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Comparison of Lower Limb and Back Exercises for Runners with Chronic Low Back Pain

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Comparison of Lower Limb and Back Exercises for Runners with Chronic Low Back Pain

ABSTRACT

Introduction: This single-blind randomized trial was conducted to compare the treatment effect of lower limb (LL) exercises versus conventional lumbar extensor (LE) and lumbar stabilization (LS) exercises in recreational runners with chronic low back pain (cLBP), since there is currently no specific protocol for managing runners with cLBP.

Methods: 84 recreational runners with cLBP were allocated to three exercise groups (LL, LE, LS) for an 8-week intervention. Outcome measures included self-rated pain and running capability, lower limb strength, back muscles function, and running gait. Participants were assessed at pre-, mid- and end-intervention; selected outcomes also followed up at three and six months. Generalized estimating equation was adopted to examine group-by-time interaction.

Results: LL group improved 0.949 points per time point in Patient Specific Functional Scale ($p < .001$), which was higher than the LE ($B = -0.198, p = .001$) and LS groups ($B = -0.263, p < .001$). All three groups improved on average 0.746 points per time point in Numeric Pain Rating Scale for running induced pain ($p < .001$). Knee extension strength increased 0.260 Nm/kg per time point ($p < .001$) in the LL group, which was higher than the LE ($B = -0.220 Nm/kg, p < .001$) and LS groups ($B = -0.206, p < .001$). LL group also showed greater increase in running step length (2.464 cm per time point, $p = .001$) than LS group ($B = -2.213, p = .013$). All three groups improved similarly in back muscles function.

Conclusion: LL exercise therapy could be a new option for cLPB management given its superior effects in improving running capability, knee extension strength, and running gait.

Key Words: legs, lumbar extensor, lumbar stabilization, spine.
INTRODUCTION

The prevalence of chronic low Back Pain (cLBP) among recreational runners was reported as high as 13.6% in the United States (56). Low back injuries accounted for about 7% of all running injuries (15) but there is no runner-specific exercise therapy protocol in the current management of cLBP. The clinical management of runners with cLBP is largely based on protocols for the general population which were built upon the understanding of fatigability (28, 47) and strength deficit (16, 23) of the lumbar extensor muscles, and/or compromise in motor control of the lumbar stabilizing muscles (12, 22). Unfortunately, randomized trials investigating the treatment effect of lumbar extensor and lumbar stabilization exercise therapies have shown inconclusive results in managing cLBP in the general population (20, 26, 35). On the other hand, lower limb muscles impairments associated with cLBP, such as knee extensor inhibition and reduction in hip extensor activation and fatigability, are often reported in this population (24, 31, 52). More specific to runners, one recent study showed that recreational runners with cLBP exhibited diminished knee extensor strength compared with asymptomatic runners (4). The authors postulated that weakness of the knee muscles may reduce capacity for shock attenuation, transmitting higher forces to the low back during running. This suggests that strengthening lower limb muscles may contribute to reducing loading and pain at the low back. Given that the treatment effects of conventional lumbar extensor and lumbar stabilization exercise therapies remain inconclusive, it is worth considering lower limb exercise therapy as an alternative approach to treat recreational runners with cLBP for potentially better rehabilitation outcomes.

To fill the research gap of lacking evidence-based exercise therapy protocols to treat runners with cLBP, this study aimed to evaluate the effectiveness of lower limb exercises,
compared with conventional lumbar extensor exercises and lumbar stabilization exercises, in managing cLBP in recreational runners. We hypothesized that specific lower limb exercises would be more effective in reducing running induced pain and improving self-rated running capability, lower limb strength, back muscles function, and running gait than the conventional back exercises.

