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DIAGNOSTIC METHODS: ORIGINAL RESEARCH

Effects of tactile feedback on lumbar multifidus muscle activity in asymptomatic healthy adults and patients with low back pain

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ABSTRACT

Background: Reduced lumbar multifidus (LM) muscle contraction has been observed in patients with low back pain (LBP). Clinicians often use various strategies to ensure LM activation, including tactile feedback and verbal instruction. However, the effects of tactile feedback on muscle activation have not been studied previously. Therefore, the purpose of this study was to investigate whether or not tactile feedback would increase LM muscle activity in adults with and without LBP.
Methods: Twenty asymptomatic adults and 20 patients with existing LBP completed the study. Two electromyographic (EMG) electrodes were applied to both sides of the LM at the L5 segment. EMG activity was collected three times at rest with and without tactile feedback, then five times during contralateral arm lifts with and without tactile feedback. The tactile feedback was applied by direct and continuous hand contact to the bilateral LM over the lumbosacral area. Lastly, two 5-second trials of maximum voluntary isometric contraction (MVIC) during a bilateral arm lift were performed. EMG activity collected at rest and during contralateral arm lifts was normalized to that collected during MVIC. Normalized EMG values of the right side of the asymptomatic group and the painful side of the LBP group were used for data analysis.
Results: Statistical analysis showed significantly decreased LM EMG activity with tactile feedback both at rest and during contralateral arm lifts compared to LM EMG activity without tactile feedback. There was no difference in LM EMG between the asymptomatic and the LBP groups.
Conclusions: The results of the study showed that adding tactile stimulation to verbal instruction appeared to provide an inhibitory effect on LM activity in both asymptomatic healthy adults and patients with LBP. Contrary to common belief, tactical feedback via direct hand contact may reduce LM muscle recruitment, and may lessen the desired treatment effect.

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1. Introduction

The function of the lumbar multifidus muscle for spinal stabilization has been well-recognized due to its anatomic proximity to the spine, particularly for the lumbar segments (Bogduk, 2005; MacDonald et al., 2006). In an ultrasonographic imaging study of patients with acute unilateral low back pain (LBP), the size of the lumbar multifidus muscle was significantly smaller on the painful side than on the un-involved side, even though the patients had significant pain reduction at the 10-week follow-up (Hides et al., 1996). Decreased lumbar multifidus muscle size at the painful segments also was found in patients in subacute and chronic stages of LBP (Hides et al., 1994, 2008; Wallwork et al., 2009). In addition, a higher amount of fatty infiltration (i.e. muscle atrophy) in the lumbar multifidus muscle is positively correlated to a lower level of physical activity in patients with LBP (Le Cara et al., 2014). Therefore, improving this muscle's function is considered to be crucial to restoring physical function in rehabilitation of LBP. Moreover, the ability to activate the lumbar multifidus muscle was identified as a predictor for clinical success with a spinal stabilization exercise program (Hebert et al., 2010). Consequently, clinicians routinely include muscle activation training specific to the lumbar multifidus muscle in spinal stabilization exercise programs for treating patients with LBP (Hicks et al., 2005; O'Sullivan et al., 1997).

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Many strategies have been employed clinically to facilitate activation of the lumbar multifidus muscle. A pressure biofeedback unit has been advocated to encourage lumbar stabilization or co-contraction of the lumbar multifidus and deep abdominal muscles during spinal stabilization exercise (Richardson et al., 2004; Cynn et al., 2006). However, a pressure biofeedback unit has been shown to be a more useful tool for identifying lumbopelvic stability impairments than for improving treatment effectiveness (Cairns et al., 2000; Mills et al., 2005). The evidence suggests ultrasound imaging to be a useful visual feedback tool for recruiting the lumbar multifidus and deep abdominal muscles in patients with LBP (Henry and Westervelt, 2005; Lee et al., 2016; Van et al., 2006). However, this mode of feedback is rarely used in clinical settings because of the high cost of ultrasound imaging machines. In contrast, verbal instructions are quick and easy to implement in clinics, and several verbal instructions have been found to be useful to activate the lumbar multifidus muscle (Van et al., 2006; Wallwork et al., 2009; Wang-Price et al., 2017). However, verbal instructions require patients to be able to understand the meaning of the instruction to perform the exercise properly.

