Altered Multifidus Recruitment During Walking in Young Asymptomatic Individuals With a History of Low Back Pain

Despite substantial research and escalating health care costs over the past few decades, the mechanisms underlying the transition from acute to persistent low back pain (LBP) are still not well understood or effectively managed. The majority of back pain research to date has focused on individuals who experience chronic, largely unremitting pain (chronic LBP). However, there is increasing recognition that a distinct subgroup of individuals with persistent LBP experience an episodic or recurrent pattern of symptoms. In these individuals, successive episodes of LBP become longer and more likely to require absence from work and medical intervention over time. In the absence of clear precipitating events or significant pathoanatomical dysfunction, it is often unclear why these individuals experience recurrences of their back pain following periods of time when they are entirely symptom free. However, persistent and maladaptive alterations in dynamic trunk postural control may contribute to this recurrence. In order to understand the development and persistence of both recurrent and chronic LBP, and to identify appropriate interventions, it is necessary to clarify whether changes in trunk postural control are an adaptive response to concurrent symptoms or reflect a persistent, maladaptive change in motor control. This can be ascertained by investigating individuals with recurrent low back pain (RLBP) during asymptomatic periods.

Research investigating postural adjustments in the trunk has demonstrated altered amplitude and timing of activity in the paraspinal muscles in persons with chronic LBP and in asymptomatic individuals.
individuals with a history of RLBP. The paraspinal muscle group comprises the muscles adjacent to the spinal column. In the lumbar region, the paraspinals can be subdivided into the erector spinae (iliocostalis lumborum and longissimus thoracis pars lumborum, hereafter termed lumbar longissimus) and the transversospinales (of which the multifidus is the major component). The lumbar multifidus is commonly subdivided into the deep portion of the muscle, with fibers that extend across only 2 vertebral segments, and the superficial portion of the muscle, with fibers that cross up to 5 vertebrae. Similarly, in the thoracic region the paraspinals comprise the erector spinae (spinalis, iliocostalis thoracis, and longissimus thoracis pars thoracis, hereafter termed thoracic longissimus) and the transversospinales. Changes in paraspinal control in individuals with LBP include delayed and decreased activation in the deep fibers of the lumbar multifidus muscle and task- and subject-dependent modifications in the timing and amplitude of activity of the lumbar and thoracic erector spinae. Impaired dynamic trunk postural control is also evident in symptomatic individuals with LBP during locomotion. Studies of treadmill walking utilizing surface electromyography (EMG) have demonstrated increased duration and amplitude of activity in the erector spinae during locomotion in persons with chronic LBP. To date, it is unclear whether these same changes in erector spinae function during walking are evident in individuals with a history of RLBP during periods when they are asymptomatic. It is also unclear whether there are impairments in the recruitment of the deep fibers of the lumbar multifidus during walking in individuals with LBP.

Research suggests that the normal increase in paraspinal activity in response to increasing locomotor speed is not affected by LBP. However, existing studies investigating paraspinal activity in individuals with LBP have used surface EMG and therefore have not been able to differentiate between the muscles comprising the paraspinal group. It is not known whether the relative contribution of the individual muscles to this increase in activity is the same, or whether individuals with LBP have an altered distribution of activity across the paraspinal group. Investigating paraspinal muscle activity with fine-wire intramuscular EMG electrodes may provide this knowledge.

In the lower limbs, modulation of muscle activity in response to increasing locomotor speed encompasses both shifts in timing and changes in amplitude, and the pattern of these modulations is muscle specific. Therefore, investigating temporal and spatial adaptations to increasing locomotor speed may help to elucidate functional differences in control of the paraspinals in individuals with a history of LBP. Postural demand in the trunk during locomotion is also greater during functional locomotor perturbations such as walking turns, particularly in the upper trunk. Thus, walking turns may provide an excellent paradigm for differentiating between activity in the lumbar and thoracic regions of the paraspinals in healthy individuals and those with a history of back pain.

The primary purpose of this study was to compare postural activity in the individual muscles of the paraspinal group during walking turns at varying speeds in healthy young individuals and in asymptomatic young individuals with a history of LBP. We hypothesized that individuals with a history of LBP would demonstrate reduced activity in the deep fibers of the multifidus compared with healthy controls, but greater activity in the lumbar and thoracic fibers of the longissimus.