METHODS

A single-blind randomized trial was conducted to evaluate the effectiveness of lower limb exercises, compared with conventional lumbar extensor exercises and lumbar stabilization exercises, in managing cLBP in recreational runners. Ethical approvals were granted from the Nanyang Technological University Institutional Review Board and the National Healthcare Group Domain Specific Review Board. Ninety-one potential participants were screened, of which 84 [male = 42] with mean age of 27.3 (5.5) years (TABLE 1, Participants’ characteristics and exercise compliance) enrolled while waiting for physiotherapy service in a hospital from November 8, 2013 to September 6, 2014. The targeted sample size of 84 was calculated using G*Power 3.1 (medium effect size = 0.25, power = 80%, α = 0.05, 3 groups for repeated measures). Written informed consents were obtained and the rights of participants were protected. Using a block randomization table, participants were evenly allocated into one of the three treatment groups (n = 28 per group with even sex distribution): 1) lower limb (LL) exercises, 2) lumbar extensor (LE) exercises and 3) lumbar stabilization (LS) exercises. The study flowchart of participants is shown as FIGURE 1.
The inclusion criteria were: 1) 21-45 years old, 2) body mass index between 18-25 kg/m², 3) had cLBP localized below the costal margin and above the inferior gluteal folds for >3 months and <36 months, 4) running 2-5 times per week for ≥2 km per session, and 5) started running six months prior to the study and have reached stable training intensity for at least three months prior to the study. The exclusion criteria were: 1) average pain intensity for the past one week <2 or >4 out of a 10-point Numeric Pain Rating Scale (NPRS), 2) specific low back pain, e.g. spine fracture, disc herniation, nerve root compression, 3) history of spine surgery, 4) current/history of lower limb conditions, e.g., fracture, ankle sprain, patellar femoral pain syndrome, anterior tibial stress syndrome, hip and knee arthritis and ligament laxity, 5) high fear-avoidance beliefs as determined by the Fear-Avoidance Beliefs Questionnaire (FABQ)(14, 55) with physical activity score >12 or work score >19 (13), 6) work involving regular heavy lifting or hard physical work, or 7) use of pain medication.

Outcome measures in current study consists of self-rated pain and running capability, lower limb strength, back muscle function and running gait. Participants were asked to rate their running induced pain using NPRS (0-10) according to the average rating during the past one week. Similarly, self-rated running capability over the past one week was measured using the Patient Specific Functional Scale (PSFS) (0 stands for unable to perform running and 10 stands for able to perform running at the same level as before the cLBP condition). The PSFS has been reported to be a more responsive functional outcome measurement tool compared with other scales for chronic LBP rehabilitation in various studies (17, 38, 42), especially in low activity limitation population (17), such as the runners recruited in the current study.
Lower limb strength was assessed using an isokinetic dynamometer (Biodex system 4 Pro, Biodex Corp., Shirley NY, US) to measure the peak concentric torque at 60°/s for knee extension, hip extension, and hip abduction. The test speed of 60°/s was reported to demonstrate high test-retest reliability for knee extension (intra-class correlation coefficients, ICC = .95) (49), hip abduction (ICC = .89) and hip extension (ICC = .90) (8) isokinetic strength measurements. Both left and right limbs were tested, with orders randomized. Details of the protocols are described elsewhere (4). The peak torque values were normalized to body mass before being used for analysis.

Back muscle function was evaluated by lumbar stabilizing muscles activation and lumbar extensor muscles fatigability, following the procedures previously used to assess runners with cLBP (4). The transversus abdominis (TrA) and lumbar multifidus (LM) activations, reflected by muscle percent thickness changes between resting and sub-maximal contraction (25), were measured using a rehabilitative ultrasound image (RUSI) device (LOGIQ P5, GEHC, Milwaukee, WI, US) by a RUSI certified physiotherapist. The test-retest reliability of this physiotherapist was excellent for both TrA ( ICC [95% CI] = .96 [.89 -. 98]; minimal detectable changes, MDC [95% CI] = 16.55%) and LM (ICC = .97 [.92 -. 99], MDC [95% CI] = 6.54%) measurements. To reflect lumbar extensor muscle fatigability, surface electromyography (EMG) signals of the bilateral iliocostalis and longissimus during a 2-minute Sorensen test were also recorded at 1,000 Hz (Bagnoli™ Desktop EMG system, Delsys® Boston, MA, US). Raw EMG data were band-pass filtered at 20-450 Hz, and then analyzed in the frequency domain using a build-in software (EMGworks® Software, Delsys® Boston, MA, US). The medium frequency was determined from the power density spectrum obtained using the fast Fourier transform...
technique with a Hamming windowing of 0.1 second. Finally, the medium frequency slope (MFS) was calculated as the slope of the medium frequency plotted over time for each muscle.