Because the depth of the lumbar multifidus muscle limits the clinician's ability to observe muscle activation, tactile feedback often is added to verbal instruction in order to confirm or further facilitate contraction of this muscle (Van et al., 2006; Wallwork et al., 2009). Tactile feedback using taping was shown to improve posture sway when adhesive tape was applied to the ankle and heel (Matsusaka et al., 2001) and to improve muscle activity when a piece of kinesiotape was applied over the pectoral muscle (Gusella et al., 2014). Although taping has positive effects on muscle recruitment, the most common form of tactile feedback technique used by clinicians is direct hand contact (i.e. palpation) over the target muscle (Henry and Westervelt, 2005; Wallwork et al., 2009; Vega Toro et al., 2016). Despite the routine practice of tactile feedback by clinicians using direct hand contact for muscle recruitment, the effect of hand contact on lumbar multifidus muscle activation has not been studied previously. Therefore, the purposes of this study were (1) to examine the effect of tactile feedback on lumbar multifidus muscle activity at rest, and (2) to compare the added effect of tactile feedback to verbal instruction during a contralateral arm lift, in adults with and without LBP.

2. Methods

2.1. Participants

This study was approved by the investigator's affiliated Institutional Review Board and registered with ClinicalTrials.gov (NCT02836860). Before data collection began, a power analysis was performed using G*Power 3.1.3 to estimate an adequate sample size (Faul et al., 2007). Using a medium effect size of 0.25 and an alpha level of 0.025, a total of 42 participants, 21 in each group, were required to reach a power of 0.80. Forty-four eligible participants, 20 asymptomatic adults and 24 patients with LBP, were recruited from April 2016–April 2017 for this study. Participants were either patients from the physical therapy clinic at which one investigator was employed, or employees/students at the investigators' affiliated institutions. Asymptomatic participants were individuals with no existing LBP and no LBP in the past year. Participants in the LBP group were individuals who had existing LBP near the L4-S1 levels and an average pain intensity score $\geq 2/10$ on the Numeric Pain Rating Scale (NPRS) within 24 h. Only participants with pain at L4-S1 were included in the study because L4, L5 and S1 are the most common painful segments found in patients with LBP, and because the lumbar multifidus activity was recorded at the L5 level (Kader et al., 2000). Exclusion criteria for all participants included systemic joint disease (e.g. rheumatoid arthritis), cancer of the lower quadrant, neurological disorders, allergic reaction to adhesive tape, or inability to obtain the testing position (i.e., prone lying). Each participant was informed of the risks and procedures of the study, and then signed a written informed consent form.

2.2. Instrumentation

A Delsys Trigno® wireless electromyographic (EMG) system (Delsys Inc., Natick, MA) and two wireless surface EMG electrodes were used to record muscle activity. Each wireless EMG electrode contains a built-in pre-amplifier and two sets of parallel silver contact bars with a fixed distance of 1 cm between the recording sites. One set of contact bars served as a reference electrode. The raw EMG signals were recorded at a sampling rate of 4000 Hz, and filtered between 20 and 450 Hz. The gain of the EMG system was 1000 with the Common Mode Rejection Ratio (CMRR) > 80 dB.

2.3. Procedures

Eligible participants were asked to complete an intake form asking them about their demographic information and past medical history. The Modified Oswestry Low Back Pain Disability Questionnaire (OSW) was administered to all participants to determine their perceived disability and functional limitations due to LBP. The OSW has been shown to be reliable and valid (Davidson and Keating, 2002; Fritz and Irrgang, 2001). Participants with LBP also were asked about their pain location, duration, and intensity at present, at worst, and at best in the past 24 h using the NPRS. The NPRS also was used to monitor the LBP level during EMG testing.

EMG activity of the lumbar multifidus muscles was recorded following a testing protocol published in previous studies by Kiesel et al. (2007). Briefly, each participant was instructed to lie prone on an examination table with the participant's shoulders abducted, elbows flexed approximately 80–90°, and the forearms hanging off the edge of the table. A pillow was placed under the participant's abdomen to minimize the lumbar lordotic curve and an inclinometer was placed on the lumbosacral junction to ensure that the lumbar curve was less than 10°.