**METHODS**

**Participants**

Twenty-nine young adults between 22 and 31 years of age participated in the study (17 women) (TABLE). Participants were recruited via word of mouth and study flyers. Control participants were individually matched to participants with RLBP by sex, age (±5 years), height, weight (±10%), and typical activity level in metabolic equivalents (±15%) (TABLE). One female participant with a history of RLBP did not complete the data collection due to a transient vasovagal reaction to intramuscular EMG insertion. Therefore, control participants were matched to the remaining 14 participants with a history of RLBP. A priori power analyses of preliminary data collected in our laboratory indicated that a minimum sample size of 10 per group would be adequate to determine a statistically significant difference between groups for duration of muscle activity at a power of $\beta = .8$, statistical significance of $\alpha = .05$, and an effect size of 1.06. The University of Southern California Health Sciences Campus Institutional Review Board approved the procedures in the

<table>
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<th>Control Group</th>
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</table>

Abbreviations: MET, metabolic equivalent; PAS, physical activity score; RLBP, recurrent low back pain.

*Both groups comprised 8 women and 6 men. Values are medium ± interquartile range.
FIGURE 1. Frontal plane schematic of the deep fibers of the lumbar multifidus and lumbar longissimus (A), and the thoracic longissimus muscles (B). Axial ultrasound images (transverse plane projections) showing location of electrode placements at L4 (deep multifidus and lumbar longissimus) and T10 (thoracic longissimus) (C), with asterisks corresponding to the level of electrode insertions in A and B. Note that all insertions were made on the same side, but are shown here on different sides for clarity. Abbreviation: SP, spinous process.
direction and turning briskly 90° (FIGURE 2B). All participants spontaneously utilized a pivot strategy to complete the turn, with the change in direction performed by pivoting on the stance foot. For consistency, all participants turned contralateral to the side of their EMG instrumentation (the symptomatic side in the RLBP group and the matched side in the control group) during the stance phase of the turn. Although preliminary data indicated minimal differences in EMG variables between turn directions, turns contralateral to the instrumentation were selected to maximize erector spinae activity at initial contact. Prior to data collection, participants practiced the walking circuit until they were consistently able to turn with the correct foot in the correct area without altering stride length or changing cadence.

**Data Processing**

Fifteen trials were analyzed for each participant at each speed. The first 15 clean trials were selected for analysis for all individuals. Trials were excluded if the participant performed the turn incorrectly. Timing of locomotor events was determined using the foot switches, and all data were analyzed across the stride cycle of the turn, from the initial contact of the limb ipsilateral to the turning direction to the next initial contact of the same limb. Electromyographic data were processed in MATLAB (The MathWorks, Inc, Natick, MA). After removal of the direct-current offset, the EMG signals were band-pass filtered (40- to 1500-Hz, digital, zero-phase Butterworth filter) and full-wave rectified.

**Data Analysis**

The onset and offset of muscle activity during each turn were calculated using the integrated profile method. This technique has been validated in experimental data for the trunk musculature and in signals with artificially simulated noise. It results in fewer errors than standard threshold-detection protocols when determining postural trunk muscle activity, as it is not dependent on baseline activity or the rate of signal increase.

The amplitude of each signal was first continuously integrated across the stride cycle and normalized so that the final value was 1. The time of the stride cycle for each individual trial was also normalized to 1. The integrated signal was then subtracted from a reference line with a slope of 1, which reflects the hypothetical condition where the muscle activity remains constant across the time series of the trial. The local maxima and minima of the deviations of the actual integrated signal from the reference line were then used to determine the timing of onset or offset. The algorithm was implemented with a visual check of the detected onset and offset events superimposed over the rectified/band-passed signal to ensure appropriate determination. The duration of the muscle burst occurring between each onset and offset event was calculated, and the sum of the duration of all bursts across each stride cycle, stance phase, and swing phase was calculated and expressed as a percentage of the total duration of the stride cycle, stance phase, and swing phase for that trial. The average amplitude of activity in each muscle was also calculated across the stride cycle and within the stance and swing phases individually for each turn at each speed. The stance phase and swing phase values were then amplitude normalized for each participant to the average value across the stride cycle during turns performed at the self-selected speed.

