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Effects of a Core Strengthening Program on Muscle Activity Patterns, Strength, and Endurance in People with and without a History of Low Back Pain: A Randomized Controlled Trial

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ABSTRACT

Background of Study: Altered patterns of abdominal and low back muscle activity have been reported in people in the sub-acute phase of low back injury. Specifically, higher overall muscle activity and less ability to match activity to task demands have been found. **Objective:** This study determined if an 8-week group exercise intervention would alter muscle activity, strength, and endurance in people with/without a history of low back pain (LBP). **Method:** In this randomized controlled trial 46 participants (age 19-55) with a history of LBP were randomized to exercise (LBPEx, n=24) and no-exercise (LBPCon, n=22) groups. 27 participants without a history of LBP (NoLBP) also exercised. 17 LBPEx and 19 NoLBP participants completed the intervention. 19 LBPCon were tested at 8-week follow-up. The exercise intervention was an 8-week, choreographed, 30-minute group exercise intervention (Les Mills Core™) focused on building core strength, stability, and endurance. Pre and post-intervention surface electromyograms from abdominal and low back muscles were recorded during a trunk stability task (TST), and analyzed using Principal Component Analysis to extract patterns corresponding to overall amplitude and relative activation during the TST loading phase. Abdominal and back extensor strength and endurance were also measured. **Results:** It was found that overall abdominal activity decreased for left anterior external oblique (p=0.019 for TST level 3), left lateral external oblique (p=0.012 for TST level 3), and right posterior external oblique (p=0.035 for TST level 3) in LBPEx and for right lateral external oblique (p=0.009 for TST level 2 and p=0.004 for TST level 3) and left posterior external oblique (p=0.014 for TST level 2 and p=0.011 for TST level 3) in NoLBP during the TST. Abdominal strength and endurance, and back extensor endurance increased for LBPEx and NoLBP ($p<0.05$). Back extensor strength increased for NoLBP ($p<0.05$). Relative abdominal activation during the TST level 2 loading phase increased for right upper rectus abdominus (p=0.05), right lateral external oblique (p=0.002), and left posterior external oblique (p=0.006) for NoLBP, and for left anterior external oblique (p=0.042) for LBPEx. **Conclusion:** Les Mills Core™ is readily available and may be recommended as a safe, accessible, and effective intervention to increase abdominal strength and endurance, and back extensor endurance, even for people with a history of LBP.

Key words: Low Back Pain, Electromyography, Exercise, Principal Component Analysis, Muscles, Core Stability

INTRODUCTION

Low back pain (LBP) is prevalent, with 65-85% of people experiencing it at one point in their lives (Manchikanti, 2000). Estimates of 1-year incidence of first-time LBP range from 6.3-15.4% (Hoy, Brooks, Blyth, & Buchbinder, 2010). While most (54-90%) cases are in remission at 1-year follow-up (Hoy, Brooks, Blyth, & Buchbinder, 2010), many people who experience LBP will go on to have recurrent episodes. In a systematic review looking at the long-term course of LBP in individuals who received no therapeutic intervention, 60% experienced relapses of pain and 33% experienced relapses of work absence at least one year following the initial LBP episode (Hestbaek, Leboeuf-Yde, & Manniche, 2003).

Altered muscle activity could contribute to high LBP recurrence. Surface electromyography (EMG) has been used to quantify differences in abdominal and back extensor activity, and has shown that individuals in the sub-acute phase of healing who were pain-free had higher overall muscle activation (Butler, Hubley-Kozey, & Kozey, 2013; Moreside, Quirk, & Hubley-Kozey, 2014) and less ability to match activity to task demands (Butler, Hubley-Kozey, & Kozey, 2013) compared to participants with no history of LBP.

A recent meta-analysis found all forms of exercise are effective for improving pain and function in people with

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LBP, but some exercise interventions are more effective than others, including core exercises (Hayden, et al., 2021). Core exercises that challenge dynamic stability have become an accepted component of LBP rehabilitation. These exercises aim to build strength and endurance using neuromuscular control strategies required to maintain dynamic trunk stability (Hubley-Kozey & Vezina, 2002a). The overall goal is to improve muscular responsiveness needed to stabilize the spine against perturbations associated with activities of daily living (Hubley-Kozey & Vezina, 2002a). Core stabilization exercises have been found to result in greater improvements in proprioception, balance, functional disability, and fear of movement relative to a strengthening intervention in participants with subacute LBP (Hlaing, Puntumetakul, Khine, & Boucaut, 2021), supporting their use in LBP rehabilitation. While dynamic stability core exercises are commonly used in LBP rehabilitation, very few studies look at their effect on muscle activity. A recent study examining muscle activity in various core strengthening exercises found that dynamic and isometric exercises, including twisting exercises, bird-dogs, front and side planks, and squats were generally well tolerated in a sample of participants with chronic LBP (Calatayud et al., 2019), but the study was conducted in a single session, and the long term effects of these exercises on muscle activity were not determined. Additionally, no studies have looked at the longitudinal effect of exercises such as these on the altered trunk muscle activity patterns observed in those with a history of LBP. Given that these altered patterns persist even in the absence of pain, they may be a factor in subsequent episodes of LBP.

This study determined if an 8-week, bi-weekly, 30-minute group exercise intervention (Les Mills Core™), focusing on dynamic core stability would alter trunk muscle activity patterns, strength, and endurance in people with and without a history of LBP. Primary objectives were to determine if the intervention reduced overall trunk muscle activity, and changed temporal patterns of activity during a trunk stability task (TST). Secondary objectives were to determine if the intervention increased abdominal and back extensor strength and endurance. It was hypothesized that trunk muscle activity would decrease (as strength and endurance increased), and relative activation during the loading phase of the TST would increase, indicating a better ability to match muscle activity to task demands. It was hypothesized that these changes would be larger in participants with a history of LBP.