To prepare for EMG recording, each participant's skin over the right and left lumbar multifidus muscles at L5 was cleaned with alcohol and, if needed, excessive hair was shaved using a disposable razor. Adhesive tape was used to affix two wireless EMG electrodes to the skin over the bilateral lumbar multifidus muscles. Following the recommendation by the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) project (http://www.seniam.org/), two surface electrodes were placed at the level of the L5 spinous process (i.e. about 2–3 cm from the midline) and aligned with a line from the posterior superior iliac spine to the interspace between the L1 and L2 spinous process. The EMG activity collected from the right side of the asymptomatic adults, and from the painful side of the participants in the LBP group, was used for statistical analysis. When the participants had bilateral LBP, EMG activity collected from the most painful side was used for data analysis. If both sides were equally painful, a coin toss was performed to select the side (heads for the right side, tails for the left side).

Prior to EMG recording, each participant was informed of the location of the lumbar multifidus muscle. Participants' knowledge of the lumbar multifidus location was necessary because the tactile feedback was given by placing a hand on the lumbar multifidus muscle during EMG recording. During EMG recording, one researcher was responsible for operating the computer and recording EMG data, and the other researcher gave verbal instructions and provided tactile feedback on the participants for lumbar multifidus muscle contraction. There were five research team members for this study, but to minimize variations of tactile feedback delivery, only two researchers administered tactile feedback, alternating depending on their availability. Prior to the commencement of the study, these two researchers standardized the application of tactile feedback, including hand contact location, timing, and pressure.

The EMG activity of the lumbar multifidus muscle was recorded three times at rest with and without tactile feedback (Fig. 1a&b). First, the participant was asked to relax and to breathe normally for the resting condition without tactile feedback. Then, the investigator who gave instructions to the participant applied a continuous, direct, light contact while the participant remained in a resting position. Three 5-second trials were recorded for each resting condition. If a participant moved during EMG recording, the trial was deemed invalid, the participant was instructed not to move, and then one more trial at rest was repeated. Next, each participant was asked to perform a contralateral arm lift five times with and without tactile feedback (Fig. 1c&d). A verbal instruction was given before the participant performed the contralateral arm lift: "Breathe normally. Without moving your pelvis or spine, think about tilting your pelvis forward without actually moving it. Now raise your arm above the table". The verbal instruction was chosen based on previously published works (Kiesel et al., 2007; Wang-Price et al., 2017). For the contralateral arm lift with tactile feedback condition, the investigator who gave the verbal instruction applied a continuous direct tactile feedback by placing one hand over the lumbar multifidus muscle during the entire contralateral arm lift. Each participant was given one practice trial before EMG recording began, and then performed an 8-second contralateral arm lift five times without tactile feedback, and five times with tactile feedback. If a participant demonstrated difficulty in holding for 8 s, the participant was allowed to hold for a shorter period of time, but a minimum of 5 s. Finally, two trials of maximal voluntary isometric contraction (MVIC) of the lumbar multifidus muscles were obtained by asking the participant to perform a bilateral arm lift from the resting position and to lift their chest off the table while the investigator applied a steady downward force on the