Spatio-temporal running gait parameters were measured using the OptoGait system comprising two parallel bars (100 cm × 8 cm) mounted on each side of the treadmill (Microgate S.r.I, Italy) which has been shown valid and reliable for gait analysis, with accuracy within 1 cm (29, 30). Step length was calculated as the distance between the tip (of the toe) of two successive foot contacts. The minimal contact time and flight time were both set at 10 ms. Each participant was instructed to run at his/her usual comfortable speed for 10 minutes. Running gait data during the 8-9th minute were collected at 1000 Hz as per manufacturer’s specification. Subsequently, four gait parameters were extracted for analysis: self-selected speed, step length, flight time, and contact time.

Participants were assessed on all outcome measures at pre-, mid- and end-intervention by a dedicated therapist who was blinded to treatment groups in the physiotherapy clinic. For self-rated pain and running capability, as well as running gait, additional follow-ups were done at three and six months post-intervention. Participants were blinded from any previous ratings and results.

Participants were requested to attend supervised exercise sessions (LL, LE, or LS) with their physiotherapists twice per week that were spread at least two days apart for eight weeks. They were also asked to perform home exercises on other days of the week, guided by an instruction sheet. For each supervised session, all participants performed a standardized warm-up comprising general stretching exercises and stationary bicycling for 15 minutes, before their 30-minute specific exercise session with the therapist.
For the lower limb exercises group (LL), participants performed resistance exercises targeting the knee and hip muscles for 8 weeks that has been shown to be effective in increasing muscle strength of the targeted muscles (1). During the supervised exercise sessions conducted in the physiotherapy department, a hip resistance training device was used to strengthen the hip extensors (FIGURE 2a) and abductors (FIGURE 2b), and a leg press machine was used to train the hip and knee extensors (FIGURE 2c). Taking into account of participants’ safety and minimizing the risk of over-exercising, for each exercise, participant performed 3 sets of 10 repetitions at an intensity of 10 repetition maximum (RM) with two minutes of rest in between each set. The training intensity and volume adopted here was recommended for muscle strengthening (27). The 10 RM was re-estimated at week 5 and the resistance was adjusted based on the new 10 RM for the remaining four weeks of training. The training volume and frequency remained the same. For the home exercises, single leg squat (FIGURE 2d) and wall-sit (FIGURE 2e) were prescribed to participants instead. The single leg squat was reported to produce 82.3% of maximal voluntary isometric contraction (MVIC) for hip extensor and 71.0% for hip abductor (2). The wall sit as a close kinetic chain knee exercise was reported to produce 46 to 80% of MVIC of knee extension (50). Participants were asked to perform 3 sets of 10 repetitions of home exercises on days when there was no supervised exercise session. From week 5 onwards, participants were instructed to hold a 2.5-kg weight during single-leg squat and to hold a 5-kg weight during wall-sit.