METHODS

Participants and Study Design

This was a randomized controlled trial. 115 individuals with and without (NoLBP) a history of LBP were recruited between October 2019 and May 2021 from local physiotherapy clinics, community posters, and social media and assessed for eligibility (Figure 1). Interested individuals were screened via email to ensure they met study inclusion criteria (specified below), could attend exercise classes, and it was safe to begin an exercise program (Warburton, Jamni, Bredin, & Gledhill, 2011). To be included in the study, individuals with a history of LBP self-reported a previous episode of LBP resulting in modification of activities of daily living severe enough to require medical intervention, but were currently experiencing minimal pain (≤ 3/10, where 0 was "no pain") and had resumed regular activities. All individuals were aged 19–55 years to be consistent with previous studies (Butler, Hubley-Kozey, & Kozey, 2013; Moreside, Quirk, & Hubley-Kozey, 2014). Participants were excluded if they presented with cardiovascular, respiratory, and/or neurological diseases that might be made worse by exercise, or put the participant at risk while exercising. 22 individuals were excluded for not meeting inclusion criteria or being unavailable during exercise class times. 20 individuals declined participation. Remaining interested participants with (n=46) and without (n=27) a history of LBP were scheduled for baseline data collection. This study was approved by the institutional research ethics board (protocol #100398) and participants signed informed consent forms.

Sample Size Calculation

Since the expected change in principal component (PC) scores was not known, the study was powered to detect a significant baseline between-group (LBPEx vs NoLBP) difference in overall abdominal muscle activity (abdominal PC1) using PC scores previously reported for a similar sample (Moreside, Quirk, & Hubley-Kozey, 2014). It was determined that to detect a significant baseline between-group difference with 80% power, 10 participants per group would be needed. The sample size calculation was performed in G*Power (Faul, Erdelder, Lang, & Buchner, 2007). To account for withdrawal, the aim was at least 20 participants each in LBPEx, LBPCon, and NoLBP groups.

Procedure

Demographic data (birthdate, sex, height, mass), LBP history (right/left/central pain, years from first episode, number of previous episodes, time since previous episode), and physical activity level (number of weekly sessions of physical activity ≥30 min) were collected (Butler, Hubley-Kozey, & Kozey, 2013). Participants filled out Roland-Morris Questionnaires (Roland & Morris, 1983) to assess LBP-related disability (Butler, Hubley-Kozey, & Kozey, 2013).

Wireless surface EMG sensors (Delsys Inc, Natick, Massachusetts, USA) were placed bilaterally over seven muscles after skin preparation (shaving, cleaning with alcohol): upper rectus abdominus (URA, midpoint between umbilicus and sternum), lower rectus abdominus (LRA, midpoint between pubis symphysis and umbilicus), anterior (AntEO, over eighth rib, adjacent to costal cartilage), lateral (LatEO, 15 cm lateral to umbilicus at 45° angle), and posterior (PostEO, halfway between iliac crest and lower rib cage) external oblique, erector spinae (ES, L1 level, 3 cm lateral to midline), and multifidus (Mult, L5 level, 2 cm lateral to midline) (Moreside, Quirk, & Hubley-Kozey, 2014; Butler, Hubley-Kozey, & Kozey, 2013; Clarke Davidson &

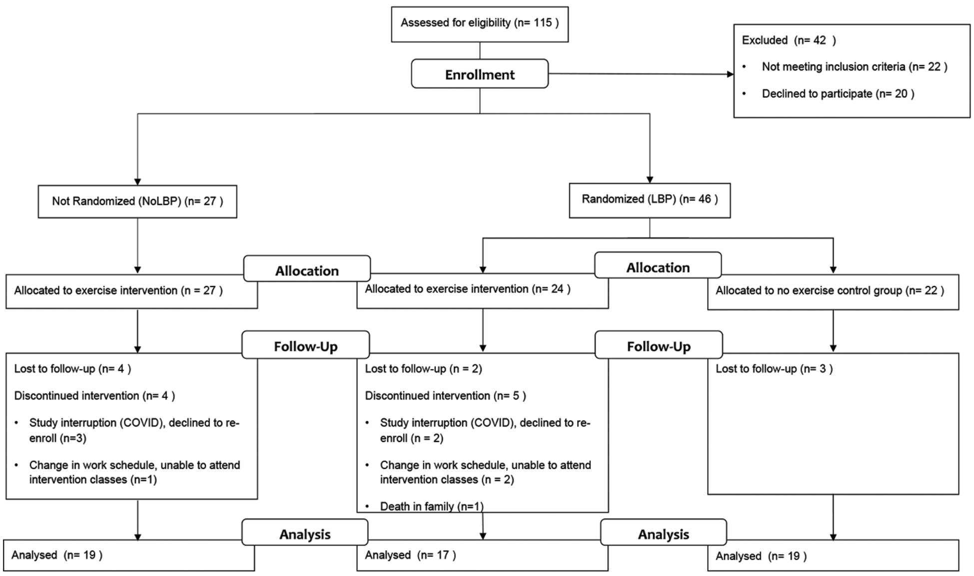

Figure 1. Participant flow diagram showing progression through recruitment, randomization, intervention, and follow-up

Hubley-Kozey, 2005). EMG data were sampled at 2148 Hz and bandpass filtered from 10 – 850 Hz.

EMG was collected while participants completed two levels of a TST used clinically to assess lumbar-pelvic stability. The TST required participants to maintain a neutral lumbar spine while performing leg movements (Clarke Davidson & Hubley-Kozey, 2005). The full TST has 5 levels of increasing difficulty (Clarke Davidson & Hubley-Kozey, 2005). For this study, levels 2 (TST2) and 3 (TST3) were performed because previous studies demonstrated that they were achievable for people with sub-acute LBP, and sensitive enough to elicit differences in muscle activity between participants with sub-acute LBP and asymptomatic controls (Moreside, Quirk, & Hubley-Kozey, 2014). Participants started supine, with feet on the testing surface and knees flexed to 90˚. The task was performed in six phases (Hubley-Kozey, Hanada, Gordon, Kozey, & McKeon, 2009):

1. Right leg lifted: hip flexed to 90˚, shin parallel to testing surface
2. Left leg lifted: hip flexed to 90˚, shin parallel to testing surface
3. Right leg extension: sliding heel along testing surface (TST2) or heel elevated (TST3)
4. Right leg flexion: sliding heel back along testing surface (TST2) or heel elevated (TST3)
5. Left leg lowered
6. Right leg lowered

Pressure sensors (Delsys Inc, Natick, Massachusetts, USA) on the participant's right foot and knee identified TST phases. The TST was performed to an 8-second count. Phases 1, 2, 5, and 6 took 1 second. Phases 3 and 4 took 2 seconds. Participants were given opportunity to practice, and when they were comfortable, 3 trials per level were collected.