The within-day standard error of the measurement (SEM) of the EMG variables was also calculated. The SEM is an index of measurement error, expressed in the measurement’s units. Changes in any variable that exceed the SEM can be interpreted as being larger than the measurement error.
RESULTS

In the RLBP group, the median ± interquartile range score was 12.50 ± 6.75 on the Fear-Avoidance Beliefs Questionnaire physical activity subscale and 88 ± 12.83 on the Low Back Activity Confidence Scale, which is higher than previously reported values in an LBP population. The median ± interquartile range score on the Oswestry Disability Index was 18.0% ± 15.0%, indicating minimal disability. At baseline, average ± SD current pain was 0.12 ± 0.24 cm in participants with a history of RLBP and 0 cm in the control participants. One individual who reported pain of less than 0.5 during the subjective screening procedures completed a VAS that was measured as 0.8 at the commencement of the data collection (after the physical examination). The decision was made to include the data, as this value was well below the minimal detectable change for the VAS. During the locomotor trials, participants reported low levels of discomfort associated with the intramuscular EMG electrodes (RLBP group, 0.50 ± 0.70 cm; control group, 0.45 ± 0.70 cm; *P = .779). Reliability was excellent, with ICC values exceeding 0.85 for all analyses was conducted to assess the main effect of speed (within-subject factor; self-selected and fast) and group (between-subject factor; control and RLBP) and the interaction effect between speed and group for the average duration of the turn stride cycle, and the duration and average amplitude of muscle activity across the stride cycle of the turn and within the stance and swing phases for each muscle. Similarly, a mixed-design analysis of variance was conducted to assess the main effect of speed and group and the interaction effect between speed and group for the average normalized amplitude of muscle activity within the stance and swing phases for each muscle. Post hoc comparisons were made using t tests with a Bonferroni correction (adjusted level of significance, .01). Effect sizes for post hoc comparisons were calculated using Cohen’s d, with 0.8 indicating a large effect size, 0.5 a medium effect size, and 0.2 a small effect size. Chi-square analysis was used to investigate the association between group and the frequency of increase or decrease in each variable. All statistical analyses were performed using PASW Statistics Version 18 (IBM Corporation, Armonk, NY).

Statistical Analysis

Self-selected average locomotor speed and the VAS for pain during the walking turns were compared between groups using paired t tests. Parametric analysis is appropriate for VAS pain data, as the VAS for pain has been demonstrated to have the properties of a ratio scale. An individual mixed-design analysis of variance was conducted to assess the main effect of speed (within-subject factor; self-selected and fast) and group (between-subject factor; control and RLBP) and the interaction effect between speed and group for the average duration of the turn stride cycle, and the duration and average amplitude of muscle activity across the stride cycle of the turn and within the stance and swing phases for each muscle. Similarly, a mixed-design analysis of variance was conducted to assess the main effect of speed and group and the interaction effect between speed and group for the average normalized amplitude of muscle activity within the stance and swing phases for each muscle. Post hoc comparisons were made using t tests with a Bonferroni correction (adjusted level of significance, .01). Effect sizes for post hoc comparisons were calculated using Cohen’s d, with 0.8 indicating a large effect size, 0.5 a medium effect size, and 0.2 a small effect size. Chi-square analysis was used to investigate the association between group and the frequency of increase or decrease in each variable. All statistical analyses were performed using PASW Statistics Version 18 (IBM Corporation, Armonk, NY).

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variables, except the duration of activity in the thoracic longissimus.

**Self-selected Locomotor Speed and Locomotor Events**

All participants were able to complete the walking turns at the self-selected and fast speeds. Self-selected locomotor speed was the same in both groups and was slower than the fast speed in all participants, except in 1 individual in the control group (average self-selected speed for control group, 1.22 ± 0.13 m/s and for RLBP group, 1.23 ± 0.10 m/s; \( P = .719 \)). The speed at which the turn was executed increased at the faster speed, with a significant decrease in the duration of the stride cycle of the turn (\( F_{1,26} = 102.274, P \leq .0001 \); self-selected speed average duration, 1.16 ± 0.09 seconds; fast speed average duration, 1.02 ± 0.06 seconds). There was no effect of group or speed-by-group interaction for locomotor speed or turn duration.

**Overview of Paraspinal Activity During Walking Turns**

Exemplar EMG data and an overview of paraspinal activity are provided in **FIGURE 3**.

**Duration of Activity**

Total duration of activity in each muscle during the stance and swing phases at each speed is shown in **FIGURES 4A and 5**. There was a significant speed-by-group interaction for the duration of deep multifidus activity (\( F_{1,26} = 7.186, P = .013 \) (**FIGURE 4A**), but no main effect of speed (\( F_{1,26} = 0.006, P = .938 \)) or group (\( F_{1,26} = 0.021, P = .886 \)). Post hoc comparisons indicated a trend toward a significant decrease in duration from self-selected speed to fast speed in the RLBP group (\( P = .04, d = 0.23 \)) and that the average duration of activity across the stride cycle increased in the control participants but decreased in the RLBP participants (average change from self-selected speed to fast speed: control group, 0.84% ± 1.87%; RLBP group, −0.79% ± 1.30%; \( P = .003, d = 1.01 \)). This difference exceeded the SEM (0.56% of stride cycle).