For the lumbar extensor exercises group (LE), participants were prescribed an 8-week progressive back extensors training program to achieve physiological changes in muscle fatigability (7, 44). To take care of participants’ safety and to prevent excessive
physical and psychological stress deriving from the exercise program, a progressive approach was used. For the first week of training, participants performed leg raise in a 4-point kneel position with the lumbar spine in a neutral position during the leg flexion and extension (FIGURE 3a). In the second week, participants performed contralateral leg and arm raises (FIGURE 3b). This arrangement enabled participants to reach approximately 40% of MVIC at beginning of the second week without increasing the risk of injury to their low back muscles (43). Three sets of 10 repetitions per session were performed for all exercises, which recommended for muscle endurance and fatigability improvement (1). Isometric contraction was also added to the end of each repetition as it was reported as an essential component to improve the lumbar extensor fatigability (7, 39). Participants were instructed to hold the end position for five seconds and rest for two seconds before the next repetition. Two minutes of rest was given in between sets. In order to reach the recommended intensity of approximately 60% of MVIC of lumbar extensors for improvement in fatigability (39), a 0.5-kg of ankle weight was added at week 3 and a 0.5-kg of wrist weight was added at week 4. Subsequently, an increment of 0.5 kg every week for the ankle and 0.5 kg every three weeks for the wrist were suggested to the participants (FIGURE 3c). Prone back extension (FIGURE 3d) was introduced to replace the 4-point kneeling exercises in week 5 because the percentage of MVIC produced by this exercise is above 65% (9). Home exercises were identical to those in the supervised session, except no prone back extension from week 5 onwards (FIGURE 3d).

For the lumbar stabilization exercises group (LS), participants received a series of TrA and LM muscle activation and motor control training as previously described by Koumantakis et al. (26). There were three stages of training: Stages 1 and 2 were
approximately two weeks and stage 3 about four weeks in duration. Participants were allowed to progress to the next stage without being restricted by the timeline as soon as they were able to complete the current stage of exercises satisfactorily. In stage 1, participants were instructed to conduct low-load activation of the lumbar stabilizing muscles, TrA and LM, with no movement (isometrically) and in minimal loading positions of sitting and standing (FIGURE 4a and b). The RUSI was used to provide visual feedback for TrA and LM activation. Excessive effort causing incorrect muscle activation in the global muscles or spinal movement at the initial stages was discouraged. Progressively, the holding time for each contraction was increased to at least 60 seconds and the duration of each exercise session was increased up to 10 minutes (45). In stage 2, integration of the lumbar stabilizing muscle activity into light dynamic functional tasks was added to participant’s exercise programs as shown in FIGURE 4c and d. The participants were instructed to practice with the same holding time and exercise duration as the first stage. In stage 3, heavier-load functional tasks were progressively introduced to participants as shown in FIGURE 4e with the resistance from the theraband during shoulder external rotation in 70°-90° abduction and in FIGURE 4f with resistance during shoulder abduction to 90°. For this stage, participants were instructed to practice the exercises for 10 minutes twice a day (41). All exercises were used for both supervised exercise sessions and home exercise, except the sitting balance integration component (FIGURE 4c), in which the gym-ball was substituted with a chair with cushion during home exercise.

All participants were informed that they should not feel exacerbation of their back pain during training, and that the body reaction to exercise should be limited to “aching” or “soreness”. Otherwise, the exercise intensity should be reduced or the program should be
terminated immediately. Participants were encouraged to continue their regular running but refrain from heavy gym weight training during the entire 8-week exercise training and 6-month follow-up periods. Exercise logs were provided to document their home exercise sessions, running frequency, and running distance. After completing the 8-week intervention, participants were asked to stop their home exercises.

Statistical analyses in current study consist of covariate screening and treatment effect comparisons. The participants’ characteristics, exercise compliant rate and running distance were compared among the three groups by one-way ANOVA (for parametric data) or Kruskal-Wallis test (for non-parametric data). Initially, variables with \( p \)-value smaller than .10 were planned to be treated as covariates for the comparison of the treatment effects but none of them had \( p \)-value smaller than .10 (TABLE 1).