Ten maximum voluntary isometric contraction (MVIC) exercises were performed for EMG amplitude-normalization: resisted sit-up, resisted hip flexion, crunch, resisted sitting axial rotation (bilaterally), resisted side-lying lateral flexion (bilaterally), resisted prone back extension, and resisted back extension/axial rotation (bilaterally). Contractions were held for three seconds, and performed twice. Verbal encouragement and feedback were provided to ensure correct performance and maximum effort (Butler, Hubley-Kozey, & Kozey, 2013). To measure abdominal and back extensor strength, the sit-up and back extension were performed against a hand-held dynamometer. The dynamometer was placed midway between the suprasternal notch and xiphoid process for the resisted sit-up, and midway between the scapulae (approximately T5 level) for resisted back extension.

To measure endurance, participants performed a plank, side plank (bilaterally), and prone back extension to voluntary failure, or five minutes (whichever came first). Planks were performed from forearms and toes.

Following data collection, participants with a history of LBP (n=46) were randomized into exercise (LBPEx, n=24) or no-exercise (LBPCon, n=22) groups, using block randomization (block size of 20, blocks generated using a random number generator). Randomization was performed prior to recruitment by someone external to the study. Group assignment letters were placed in sealed envelopes, numbered sequentially. All NoLBP participants completed the intervention. Thus, there were three groups: LBPEx, LBPCon, and NoLBP. The procedure described above was repeated at follow-up. The assessor was not blinded to group allocation at follow-up.

Exercise Intervention

The 8-week intervention was the 30-minute, choreographed, group exercise class Les Mills Core™. Classes consist of exercises using body weight, resistance bands, and free weights (Yorks, Frothingham, & Schuenke, 2017). The class consists of 6 "tracks", each one song in length and focused on a specific movement or muscle group: 1) warm-up, 2) hovers and planks, 3) integrated upper and lower extremity moves to target the entire core, 4) hip extensors and abductors, 5) oblique training, 6) upper and lower back extensors and hip extensors. Each exercise has options to accommodate and challenge fitness levels. Consistent with American College of Sports Medicine guidelines (2010), participants were asked to attend two classes per week, on non-consecutive days. Classes were delivered by a certified instructor (GLH).

Data Processing

Raw EMG signals were corrected for voltage offset, full-wave rectified, and low-pass filtered (4^{th} order recursive Butterworth, 6 Hz) to get a linear-enveloped profile (Moreside, Quirk, & Hubley-Kozey, 2014). A 500-ms moving average window determined maximum EMG from each muscle for each MVIC. The maximum amplitude for each muscle, regardless of exercise, was used for amplitude-normalization (Hubley-Kozey, Hanada, Gordon, Kozey, & McKeon, 2009). TST EMG was time-normalized to 100% of task (right foot-off to right foot-on) using a linear interpolation algorithm, and amplitude-normalized (Moreside, Quirk, & Hubley-Kozey, 2014). Waveforms for 3 trials per TST level were averaged to produce ensemble averages for each muscle (Hubley-Kozey, Hanada, Gordon, Kozey, & McKeon, 2009). Ensemble averages were used as input for Principal Component Analysis (PCA).

PCA is a pattern recognition technique that extracts main patterns in waveform data. This technique has been used previously in the study of trunk muscle activation during dynamic tasks, and extensive detail has been published (Butler, Hubley-Kozey, & Kozey, 2013; Clarke Davidson & Hubley-Kozey, 2005; Hubley-Kozey & Vezina, 2002a; Hubley-Kozey & Vezina, 2002b; Hubley-Kozey, Hanada, Gordon, Kozey, & McKeon, 2009; Hubley-Kozey, Hatfield, & Clarke Davidson, 2010; Moreside, Quirk, & Hubley-Kozey, 2014). A covariance matrix was constructed from ensemble average waveforms from each participant, for each muscle, for each task. An eigenvector decomposition on the covariance matrix was performed. The resulting eigenvectors are main patterns (principal components, PCs) in the data. PCs accounting for a total of at least 80% of the variation in the waveform data were retained for the statistical analysis (PC1 and PC2 for the abdominals, PC1 for the back extensors), and a score was calculated for each individual waveform based on how closely it matched a PC. PC scores were used in statistical hypothesis testing. Two PCA models were performed; one for the back extensors, and one for the abdominals.

Statistical Analysis

The primary dependent variables for this study were abdominal and back extensor muscle PC scores (PC1 and PC2 for all abdominal muscles and PC1 for back extensor muscles). The effect of the exercise intervention was determined using a repeated measures (time) linear mixed model analysis, with the fixed factors of group (NoLBP, LBPEx, LBPCon), TST level (level 2, level 3), muscle, and time (pre and post intervention), and the random factor of participant. Three models were performed: PC1 for abdominals, PC2 for abdominals, and PC1 for back extensors. Since PC1 was analyzed for the abdominals and back extensors separately, the significance level for main effects and interactions was set at 0.05/2=0.025. Since one model was run for PC2 (only abdominals), the significance level for main effects and interactions was 0.05. Significant main effects and interactions were further explored using pairwise comparisons with a Bonferonni correction based on the number of comparisons. Since the main research question for this study was whether an exercise intervention would affect abdominal and back extensor muscle activation amplitude and temporal patterns, pairwise comparisons were focused on looking at pre to post intervention changes in PC scores for each muscle, for each group. Differences in activation patterns between muscles, between levels of the TST, and between participants with and without a history of low back pain have previously been explored (Hubley-Kozey & Vezina, 2002b; Hubley-Kozey, Hanada, Gordon, Kozey, & McKeon, 2009; Hubley-Kozey, Hatfield, & Clarke Davidson, 2010; Moreside, Quirk, & Hubley-Kozey, 2014), thus the novel aspect of this study was the effect of an intervention on the PC scores.