Analyses of stance and swing phase individually indicated that this interaction effect was significant during the swing phase (swing phase speed-by-group interaction: \( F_{1,26} = 4.861, P = .037 \) but not during the stance phase (\( F_{1,26} = 2.467, P = .128 \)). Eight of the individuals in the control group demonstrated an increase in duration of activity, compared with only 3 individuals in the RLBP group, resulting in a trend toward a significant association between group and change in duration of deep multifidus activity (\( \chi^2 = 0.058 \) (**FIGURE 4B**)).

There was no main effect of speed or group or interaction of speed by group for the lumbar longissimus activity across the stride cycle of the turn (**FIGURE 5**). Although the duration of lumbar longissimus activity increased in both groups during the swing phase of the turn at the faster speed (main effect of speed: \( F_{1,26} = 14.109, P = .001 \)), the change in the duration of lumbar longissimus activity in response to increasing speed did not exceed the SEM for that muscle (1.51%).

Duration of thoracic longissimus activity significantly increased at the faster speed in both groups (\( F_{1,26} = 6.09, P = .020 \) (**FIGURE 5**), and the extent of this increase exceeded the SEM (0.75%). Individual analyses of the stance and swing phases indicated that a significant increase in duration of activity primarily occurred during the swing phase (\( F_{1,26} = 12.542, P = .002 \)). However, there was no main effect of group or group-by-speed interaction.
Amplitude of Activity

The normalized amplitude of activity in the deep fibers of the multifidus increased significantly from the self-selected to the fast speed. This change was evident during the stance phase ($F_{1,26} = 9.67, P = .005$) and within the swing phase ($F_{1,26} = 16.36, P < .0001$), but was not significantly different between groups (FIGURE 6). The extent of the increase in multifidus activity exceeded the SEM (0.001 mV). Normalized amplitude of activity in the lumbar longissimus and thoracic longissimus also significantly increased during stance and swing phases (lumbar longissimus stance: $F_{1,26} = 8.317, P = .008$; lumbar longissimus swing: $F_{4,26} = 21.035, P < .001$; thoracic longissimus stance: $F_{1,26} = 10.567, P = .003$; thoracic longissimus swing: $F_{4,26} = 21.358, P < .001$) (FIGURE 6), but this change did not exceed the SEM in either case (lumbar longissimus SEM, 0.27 mV; thoracic longissimus SEM, 0.09 mV).

DISCUSSION

The present study found that activation of the deep fibers of the multifidus during a locomotor task was altered in people with RLBP. In contrast with healthy individuals, a majority of participants with a history of RLBP responded to increasing mechanical demand by reducing the duration of activity of the deep fibers of the multifidus. Impaired timing of the anticipatory activity of the deep multifidus muscle and reduced amplitude of deep multifidus activity have previously been demonstrated in asymptomatic individuals with RLBP during standing postural perturbations and voluntary trunk flexion. 11,20 Taken together, the results from the present and previous studies suggest that changes in recruitment of the deep fibers of the multifidus persist between painful episodes in individuals with a history of LBP. The differences between groups in the present study were small. However, it is striking that changes in recruitment were still evident in a majority of young, asymptomatic individuals with a history of LBP, who had minimal disability, low levels of fear avoidance, and high self-efficacy. Additionally, it is important to note that walking turns are a submaximal task for the paraspinal musculature, with levels of muscle activity of less than 20% of maximum voluntary contraction (Smith and Kulig, unpublished data), and that walking is rarely a pain-producing activity in individuals with LBP. 24,27,59 Therefore, it is likely that these differences would be more pronounced during more demanding tasks. As there are changes in the morphology and fatigability of the deep multifidus muscle in persons with LBP, further research is needed to determine whether this altered strategy is adaptive to compensate for altered morphology in the multifidus muscle or a maladaptive consequence of pain. However, as changes in multifidus recruitment during anticipatory postural adjustments occur in response to anticipated experimental pain in healthy individuals without injury or muscle impairment, we propose that they represent a maladaptive postural control response. This study did not find significant differences in the duration or amplitude of activity in the lumbar or thoracic longissimus in asymptomatic persons with a
history of RLBP compared to controls. This is in contrast to findings of increased erector spinae muscle activity in symptomatic individuals with chronic LBP. Investigations of acute experimental LBP have also found increased amplitude of erector spinae activity during walking. Taken together, the results of the present study and earlier work suggest that changes in postural trunk control during walking may form a continuum. Significant adaptations in superficial paraspinal muscle activity may be evident both acutely and persistently in response to concurrent pain, but may not persist between symptomatic episodes during submaximal locomotor tasks. Clinically, this study adds valuable information regarding the timing of the development of the control changes that occur in association with LBP and how these changes are associated with symptoms. This is important to effectively subgroup individuals with LBP for treatment and research, and to determine when interventions targeting these impairments may be warranted.