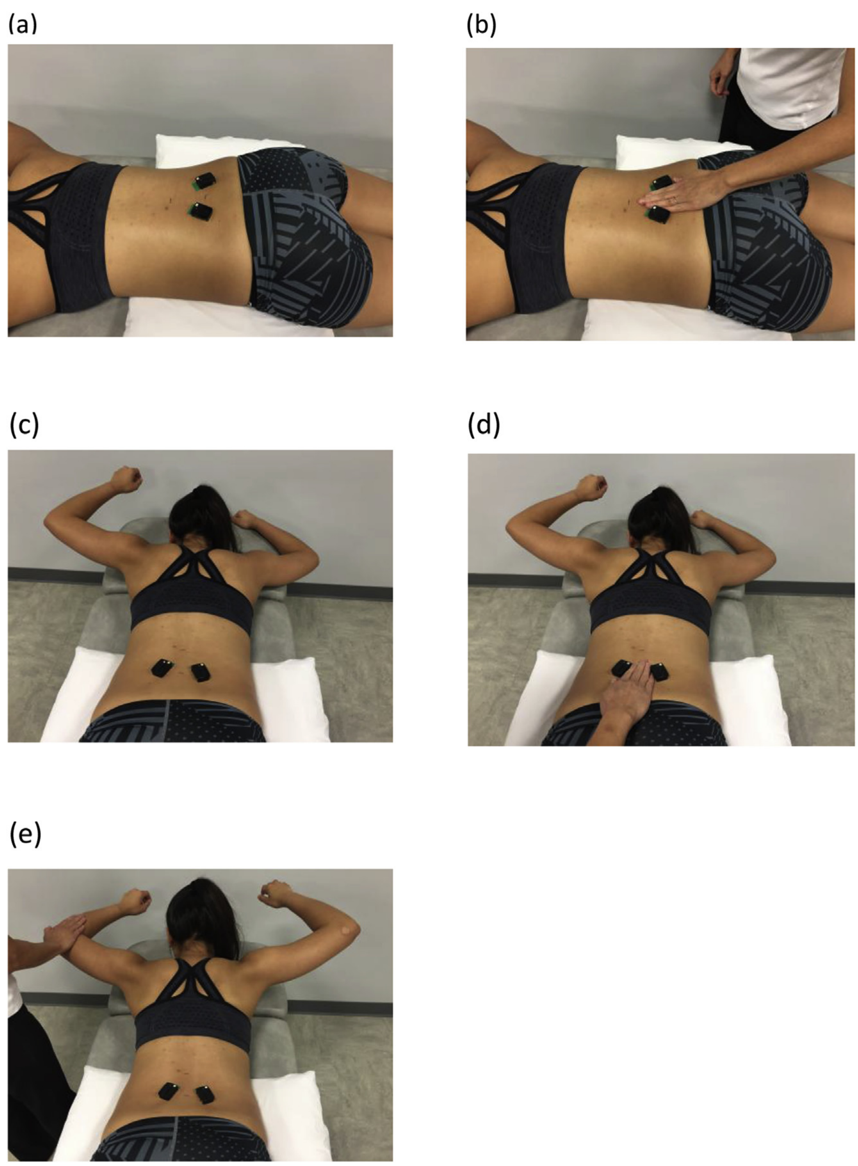

Fig. 1. (a) Electrode placements for the right and left lumbar multifidus muscles, (b) application of tactile feedback at rest, (c) contralateral arm lift task without tactile feedback, (d) contralateral arm lift task with tactile feedback, and (e) bilateral arm lift for maximal voluntary isometric contraction.

Table 1
Characteristics of the participants in the asymptomatic group (n = 20) and the low back pain group (n = 20).

Variables	Asymptomatic Group	Low Back Pain Group	*P* value
Age (years)	31.7 ± 10.5	36.3 ± 18.8	.342
Gender	9 men	7 men	.748
	11 women	13 women	
Height (m)	1.70 ± 0.74	1.70 ± 0.11	.984
Weight (kg)	71.6 ± 13.2	72.0 ± 17.2	.938
OSW (%)	0.20 ± 0.89	17.7 ± 9.8	.001*
NPRS (out of 10)			
Now	–	2.6 ± 1.66	
Worst	–	5.0 ± 1.4	
Best	–	1.8 ± 1.6	
Average	–	3.1 ± 1.3	
Duration of low back pain (wks)	–	158.4 ± 209.5	

OSW: modified Oswestry low back pain disability questionnaire. NPRS: numerical pain rating scale. *$P < .05$ for independent *t*-test or chi-square test.

elbow opposite the side of the tested lumbar multifidus muscle (Fig. 1e). Two 5-second MVIC trials were recorded for the right and left lumbar multifidus muscles, respectively. Upon completion of EMG recording, each participant was asked to identify if adding tactile feedback was useful to help them to contract the lumbar multifidus muscle.

2.4. Data analysis

Descriptive statistics were calculated for participant characteristics and normalized EMG activity of all participants. Independent *t*-tests were used to compare the ratio data of participant characteristics and EMG data at rest between groups. Chi-square statistics were used to analyze categorical data of participant characteristics. Root-mean square (RMS) values were extracted from each EMG trial using Delsys EMGWorks (Delsys Inc., Natick, MA) for qualifying EMG activity. The middle three seconds of each 5-second EMG recording at rest and during MVIC tasks, as well as the middle five seconds of the 8-second EMG recording during each contralateral arm lift, were used for statistical analysis. The larger EMG RMS value of the two MVIC tasks was used for normalization. Each EMG RMS value at rest or during a contralateral arm lift was normalized to the EMG RMS value of the MVIC using the following formula: (EMG RMS at rest/EMG RMS of MVIC) x 100, and (EMG RMS during contralateral arm lift/EMG RMS of MVIC) x 100.