The secondary dependent variables were abdominal and back extensor strength, and endurance (measured during a plank, a side plank (bilaterally), and prone back extension). For these variables, repeated measures (time) linear mixed model analysis, with the fixed factors of group (NoLBP, LBPEx, LBPCon), and time (pre and post intervention), and the random factor of participant were performed. The significance level was 0.05. Main effects and interactions were explored using pairwise comparisons with a Bonferonni correction.

Effect sizes for primary and secondary outcomes were calculated using Cohen's d statistic, where 0.2, 0.5, and 0.8 corresponded to small, medium, and large effect sizes, respectively. Statistical analyses were performed in SPSS 25 (IBM, Armonk, New York, USA).

RESULTS

Participant Characteristics, Attrition, Adherence, and Adverse Events

73 participants completed initial data collections, but 18 withdrew over the 8 weeks (Figure 1). Most participants not completing follow-up collections (n=13) resulted from the study interruption in March 2020 due to COVID, and those participants being lost to follow-up or declining to re-enroll and re-start exercise classes (due to fear of catching COVID) when the study resumed in April 2021. Descriptive statistics and LBP history data for participants with baseline and follow-up data are in Table 1. Adherence was 15.0 ± 1.4 (94%) in NoLBP and 15.7 ± 0.6 (98%) in LBPEx (p=0.06), out of a total of 16 sessions in the program. No adverse events were reported.

Principal Component Analysis

The first two waveforms extracted using PCA were kept for the abdominals (Figure 2), and the first waveform extracted

Table 1. Baseline demographics for participants with no history of low back pain (nolbp) and participants with low back pain who did (lbpex) and did not (lbpcon) complete the 8-week exercise intervention. Data presented as mean (standard deviation)

Variable	NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)	p-value*
Age (years)	31.1 (12.5)	38.2 (10.7)	34.4 (10.1)	0.17
Mass (kg)	67.4 (14.8)	81.2 (19.6)	80.0 (20.4)	0.05
Height (m)	1.66 (0.08)	1.75 (0.13)	1.68 (0.10)	**0.03‡**
BMI (kg/m^2)	24.53 (5.17)	26.09 (3.80)	28.39 (6.72)	0.10
Physical activity (times/week)	3.4 (1.4)	4.9 (2.9)	3.7 (2.7)	0.15
Pre-data collection pain (/10)	0.4 (0.5)	1.3 (1.7)	2.5 (1.9)	**< 0.001§**
Post-data collection pain (/10)	0.9 (0.9)	1.1 (1.7)	2.4 (2.2)	0.005‖
Roland-Morris disability scale (/24)	0.0 (0.0)	1.88 (2.55)	5.42 (4.26)	**< 0.001¶**
Years from first LBP episode†				
<1 year		6%	6%	
1-4 years		18%	6%	
5-10 years		29%	44%	
>10 years		47%	44%	
Number of previous episodes of LBP†				
< 5 episodes		24%	11%	
5-10 episodes		35%	22%	
>10 episodes		41%	67%	
Time from previous LBP episode†				
0 months		44%	72%	
1-3 months		6%	17%	
3-11 months		25%	0%	
>1 year		25%	11%	

*Significant main effects of group are in **bold**.
†LBP history descriptive data categories are presented as percentage of participants in each category.
‡The LBPEx group was significantly taller than the NoLBP group
§The LBPCon group had significantly higher pain than NoLBP and LBPEx groups pre-data collection
‖The LBPCon group had significantly higher pain than the NoLBP group post-data collection
¶The LBP Con group had significantly higher baseline self-reported disability than NoLBP and LBPEx groups

using PCA was kept for the back extensors (Figure 3). PC1 captured overall muscle activation amplitude and shape for both muscle groups, with higher PC scores indicating higher overall muscle activation. PC1 explained 77.3% of variation in abdominal waveforms, and 84.4% of variation in back extensors. For the abdominal PC1 scores, there were significant main effects of time, TST level, and muscle (p<0.001 for all) and significant group*time (p<0.001) and group*muscle (p=0.039) interactions. Abdominal PC1 scores significantly decreased from pre to post intervention, and were higher for level 3 of the TST. When examining changes within muscles for each group, in TST2 abdominal (Table 2) PC1 scores for right LatEO (p=0.009, d=0.48) and left PostEO (p=0.014, d=0.59) significantly decreased for NoLBP. PC1 scores for right LatEO significantly decreased (p=0.037, d=0.13) in LBPCon. In TST3, abdominal (Table 3) PC1 scores for right LatEO (p=0.004, d=0.51), and left PostEO (p=0.011, d=0.59) significantly decreased for NoLBP. PC1 scores for left AntEO (p=0.019, d=0.46), left LatEO (p=0.012, d=0.51), and right PostEO (p=0.035, d=0.48) significantly decreased for LBPEx. There were no significant changes in LBPCon.

For the back extensor PC1 scores, there were significant main effects of time (p=0.033), and muscle (p<0.001) and a significant group*time (p=0.004) interaction. Back extensor PC1 scores significantly increased from pre to post intervention. When examining changes within muscles for each group, for TST2 (Table 4) PC1 scores for right Mult significantly increased (p=0.014, d=0.37) in LBPCon. For TST3 (Table 5), PC1 scores for right Mult significantly increased (p=0.037, d=0.21) in LBPEx.