A generalized estimating equation (GEE) approach using SPSS 21.0 was used to compare the treatment and interaction effects. Given GEE’s capability of handling outcomes with missing data and various correlations between time points (32), we could include all 84 participants’ data in the analysis. The dependent variables entered to GEE were the NPRS score, PSFS score, peak isokinetic torques, TrA and LM percent thickness change, MFS for iliocostalis and longissimus, and running gait parameters. Targeted main effects (group, time, sex) and interactions (group × time, group × sex, group × body side) were entered as the independent variables to form the GEE models. A backward elimination approach (\( \alpha = .05 \)) was applied during the model formation. Except for group and time, independent variables which did not significantly contribute to the model were removed. The model was then re-run with those significant independent variables.
RESULTS

In total, 74 participants completed all measurement sessions by April 27, 2015 (FIGURE 1). In the LL group, one participant injured her back during 5th week of the intervention period and her subsequent follow-up data was not included in the analysis. The back injury was not related to the study. There were also one participant loss of contact after his pre-intervention measurement session and one participant that missed out her final measurement (6 months follow-up) due to migration. In the LE group, one participant injured his ankle in the 3rd week of the intervention period by a minor traffic accident, and his subsequent follow-up data was not included in the statistical analysis. There were also one participant loss of contact after his initial measurement session, one participant loss of contact after his mid-intervention measurement session (end of week 4) and one participant missed out his end-intervention measurement session (end of week 8) due to busy schedule. In the LS group, one participant injured her back during the 7th week of the intervention period and her subsequent follow-up data was not included in the analysis. Another participant injured his ankle during the 8th week of the intervention period, and thereafter he was loss of contact, thus only his pre-intervention and mid-intervention measurement data were included in the analysis. Both injuries were not related to the study. There was also one participant in this group that missed out his end-intervention measurement session (end of week 8) due to his busy schedule.

Among the three exercise groups, there was no significant difference in the participants’ characteristics, compliant rate, or running habit (TABLE 1). The means (SD) for all outcome measures during the intervention and follow-up periods are presented in
TABLE 2. Since group × body side did not contribute to any GEE model, the averaged readings from both sides are presented in TABLE 2.

GEE analyses of all outcome measures are presented as below. For the NPRS score of average running induced pain during the past 1 week, there was a main effect of time ($p < .001$). Participants in all three groups achieved an average rate of improvement of 0.746 points over each time point [B = 0.746, 95% confidence interval (CI): (-0.799, -0.693), $p = .001$]. Mean NPRS score differed across the three groups ($p = .009$). The LL group had 0.273 points lower mean NPRS score than the LE group [B = -0.273, 95% CI: (0.041, 0.505), $p = .021$], and 0.329 points lower than the LS group [B = -0.329, 95% CI: (0.088, 0.570), $p = .008$].

For PSFS score, the changes in score significantly differed across the three groups over time (group × time interaction, $p < .001$). LL group achieved an average rate of improvement of 0.949 points over each time point [B = -0.949, 95% CI: (0.877, 1.021), $p < .001$], which was 0.198 [B = -0.198, 95% CI: (-0.316, -0.080), $p = .001$] and 0.263 [B = -0.263, 95% CI: (-.406, -0.120), $p < .001$] more than the LE and LS groups, respectively.

For lower limb isokinetic strength, there was a significant group × time interaction ($p = .001$) in peak knee extension torque. LL group improved on average 0.260 Nm/kg over each time point [B = 0.260, 95% CI: (0.193, 0.326), $p < .001$], which was 0.220 Nm/kg [B = -0.220, 95% CI: (-0.307, -0.133), $p < .001$] and 0.206 Nm/kg [B = -0.206, 95% CI: (-0.306, -0.105), $p < .001$] higher than the LE and LS groups, respectively. Peak knee extension torque differed between sexes ($p < .001$), with male participants presenting 0.276 Nm/kg higher compared to the female participants [B = 0.276, 95% CI: (0.115, 0.437), $p = .001$]. Peak hip extension torque increased over time [0.078 Nm/kg per time
point, 95% CI: (0.042, 0.113), \( p < .001 \) but did not differ across the three groups (\( p = .154 \)). Similarly, peak hip abduction torque increased over time [0.106 Nm/kg per time point, 95% CI: (0.075, 0.137), \( p < .001 \]), with no between-group difference (\( p = .363 \)).