IBM SPSS Version 23.0 (IBM Corp., Armonk, NY, USA) was used to analyze normalized EMG data (% of MVIC) of the lumbar multifidus muscle. First, a concurrent reliability analysis was performed to assess the test-retest reliability of the normalized EMG data collected during each condition and for the asymptomatic group and the LBP group, respectively. Next, two separate 2 (group) x 2 (condition) ANOVAs with repeated measures were performed to determine differences in normalized EMG data between groups and across conditions at rest and during contralateral arm lift, respectively. After a Bonferroni correction, the α level was set at 0.025 for each ANOVA with repeated measures.

3. Results

Forty-two participants were enrolled in the study and 40 participants completed the study. One participant had to leave for another medical appointment and was not able to complete the study. EMG recording from one participant was incomplete because an unexpected software problem occurred. Both drop outs were in the LBP group. Table 1 illustrates the characteristics of participants, including age, gender, height, weight and, the OSW scores of both groups, and the NPRS score and duration of pain of the LBP group. There was no difference in age, the number of men and women, height, and weight between groups. The OSW score (17.7 ± 9.8) and the average NPRS score (3.1 ± 1.3) indicate that participants in the LBP group had mild disability due to low level of LBP. However, the long duration of LBP (158.4 ± 209.5 weeks) indicates their LBP had become chronic.

The reliability analysis revealed excellent test-rest reliability of EMG data collected in the study, with intraclass correlation coefficient ($ICC_{3,1}$) values ranging from 0.912 - 0.997 for the asymptomatic group, and 0.909–0.998 for the LBP group (Table 2). Normalized EMG RMS values (% of MVIC) (means and SDs) of lumbar multifidus at rest and during the contralateral arm lifts are listed in Table 3. For the normalized EMG data at rest, there was no significant interaction between groups across the two conditions, with and without tactile feedback ($P = .829$), but there was a significant main effect of condition ($P = .013$), with the EMG value being significantly decreased during the tactile feedback condition (see Fig. 2). Similar to the results at rest, there was no significant interaction between groups across the two conditions ($P = .878$) during contralateral arm lifts, but a significant main effect of condition ($P = .010$), in which the EMG value was significantly

Table 2
Test-retest reliability (ICC values and 95% confidence interval) of electromyographic (EMG) activity measurements at rest and during contralateral arm lifts for the asymptomatic group and the low back pain group.

	Asymptomatic Group (n = 20)		Low Back Pain Group (n = 20)	
	Left	Right	Left	Right
At Rest				
Without tactile feedback	0.994 (0.987, 0.998)	0.992 (0.984, 0.997)	0.909 (0.818, 0.961)	0.994 (0.994, 0.999)
With tactile feedback	0.997 (0.993, 0.999)	0.936 (0.868, 0.973)	0.909 (0.997, 0.999)	0.998 (0.997, 0.999)
During Contralateral Arm Lifts				
Without tactile feedback	0.954 (0.912, 0.980)	0.912 (0.839, 0.960)	0.956 (0.916, 0.981)	0.949 (0.901, 0.979)
With tactile feedback	0.961 (0.924, 0.983)	0.952 (0.909, 0.979)	0.965 (0.986, 0.997)	0.932 (0.871, 0.970)

ICC: intraclass correlation coefficient.

Table 3
Normalized electromyographic activity (% MVIC) of the lumbar multifidus muscle at rest and during contralateral arm lift with and without tactile feedback for all participants (n = 40), the asymptomatic group (n = 20), and the low back pain group (n = 20).

	All Participants	Asymptomatic Group	Low Back Pain Group	*P* value
At Rest				.013*
Without tactile feedback	17.26 ± 12.47	14.83 ± 11.07	19.68 ± 13.57	
With tactile feedback	14.36 ± 11.32	12.17 ± 8.90	16.54 ± 13.18	
During Contralateral Arm Lifts				.010*
Without tactile feedback	32.01 ± 16.28	28.96 ± 13.27	35.07 ± 18.67	
With tactile feedback	29.50 ± 15.10	25.29 ± 12.10	33.72 ± 16.85	

MVIC: maximal voluntary isometric contraction. *$P < .025$.

decreased during the tactile feedback condition (see Fig. 2). Both statistical analyses indicate significantly reduced lumbar multifidus EMG activity when tactile feedback was applied for both groups at rest and during the contralateral arm lifts. Lastly, 35% of asymptomatic participants and 50% of patients with LBP perceived tactile feedback to be helpful for activating the lumbar multifidus muscle.