PC2 explained 4.7% of variation in abdominal waveforms and captured higher relative muscle activity during leg extension and flexion phases of the TST (phases 3-4) compared to leg lifting and lowering phases (phases 1-2, 5-6). Higher scoring waveforms had greater muscle activation during leg extension and flexion, relative to leg lifting and lowering, whereas lower scoring waveforms showed the same relative level of muscle activity throughout the entire task, indicating an inability to adjust muscle activity to task demands. For the abdominal PC2 scores, there were significant main effects of time (p=0.037), TST level (p<0.001), and muscle (p<0.001) and significant group*time (p<0.001),

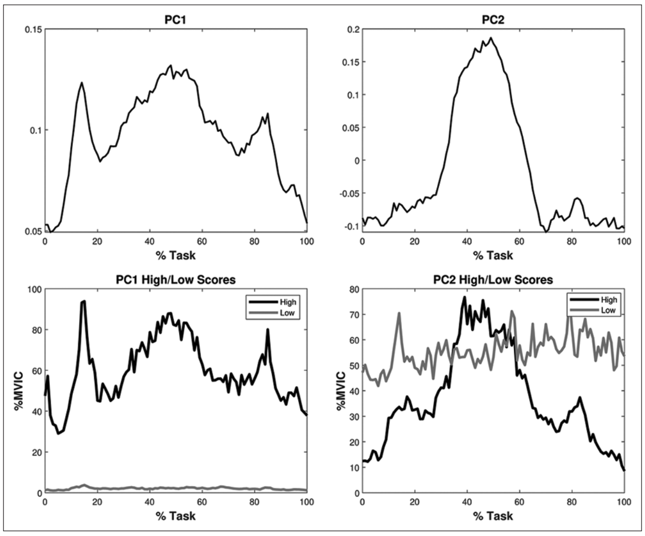

Figure 2. Principal components (top row) for the abdominal muscles. Based on original waveforms for high (black) and low (grey) scoring participants (bottom row), PC1 corresponded to the overall shape and amplitude of abdominal activity, and PC2 corresponded to higher activity during the middle (leg extension and flexion) phase of the task. PC1 explained 77.3% of variability in abdominal muscle activity waveforms, and PC2 explained 4.7% of variability in waveforms

group*TST level (p<0.001), and group*muscle (p=0.029) interactions. Abdominal PC2 scores significantly increased from pre to post intervention, and were higher for level 3 of the TST. When examining changes within muscles for each group, in TST2, abdominal (Table 2) PC2 scores significantly increased for right URA (p=0.05, d=0.81), right LatEO (p=0.002, d=0.79), and left PostEO (p=0.006, d=0.74) for NoLBP. PC2 scores significantly increased for left AntEO (p=0.042, d=0.82) for LBPEx. No significant changes were seen in LBPCon. For TST3, abdominal (Table 3) PC2 scores significantly decreased for left LRA (p=0.029, d=0.33) for LBPEx. PC2 scores significantly decreased for left PostEO (p=0.041, d=0.56) for LBPCon

Strength, Endurance, Self-Reported Disability

Strength, endurance, and self-reported disability are in Table 6. All strength and endurance measures significantly increased (p<0.05) for NoLBP, with medium to large effect sizes. Abdominal strength, and back extension, plank, and right side plank endurance significantly increased (p<0.05) for LBPEx, with small to large effect sizes. There were no significant changes in strength or endurance for LBPCon. Self-reported disability did not significantly change for NoLBP or LBPEx, but significantly decreased (p<0.05) for LBPCon.

DISCUSSION

This study determined if an 8-week dynamic core stability group exercise intervention would alter muscle activity, strength, and endurance in people with and without a history of LBP. Consistent with the hypothesis, overall abdominal

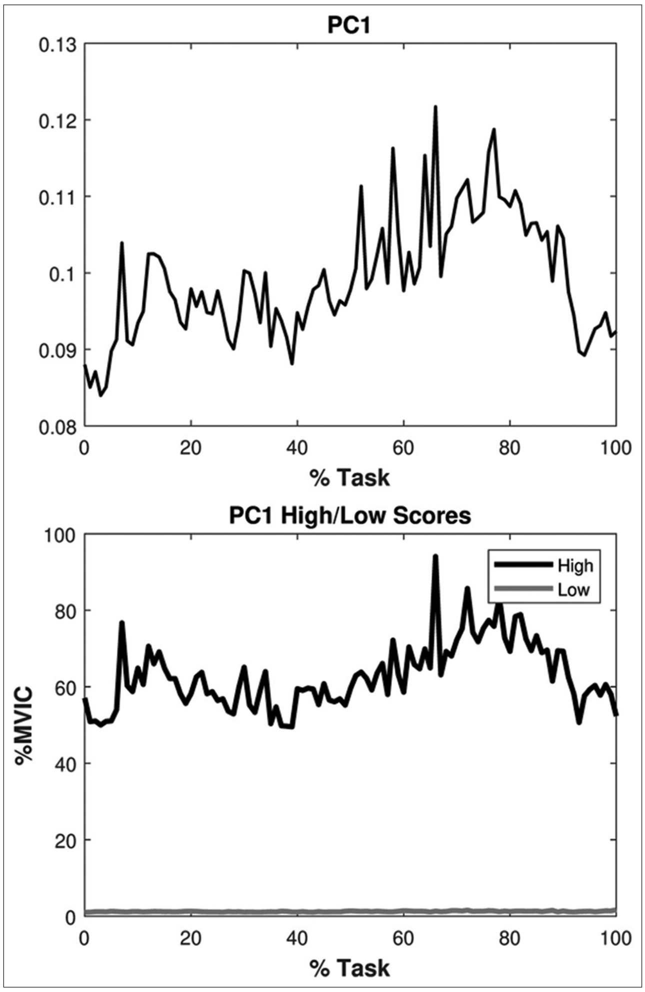

Figure 3. Principal components (top row) for the back extensor muscles. Based on original waveforms for high (black) and low (grey) scoring participants (bottom row), PC1 corresponded to the overall shape and amplitude of back extensor activity. PC1 explained 84.4% of variability in back extensor muscle activity waveforms

muscle activity decreased in the TST for most muscles for both groups that completed the intervention, reaching significance for two muscles for the NoLBP group for TST2 and TST3, and three muscles for LBPEx in TST3. These decreases are consistent with significant increases in abdominal strength and endurance in both groups; the abdominals would not have to activate to as high a level in order to generate the force required to complete the TST. It was hypothesized that decreases would be larger in LBPEx, however there were a greater number of significant changes in the NoLBP group, and effect sizes were generally larger for NoLBP. Likewise, changes in strength and endurance had larger effect sizes in NoLBP. This is likely because it took a few weeks for LBPEx participants to feel confident they wouldn’t increase LBP. Thus, more significant changes and larger effects might have been seen in LBPEx had the intervention been longer than 8 weeks.