For lumbar stabilizing muscle activation, TrA percent thickness changes increased on average 11.4% over each time point [\( B = 11.4, 95\% \text{ CI}: (8.30, 14.40), p < .001 \] with no differences among the three groups (\( p = .061 \)). There was a main effect of body side (\( p = .001 \)), with the dominant side exhibited 8.4% greater thickness change than the non-dominant side [\( B = 8.4, 95\% \text{ CI}: (3.50, 13.40), p = .001 \]). LM percent thickness changes improved on average 9.2% over each time point [\( B = 9.2, 95\% \text{ CI}: (2.20, 16.20), p < .001 \] but did not differ among the three groups (\( p = .188 \)).

For lumbar extensor muscles fatigability measured using longissimus MFS, all three groups slightly improved over each time point by 0.023 [\( B = 0.023, 95\% \text{ CI}: (0.007, 0.040), p = .005 \)]. Means of MFS were different between male and female participants (\( p < .001 \)) and the LE group presented lower MFS than the LL group [\( B = -0.058, 95\% \text{ CI}: (-0.101, -0.015), p = .008 \)]. For iliocostalis, the MFS differed across the three groups over time (\( p = 0.033 \)). While there was no change in MFS over time in LL [\( B = 0.006, 95\% \text{ CI}: (0.008, 0.021), p = .398 \] and LS groups [\( B = 0.010, 95\% \text{ CI}: (-0.027, 0.047), p = .609 \], LE group improved their MFS by 0.055 more over each time point [\( B = 0.055, 95\% \text{ CI}: (0.014, 0.097), p = .009 \)].

For running gait, self-selected running speed did not differ across the three groups (\( p = .444 \)) or change over time (\( p = .185 \)). There was a main effect of sex (\( p < .001 \)), with male participants running 2.366 km/h faster than their female counterparts [\( B = 2.366, 95\% \text{ CI}: (1.875, 2.856), p < .001 \]). Changes in running step length differed across the three
groups over time ($p = .046$). Participants in the LL group achieved an average increase of 2.464 cm in step length over each time point [$B = 2.464$, 95% CI: (0.953, 3.975), $p = .001$], which was similar to the LE group [$B = -1.690$, 95% CI: (-3.639, 0.260), $p = .089$] but greater by 2.213 cm per time point compared to the LS group [$B = 2.213$, 95% CI: (-3.959, -0.468), $p < .001$]. Step length differed between sexes ($p < .001$), with longer step length in male participants [$B = 26.12$, 95% CI: (21.384, 31.839), $p < .001$]. Flight time remained stable with no changes over time ($p = .208$) and no difference across the three groups ($p = .931$). Similarly, contact time also did not change over time ($p = .356$) or differ among the three groups ($p = .371$).

**DISCUSSION**

This single-blinded randomized trial was conducted to evaluate the effectiveness of the lower limb exercises, as compared with conventional back exercises, in managing non-specific cLBP in the recreational runner population. The study hypothesis that lower limb exercises would be more effective in improving rehabilitation outcomes was partially supported by our key findings: 1) greater improvement in self-rated running capability and knee extension strength in LL group than LE and LS groups; 2) greater increase in running step length in LL and LE groups than LS group; and 3) similar reduction in running induced pain, and improvement in back muscle function across all three exercises groups.

Pain reduction is a key rehabilitation outcome in the treatment and management of cLBP. This study showed that running induced pain improved over time for all participants regardless of the exercise groups. At 6-month post-intervention, the total reduction in NPRS score was 2.984 points ($0.746 \times 4$ time points). This improvement exceeded the
MDC (95% CI) of 2.0 (6), and hence can be considered clinically significant. While there are no studies directly comparing lower limb exercise to conventional back exercises on pain reduction in runners with cLBP, others have shown that general exercise (which included lower limb components) reduced back pain to a similar extent as specific lumbar extensor or lumbar stabilization exercises (11, 33, 37). Thus, the reduction in running induced pain observed among runners with cLBP in the present study is likely due to the general effect of exercise rather than a specific type of exercise.