4. Discussion

All of the participants with or without LBP demonstrated decreased lumbar multifidus muscle activity by 2–3% of MVIC with tactile feedback at rest and during the contralateral arm lift. The results suggest that when tactile feedback is applied via continuous hand contact over the lumbar multifidus muscle, the hand contact appeared to produce an inhibitory or relaxing effect, rather than a facilitating effect, on lumbar multifidus muscle activity in both asymptomatic healthy adults and patients with LBP. This inhibitory or relaxing effect is not considered a desired treatment effect when clinicians attempt to recruit or activate the lumbar multifidus muscle during the rehabilitation of LBP. The results of this study are in disagreement with the finding of a previous study (Konishi, 2013) in which increasing muscle activity of quadriceps was observed with adhesive tape applied around the knee. In that study, the increased muscle activity was speculated to be due to increasing sensory input to skin (Ia afferent), thus facilitating activation of alpha motor neurons (Gusella et al., 2014; Konishi, 2013). Providing tactile feedback using continuous hand contact such as the one used in this present study may have attenuated Ia afferent activity, thus reducing alpha motor activity for the lumbar multifidus muscle. The hand contact could have generated an effect similar to that of inhibitory taping applied perpendicular to the orientation of the muscle fibers with tension (McCarthy Persson et al., 2007; Takasaki et al., 2015). Although the hand placement in this study was not perpendicular to the orientation of the lumbar multifidus muscle fibers, the hand was placed crossed over the muscle fibers. Nevertheless, the underlying mechanism of inhibitory taping is unclear. It is also noted that the temperature of the research's hand could have impacted the different results of this study. An EMG study examining the effect of skin temperature on EMG activity of the quadriceps showed that the EMG activity was reduced as skin temperature increased at a given force (Bell, 1993). Factors such as fluid shifts within the muscle, conduction velocity changes within the muscle, and sweating were hypothesized to contribute to the phenomenon of reduced EMG activity (Bell, 1993). Furthermore, varying temperatures of the investigator's hand at the time of the testing may have affected muscle activation.

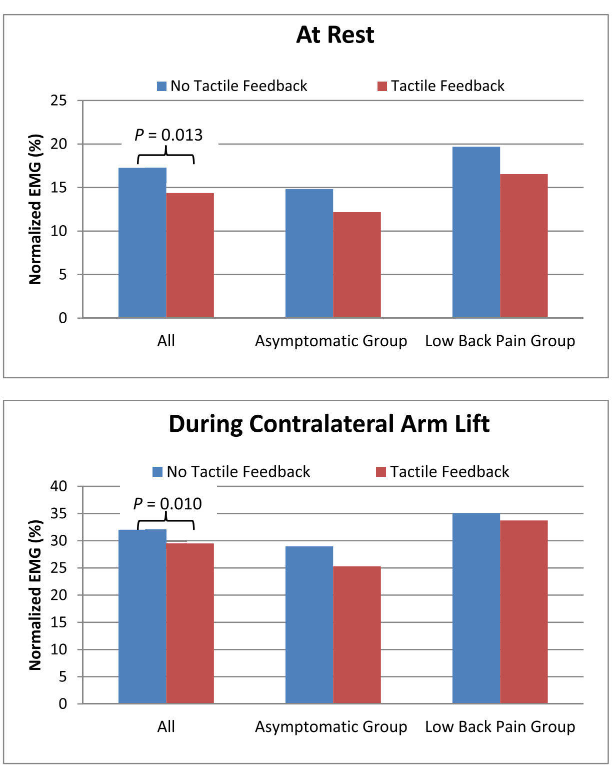

Fig. 2. Significant difference in the normalized electromyographic (EMG) activity between no tactile feedback and tactile feedback both at rest and during contralateral arm lifts.