Back extensor endurance significantly increased in NoLBP and LBPEx groups. Back extensor strength increased in both groups, however was only significant for NoLBP.

Table 2. PC scores for the abdominal muscles during level 2 of the trunk stability task for participants with no history of low back pain (NoLBP) and participants with low back pain who did (LBPEx) and did not (LBPCon) complete the 8-week exercise intervention*†

Muscle‡	Time	PC1			PC2		
		NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)	NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)
RURA	Pre	-21.89 (56.27)	-44.30 (83.63)	-67.51 (52.71)	-17.33 (12.46)	-8.08 (11.08)	-12.23 (7.65)
	Post	-40.96 (57.57)	-61.81 (54.16)	-50.45 (59.48)	**-7.86 (10.98)**	-6.21 (10.80)	-14.44 (10.16)
LURA	Pre	-33.00 (63.92)	-32.72 (88.20)	-49.83 (70.30)	-10.22 (12.21)	-4.60 (14.56)	-12.54 (16.07)
	Post	-48.39 (49.00)	-39.48 (77.40)	-56.07 (60.11)	-1.72 (9.46)	-1.97 (11.59)	-10.56 (10.27)
RLRA	Pre	-5.94 (70.06)	4.28 (96.60)	-14.32 (83.31)	-17.98 (13.78)	-9.44 (12.07)	-21.17 (13.96)
	Post	-17.46 (55.42)	-31.30 (58.68)	-19.06 (79.79)	-10.17 (14.31)	-6.39 (11.85)	-18.47 (11.38)
LLRA	Pre	-4.28 (105.60)	3.77 (99.01)	-9.90 (92.10)	-17.08 (32.26)	-6.40 (14.45)	-15.07 (28.36)
	Post	-24.52 (44.06)	-26.50 (71.12)	-10.08 (88.01)	-8.39 (8.57)	-10.00 (10.94)	-20.12 (16.63)
RAntEO	Pre	-26.79 (84.10)	9.77 (117.50)	-30.31 (82.97)	-15.42 (14.63)	-6.58 (11.06)	-16.55 (15.70)
	Post	-21.51 (72.33)	-18.27 (106.94)	-15.50 (81.93)	-13.63 (9.70)	-8.31 (13.51)	-15.22 (12.13)
LAntEO	Pre	-17.52 (87.94)	32.98 (100.37)	-18.70 (85.89)	-17.11 (16.46)	-14.79 (12.53)	-18.64 (15.99)
	Post	-17.13 (63.81)	-10.87 (111.16)	-2.24 (96.08)	-9.63 (10.50)	**-4.76 (11.95)**	-13.39 (14.86)
RLatEO	Pre	35.31 (130.90)	58.73 (116.50)	**-17.63 (83.82)**	-24.98 (25.02)	-7.80 (17.79)	-17.71 (13.78)
	Post	**-17.05 (81.37)**	39.43 (110.42)	**-37.07 (187.43)**	**-9.92 (10.12)**	-8.63 (22.06)	-22.20 (23.97)
LLatEO	Pre	-11.04 (114.84)	23.13 (107.50)	-37.34 (66.68)	-16.28 (17.27)	-12.52 (11.27)	-15.99 (12.95)
	Post	-39.79 (68.88)	-15.21 (75.01)	2.10 (153.97)	-9.90 (11.35)	-11.72 (13.06)	-16.06 (11.27)
RPostEO	Pre	32.26 (109.09)	43.89 (102.04)	13.85 (100.34)	-25.39 (19.80)	-13.00 (14.94)	-20.41 (19.10)
	Post	22.41 (74.41)	3.95 (84.51)	40.40 (109.85)	-17.65 (14.71)	-7.18 (11.90)	-23.03 (11.57)
LPostEO	Pre	32.37 (97.39)	34.14 (105.76)	9.02 (63.52)	-24.13 (22.20)	-14.87 (17.34)	-18.94 (14.45)
	Post	**-16.92 (67.56)**	-2.06 (83.98)	-7.14 (71.00)	**-10.87 (11.97)**	-11.46 (11.42)	-16.84 (10.31)

*Data presented as mean (standard deviation).
†Significant ($p<0.05$) pre to post-intervention changes are in **bold**
‡: URA = upper rectus abdominus, LRA = lower rectus abdominus, AntEO = anterior fibres of external oblique, LatEO = lateral fibres of external oblique, PostEO = posterior fibres of external oblique; R = right, L = left

A significant change might have been seen in LBPEx had the intervention been longer than 8 weeks. Changes in back extensor strength and endurance did not translate to changes in overall back extensor activity during the TST (PC1). This could be because the TST mainly challenged abdominal muscles to maintain a neutral pelvis as the leg extended, and did not sufficiently challenge back extensors where a change in activation would be seen. Clarke Davidson et al reported that the TST is more demanding for abdominals, with activation of ES and Mult <6%MVIC for TST2 and TST3, and abdominal activation of 15-25%MVIC (TST2) and 22-29%MVIC (TST3) in participants with no history of LBP (Clarke Davidson & Hubley-Kozey, 2005). Perhaps changes in back extensor activation would have been seen in another assessment task that was more specific to low back musculature.

