excess hair and cleaning the skin using alcohol and sanding, the electrodes were placed 2.5 cm apart and aligned parallel to muscle fibers over the following muscles: the EO (approximately 15 cm laterally to the umbilicus), transversus abdominis/internal abdominal oblique (TrA/IO) (2 cm inferiorly and medially to the anterior superior iliac spine), ES (approximately 3 cm laterally to L1 spinous process), lumbar MF (at the L5 level aligned parallel to the line between the posterior superior iliac spine and L1-L2 interspace), and anterior deltoid (two finger widths distally and anteriorly to the acromion). In the recurrent LBP group, all electrodes were attached to the side where LBP had been more severe, and in the control group, they were attached to the right side. A ground electrode was attached to the iliac crest. EMG data were sampled at 1000 Hz.

2.3. Arm movement

The speed of arm movement was evaluated using an angular rate sensor (MVP-RF10-AC; Microstone, Nagano Japan), which was strapped to the right wrist. Movement data were sampled at 1000 Hz. Peak angular velocities of arm movement were calculated for analysis.

2.4. Data collection procedures

Severity of average LBP experienced during the previous week was evaluated using a numeric rating scale (NRS) from 0 (no pain) to 10 (worst possible pain).

While in a standing position, the subject grasped, using both hands with an elbow extension of 0° and a shoulder flexion of 40°, the handle of a 5-kg box placed on a table in front (Fig. 1). A pressure sensor synchronized with the electromyograph was attached to the bottom of the box to detect the moment when the box left the table. An indicator bar was set such that the flexion angle of the shoulder was 90° when the box was in the uppermost position. When a diode lamp placed at the eye level was turned on, subjects lifted the box as rapidly as possible until their arm touched the indicator bar while minimizing trunk and pelvis motion and keeping the elbow extended (Fig. 1). This position was maintained for 3 s. If trunk or pelvis motion was detectable during the trial, the data were discarded. Before testing, participants practiced the lifting task several times to familiarize themselves with the experimental procedure. Each participant performed three trials with a 1-min rest between repetitions.

2.5. Data analyses

EMG data were bandpass-filtered (15–500 Hz), and full-wave rectification was conducted. EMG amplitudes were averaged over the 3 s from the moment when the box left the table. The average EMG amplitudes of trunk muscles were represented as percentage of the maximal voluntary contraction (%MVC) for normalization. MVC values of the trunk muscles were obtained in the manual muscle testing positions. Although pain did not occur during MVC efforts in individuals with recurrent LBP and controls, it is possible that participants with recurrent LBP were less willing or able to maximally activate their trunk muscles because of fear of pain and other personal factors. Therefore, the raw EMG signal during the MVC effort was compared between the groups to ensure the validity of the normalized EMG amplitudes. There was no difference for any muscle (main effects for Group: $F = 0.008$, $p = 0.93$, effect size $f = 0.007$, power = 0.05; interaction effect between Group and Muscle: $F = 0.938$, $p = 0.42$, effect size $f = 0.127$, power = 0.09). This indicates that there was no systematic difference in activity during MVC, confirming that individuals with recurrent LBP performed true MVCs. After normalization, we combined the amplitudes of EO and IO to evaluate the overall activity of the abdominal muscles and amplitudes of ES and MF to evaluate the overall activity of the back muscles.

Onset time of muscle activity was determined visually as the first increase of EMG activity above the baseline that lasted for 50 ms (Masse-Alarie et al., 2015). In cases when reliable determination was difficult, the onset time of muscle activity was set to the moment when the muscle activity exceeded two standard deviations from the baseline level for a period of 50 ms (Hodges and Bui, 1996). The relative onset difference between each trunk muscle and the prime mover (the anterior deltoid) was calculated using the following equation (Silfies et al., 2009, Tsao and Hodges, 2007):

Relative onset difference = onset time of trunk muscle activity − onset time of anterior deltoid (ms).

Thus, positive values corresponded to the target trunk muscle being activated after the deltoid muscle.

2.6. Statistical analysis

Statistical analyses were performed using the SPSS software, version 21.0 (IBM Inc, Chicago, IL). The Shapiro-Wilk statistic was used to assess the normality of distribution for all continuous variables. To identify differences between the groups in participants' characteristics, baseline EMG amplitude, standard deviations of baseline EMG amplitude, speed of arm movement, and the overall activity of abdominal muscles or back muscles during lifting, the independent *t*-test was performed. When dependent variables were not normally distributed, the Mann-Whitney *U* test was employed. Because of the effect of speed of arm movement (Hodges and Richardson, 1997), baseline EMG amplitude, and standard deviations of baseline EMG amplitude on the onset of trunk muscles activity (Allison, 2003), analysis of covariance (ANCOVA) with speed of arm movement, baseline EMG amplitude, and standard deviations of baseline EMG amplitude as the covariates was conducted to compare onsets of trunk muscles activity between the groups.

One-way multivariate analysis of variance (MANOVA) was used to compare EMG amplitudes of trunk muscles between the groups. Post-hoc analyses using univariate ANOVA were performed when MANOVA produced statistically significant results. The level of statistical significance was chosen as $p < 0.05$. The G-power 3.1.7 software was used to calculate the effect size and power.