The EMG values of the LBP group were about 4–5% higher at rest and 6–8% higher during contralateral arm lifts than the asymptomatic group. A muscle spasm model could be used to explain the higher lumbar multifidus muscle activity at rest in the patients with LBP, as increased muscle activity is used for providing lumbar stability in the prone-lying position (Cassisi et al., 1993). In addition, increased muscle activity of the trunk extensors has been shown previously in patients with chronic LBP during a contralateral hip extension (Kim et al., 2014). It was suggested that patients with chronic LBP may need more activation of the contralateral trunk muscles to achieve the same task as compared to asymptomatic individuals. This difference in muscle activation could have occurred during contralateral arm lifts in the participants of this present study. However, other literature shows reduced lumbar multifidus muscle activation in patients with LBP (Danneels et al., 2002; Ng et al., 2002). Therefore, it is speculated by the authors of this study that the MVIC may not be achieved due to pain inhibition. Although only three of 20 participants in the LBP group expressed pain increased during the MVIC tests, the researcher may not have applied enough force on the participant's elbow to produce maximal lumbar multifidus contractions while the participant attempted to maintain isometric contraction. It is also noted that the test-retest reliability for the EMG testing protocol was good-to-excellent for both groups. Therefore, it is doubtful that EMG variation could have impacted the higher EMG of the lumbar multifidus muscle in the LBP group.

In this study, the EMG value of the asymptomatic group increased from 12.17% of MVIC at rest to 14.83% of MVIC during a contralateral arm lift. When comparing these results with those of Kiesel et al. (2007), in which a similar EMG testing protocol was used, the EMG value in this study was about 5% lower during a contralateral arm than the value (19.5% of MVIC) reported by Kiesel et al. The use of fine-wire electrode and electrode insertion at L4 in Kiesel et al.'s study could have contributed to the different results. Due to the cross-talk effect, surface EMG values are often higher than fine-wire EMG values when both methods are used to collect activity from the same muscle simultaneously (Semciw et al., 2014). However, higher fine-wire EMG values than surface EMG values of shoulder muscles also have been reported (Rajaratnam et al., 2014). Therefore, surface EMG results should not be compared with fine-wire EMG results. EMG values were not reported by Kiesel et al. for the rest condition or for patients with LBP (Kiesel et al., 2007, 2008).

Interestingly, 35% of asymptomatic participants and 50% of patients with LBP perceived tactile feedback to be helpful for activating the lumbar multifidus muscle, whereas lumbar multifidus muscle activity actually was reduced when tactile stimulation was applied. This may indicate a disconnect between these participants' perception of tactile feedback and their ability to perform lumbar multifidus contraction, particularly in those with LBP. Similarly, patients with chronic LBP were found to have difficulty in subtle movements of their back and pelvis coinciding with their decreased tactile acuity, as determined by the two-point discrimination threshold, in the area of pain (Moseley, 2008). Further, the perception of the participants who considered tactile feedback to be helpful for lumbar multifidus contraction could be a Hawthorne effect given that the participants were informed of the purpose of the study, possibly biasing their perception of the tactile feedback effect (McCambridge et al., 2014).

A limitation of this study was the use of surface EMG to study muscle contraction. Although the reliability of the EMG testing protocol used in this study was shown to be good-to-excellent, the cross-talk effect from other paraspinal muscles cannot be completely eliminated (De Luca and Merletti, 1988). A fine-wire EMG electrode approach may be capable of isolating lumbar multifidus, but needle and fine-wire insertion may elicit pain and result in muscle inhibition. Further, the fatigue effect could have affected the result of the study. To minimize the fatigue effect, sufficient rest was given between contralateral arm lifts and MVIC tests, and the MVIC was tested last. However, none of the participants complained of fatigue during muscle contraction, and all participants in the LBP group performed 8-second contralateral arm lifts and 5-second MVICs. Lastly, the continuous direct hand contact on the skin over the lumbar multifidus muscle may not reflect clinical practice, as intermittent light-tapping and deep pressure modes of tactile feedback are more commonly used by clinicians. However, because surface EMG was used for quantifying muscle activity in this study, intermittent light-touch tapping or deep palpation was not feasible. In spite of the above limitations, one of the strengths of the study was the use of the objective EMG method to quantify muscle activation. In addition, the results of the study increase our understanding of how direct and continuous hand contact affects muscle activation.

In conclusion, the results of the study show that the application of tactile feedback appeared to provide an inhibitory effect on lumbar multifidus muscle activity in both asymptomatic healthy adults and patients with LBP. Contrary to common belief, tactile feedback via direct hand contact may reduce lumbar multifidus muscle recruitment, and may lessen the desired treatment effect. However, more research is needed, including research into the effects of other forms of tactile feedback, such as light tapping or deep palpation, on muscle recruitment.

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