It was hypothesized that relative activation during the TST loading phase (PC2) would increase, indicating better ability to match muscle activity to task demands. Increases in activity during leg extension and flexion phases were seen in most abdominals for both task levels for NoLBP, reaching significance for three muscles in TST2. For LBPEx, PC2 scores increased in some muscles (i.e. higher relative activation) and decreased in others. The only significant increase was seen in left AntEO for TST2, and left LRA PC2 scores actually significantly decreased for TST3. This indicates that LBPEx were unable to adjust muscle activation to task demands, and activated abdominals to a high level throughout the task. Though there were increases in relative activation in NoLBP in TST3, larger changes were seen in the easier TST2, and no significant changes were found in TST3. This indicates that as the challenge increases, it becomes more difficult to adjust muscle activity to respond to changes in external loading, regardless of the presence of LBP.

PC1 and PC2 for the abdominal muscles were similar to the first two abdominal PCs extracted by Moreside et al in a similar sample, and explained similar amounts of variation in abdominal activity (Moreside, Quirk, & Hubley-Kozey, 2014). These PCs captured overall muscle activation amplitude and shape, and higher activity during the leg extension and flexion component of the task, respectively. PC1 explained less variation for back extensors than previously reported by Moreside et al (Moreside, Quirk & Hubley-Kozey, 2014). A potential reason is that the PCA model for the back extensors in this study was derived from two low back muscles bilaterally, whereas Moreside et al had four low back muscle sites bilaterally. Since extracted PCs are based on waveforms in the dataset, differences in muscles included in

Table 3. PC scores for the abdominal muscles during level 3 of the trunk stability task for participants with no history of low back pain (NoLBP) and participants with low back pain who did (LBPEx) and did not (LBPCon) complete the 8-week exercise intervention*†.

Muscle‡	Time	PC1			PC2		
		NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)	NoLBP (n-19)	LBPEx (n=17)	LBPCon (n=19)
RURA	Pre	-1.22 (59.17)	-29.35 (88.68)	-44.76 (63.59)	16.56 (24.13)	8.82 (14.01)	8.88 (13.79)
	Post	-30.41 (60.37)	-48.46 (53.72)	-26.32 (74.52)	17.13 (19.75)	9.31 (15.45)	5.30 (11.25)
LURA	Pre	-16.08 (63.53)	-16.49 (88.69)	-35.49 (53.92)	19.20 (21.12)	12.05 (22.59)	12.67 (14.99)
	Post	-31.88 (50.81)	-31.02 (73.46)	-40.34 (57.18)	25.58 (17.36)	14.70 (15.67)	9.11 (12.65)
RLRA	Pre	13.51 (68.66)	12.98 (97.36)	11.97 (82.92)	22.26 (13.40)	18.09 (23.41)	13.25 (21.24)
	Post	0.73 (60.97)	-16.37 (67.25)	-1.25 (71.74)	25.11 (15.17)	17.27 (25.08)	7.62 (14.57)
LLRA	Pre	22.55 (113.36)	24.82 (106.22)	6.95 (85.47)	21.57 (20.15)	24.75 (32.14)	15.74 (22.19)
	Post	0.48 (75.78)	-1.44 (82.62)	-8.55 (73.92)	25.33 (26.08)	**14.39 (30.38)**	5.23 (17.80)
RAntEO	Pre	3.00 (85.67)	32.81 (124.47)	-13.53 (78.21)	15.23 (15.23)	14.77 (21.48)	9.75 (14.19)
	Post	-2.81 (69.42)	1.61 (110.76)	-0.83 (85.28)	13.22 (16.53)	13.47 (18.31)	9.04 (23.58)
LAntEO	Pre	13.17 (95.52)	51.50 (105.55)	-3.23 (82.16)	17.02 (16.15)	10.41 (29.16)	3.99 (16.00)
	Post	4.46 (65.62)	**1.54 (112.06)**	11.39 (88.68)	18.44 (16.90)	9.83 (18.55)	7.19 (19.30)
RLatEO	Pre	59.59 (138.26)	79.46 (125.01)	11.78 (97.38)	10.16 (32.94)	23.74 (38.00)	4.45 (20.36)
	Post	**-0.12 (90.40)**	51.90 (115.83)	46.66 (192.94)	14.75 (16.46)	17.96 (26.18)	-1.34 (27.13)
LLatEO	Pre	11.15 (118.64)	42.45 (117.11)	-3.24 (95.86)	10.65 (23.09)	15.21 (30.24)	3.89 (17.94)
	Post	-21.98 (79.75)	**-10.72 (89.13)**	10.17 (153.07)	12.01 (16.69)	6.68 (16.38)	5.43 (15.61)
RPostEO	Pre	62.55 (113.98)	65.59 (108.16)	45.02 (91.94)	13.85 (28.40)	13.08 (23.99)	6.84 (21.34)
	Post	44.72 (79.70)	**18.32 (87.05)**	52.89 (107.92)	16.44 (17.37)	14.14 (21.31)	4.48 (23.85)
LPostEO	Pre	63.57 (89.64)	56.09 (111.72)	41.04 (67.04)	21.21 (27.53)	16.09 (24.83)	18.87 (20.80)
	Post	**12.70 (81.66)**	15.02 (86.20)	11.13 (77.94)	26.37 (21.95)	11.72 (16.19)	**8.50 (16.05)**

*Data presented as mean (standard deviation).
†Significant ($p<0.05$) pre to post-intervention changes are in **bold**
‡: URA = upper rectus abdominus, LRA = lower rectus abdominus, AntEO = anterior fibres of external oblique, LatEO = lateral fibres of external oblique, PostEO = posterior fibres of external oblique; R = right, L = left

Table 4. PC1 scores for the back extensor muscles during level 2 of the trunk stability task for participants with no history of low back pain (NoLBP) and participants with low back pain who did (LBPEx) and did not (LBPCon) complete the 8-week exercise intervention*†