All individuals in this study were able to complete the walking circuit at the faster, controlled speed. Interestingly, the asymptomatic individuals with a history of RLBP in this study did not have significantly different self-selected locomotor speed from that of the healthy individuals. This is in contrast to studies investigating steady-state locomotor speed in symptomatic individuals with chronic LBP that have consistently reported slower locomotion in the affected group. This may be due to a number of factors. Unlike previous studies, the individuals with LBP in the present study were asymptomatic at the time of the data collection. Additionally, participants in this study were in their mid-twenties, whereas those in existing studies were at least a decade older. However, the current study actually reported a longer duration of symptoms than did the previously cited studies, suggesting that deficits in locomotor speed may be more related to current pain intensity than to duration of symptoms.

On the whole, the activity of the paraspinal muscles during walking turns is consistent with that of previous studies that have investigated steady-state treadmill locomotion in healthy individuals. Paraspinal activity during locomotion occurs at initial contact and during the double-support phases of the locomotor cycle and controls spinal flexion and sidebending. To our knowledge, the only study previously investigating trunk muscle activity during turning reported continuous activity of the erector spinae during 180° turns. The authors hypothesized that this activity helped to decelerate forward momentum and balance the trunk over the limb during the turn. The more phasic activity evident in this present research is likely due to the turns in this study being both anticipated and of smaller amplitude. Observing the modulation in the activity in each muscle in response to increasing speed highlighted functional differentiation within the paraspinal group. The deep fibers of the lumbar multifidus exhibited the most pronounced changes in response to greater mechanical demand, with an increase in both duration and amplitude of activity at the faster speed. This is likely a reflection of the unique functional role of these fibers. The very small moment arm of the deepest fascicles of the multifidus relative to the segmental axis of rotation in the sagittal plane suggests that the primary function of this portion of the multifidus is to control spinal segmental motion via intersegmental compression, rather than to generate torque. As locomotor speed increases, ground reaction forces and, therefore, segmental shear forces increase. The deep fibers of the multifidus are ideally suited to control these segmental forces without generating large multisegmental torques. In contrast, activity in the lumbar longissimus was relatively unaffected by speed, while the thoracic longissimus exhibited increased duration of activity only. More prolonged thoracic activity may be necessary to decelerate motion of the trunk on the pelvis at initial contact at the faster speed.

It is important to note that further research is necessary to clarify the relationship between altered paraspinal muscle activation in individuals with LBP and altered kinematic postural control strategies, in order to determine the mechanical consequences of changes in muscle activation. Additionally, although the integrated profile method of EMG activity onset/offset detection is the most appropriate analysis technique for postural trunk muscle data, like all EMG detection methods, it is subject to the characteristics of the EMG signal and the task, and requires careful visual checking to avoid anomalous results.

CONCLUSION

In both groups, increases in walking speed were associated with significant increases in duration of activity in the thoracic longissimus and amplitude of activity in the deep multifidus. However, this study demonstrated for the first time that, even between symptomatic episodes, some young individuals with a history of RLBP demonstrate selectively altered modulation of the duration of deep multifidus activity in response to changing locomotor demands.

KEY POINTS

FINDINGS: In comparison with healthy adults, young asymptomatic individuals with a history of RLBP demonstrated altered patterns of recruitment of the deep fibers of the lumbar multifidus muscle when increasing speed during walking turns. IMPLICATIONS: This study provides evidence of persistent alteration in the recruitment of the lumbar multifidus muscle, even between symptomatic episodes of LBP, and may help with the further development of targeted treatment approaches for individuals with LBP. CAUTION: The individuals with a history of LBP in this study were young and minimally disabled. The results may be different in individuals who are older or more disabled. Additionally, causality in
the relationship between altered multifidus recruitment and RLBP cannot be determined by this study.

REFERENCES


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