Muscle‡	Time	PC1		
		NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)
RES	Pre	-26.44 (43.48)	-21.68 (44.82)	-34.93 (35.34)
	Post	-41.96 (28.38)	-21.88 (48.27)	-4.62 (66.44)
LES	Pre	-28.18 (37.26)	-18.49 (27.38)	-28.61 (39.73)
	Post	-40.17 (30.09)	-26.56 (59.84)	-7.83 (76.80)
RMult	Pre	41.03 (109.05)	45.05 (98.97)	21.90 (72.85)
	Post	32.79 (131.03)	13.75 (116.34)	**62.72 (135.94)**
LMult	Pre	8.38 (66.96)	17.18 (72.20)	5.51 (73.87)
	Post	-8.79 (49.62)	14.43 (73.27)	51.10 (151.53)

*Data presented as mean (standard deviation).
†Significant ($p<0.05$) pre to post-intervention changes are in **bold**.
‡: ES = erector spinae, Mult = multifidus; R = right, L = left

the matrix will affect patterns extracted. Despite differences in variance explained by PC1, the interpretation of PC1 (overall muscle activation amplitude and shape) was consistent with previously published data (Moreside, Quirk, & Hubley-Kozey, 2014).

Study Limitations

One study limitation is the difference in LBP severity between LBP groups. LBPCon had higher baseline pain and disability scores. That group was closer to LBP episode on-

Table 5. PC1 scores for the back extensor muscles during level 3 of the trunk stability task for participants with no history of low back pain (NoLBP) and participants with low back pain who did (LBPEx) and did not (LBPCon) complete the 8-week exercise intervention*†

Muscle‡	Time	PC1		
		NoLBP	**LBPEx**	**LBPCon**
RES	Pre	-25.39 (45.14)	-31.29 (33.56)	-20.16 (73.91)
	Post	-42.67 (28.22)	-25.72 (48.94)	-4.69 (73.33)
LES	Pre	-30.98 (36.84)	-29.97 (22.85)	-28.68 (30.88)
	Post	-40.63 (27.40)	-22.65 (78.75)	-14.90 (69.95)
RMult	Pre	30.41 (99.92)	35.58 (88.00)	19.33 (86.64)
	Post	52.57 (161.27)	**73.22 (232.42)**	55.78 (122.69)
LMult	Pre	7.73 (66.72)	9.90 (63.70)	30.33 (93.81)
	Post	-1.79 (60.15)	8.57 (78.00)	30.39 (93.57)

*Data presented as mean (standard deviation).
†Significant (p<0.05) pre to post-intervention changes are in **bold**.
‡: ES = erector spinae, Mult = multifidus; R = right, L = left

Table 6. Strength, endurance, and self-reported low back pain-related disability scores for participants with no history of low back pain (NoLBP) and participants with low back pain who did (LBPEx) and did not (LBPCon) complete the 8-week exercise intervention*†.

Variable		Time	NoLBP (n=19)	LBPEx (n=17)	LBPCon (n=19)
Strength (lbs)	Abdominals	Pre	46.31 (12.16)	51.40 (14.19)	50.12 (16.52)
		Post	**55.77 (15.84)**	**58.41 (15.05)**	51.09 (14.48)
	Back extensors	Pre	49.14 (12.24)	55.51 (9.41)	60.10 (13.40)
		Post	**67.13 (21.08)**	63.23 (16.75)	59.17 (17.89)
Endurance (s)	Prone back extension	Pre	168.00 (90.02)	175.94 (90.24)	160.53 (85.32)
		Post	**254.21 (76.49)**	**237.00 (81.35)**	175.95 (98.69)
	Plank	Pre	84.47 (38.21)	107.94 (41.17)	82.44 (45.51)
		Post	**132.74 (63.73)**	**156.76 (72.29)**	83.89 (52.14)
	Right side plank	Pre	52.58 (22.82)	56.53 (21.52)	46.17 (25.41)
		Post	**75.95 (39.03)**	**72.00 (29.53)**	47.17 (28.05)
	Left side plank	Pre	63.61 (33.52)	64.41 (26.99)	45.94 (24.00)
		Post	**85.61 (42.28)**	68.29 (22.03)	47.94 (27.60)
Roland-Morris (/24)		Pre	0.00 (0.00)	1.88 (2.55)	5.42 (4.26)
		Post	0.00 (0.00)	1.24 (2.54)	**4.47 (4.01)**

*Data presented as mean (standard deviation).
†Significant (p<0.05) pre to post-intervention changes are in **bold**

set (72% <1 month from previous episode vs 44% in LBPEx), but all LBP participants reported minimal pain and resumption of normal activities prior to data collection, and there was no between-group difference in pain after data collection. A larger sample size could help correct for this difference, or randomization could be stratified based on injury history or symptom level in future studies. A major limitation of this study is that the assessor was not blind to group allocation. However, the lack of blinding would not have affected EMG measures, and baseline strength and endurance measures were not looked at until all follow-up data had been collected. An additional limitation is that the intervention instructor also collected data, thus there may have been participant bias in LBPEx and NoLBP groups. However, participant bias is unlikely to affect EMG measures. Finally, participants were aged 19-55, and results cannot be generalized to participants outside of this age range.

CONCLUSION

This was the first study to examine the effects of an exercise program on altered abdominal and back extensor muscle activation patterns previously identified in participants in the sub-acute phase of low back injury. The 8-week, bi-weekly, 30-minute group exercise intervention Les Mills Core™ resulted in increased abdominal strength and abdominal and back extensor endurance in people with and without a history of LBP. There were decreases in overall abdominal muscle activity during tasks designed to challenge lumbar-pelvic stability for NoLBP and LBPEx groups, and a better ability to match abdominal muscle activity to task demands during the easier level of the task for the NoLBP group. Temporal patterns of abdominal activity did not change for LBPEx participants, indicating changes in strength and endurance may not be sufficient to alter patterns of muscle activity in this group. Importantly, this challenging exercise program was safe for participants with a history of LBP who were currently experiencing minimal LBP. Thus, the practical implication of this study is that this readily available, standardized, commercial program can be recommended as a beneficial exercise modality for those with a history of LBP, provided they are experiencing minimal current symptoms.

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