Using the PSFS to assess self-rated running capability, participants in the LL group improved 3.796 (0.949 × 4 time points) at 6-month follow-up, compared to 3.004 for LE and 2.744 points for LS groups, respectively. While all three groups responded positively to the exercise treatments, it is important to note that only the LL group had achieved clinically significant improvement by exceeding the MDC (95% CI) of 3.521 points for single activity PSFS [calculated from the MDC = 3.0 (90% CI)] (51). This demonstrates that lower limb exercise therapy is more effective than conventional back exercises in improving self-rated running capability and therefore is a promising approach to treat cLBP among runners. Previous studies on older, less active population revealed mixed results when comparing the treatment effect of general exercise and lumbar stabilization exercise on self-rated general functional outcome measured using Oswestry Low Back Pain Disability Index or Roland Morris Disability Questionnaire (11, 33, 37). To our best knowledge, the present study is the first to use PSFS-running as a specific functional outcome to evaluate the effectiveness of exercise therapy in managing cLBP. Among the various survey instruments commonly used to evaluate back pain, PSFS was reported to be more responsive (effect size = 1.7) and specific for population with low physical activity
limitation (17) and hence this tool was chosen for the runners recruited in the current study. Using a running specific functional outcome measurement, it is convincing to note the superior treatment effect on the improvement in self-rated running capability achieved by LL group than the other groups.

Regarding the lower limb isokinetic strength, we initially hypothesized greater improvements in all hip and knee muscle strengths in the LL group compared with LE and LS groups. This hypothesis was partially supported by our findings that peak knee extension torque increased more in the LL group than the two conventional approaches but similar improvements in hip extension and hip abduction torque were observed. By the end of the 8-week intervention, peak knee extension torque increased by 31.82 Nm in total [0.260 Nm/kg × 61.2 kg (mean body weight, TABLE 1) × 2 time points], compared with 4.8 Nm for LE and 6.5 Nm for LS groups, respectively. The improvement in the LL group is of clinical importance as it has far exceeded the MDC (95% CI) of 17.88 Nm (49). Comparing to the knee, the overall improvements in hip muscle strength were too small to be practically meaningful (hip extension: 9.55 Nm [MDC (95% CI) = 28.82 Nm], hip abduction: 12.97 Nm [MDC (95% CI) = 34.00 Nm]) (8).

It is interesting to note that among all muscle functions tested, lower limb exercises only induced greater improvement in knee extensor strength compared with conventional back exercises. Other functions including hip muscle strength, lumbar stabilizing muscle activation, and lumbar extensor muscle fatigability were similarly impacted regardless of type of exercises prescribed. This suggests that the higher self-rated running capability observed in the LL group is likely related to greater gain in knee strength, supporting a previous speculation that weak knee extensors may compromise one’s ability to absorb
impact shock during running and hence transmitting higher forces to the low back (4).

Thus, improving knee extensor strength may be the step needed to break the vicious cycle of knee and back muscle dysfunction previously reported in LBP population (19, 46).

In current study, similar improvements in lumbar stabilizing muscles activation are seen across all three groups for both muscles. By the end of the 8-week intervention, TrA activation improved by 22.8% which was approaching the MDC (95% CI) of 25.4% (25). Similarly, LM activation improved by 18.4% at end of 8 weeks and this change overcame the MDC (95% CI) of 11.0% (25). One previous study reported non-exercise specific improvement in TrA activation when comparing lumbar extensor and lumbar stabilization exercises in the general LBP population (54). Lower limb weight bearing exercises were also observed to induce similar TrA activation as back muscle exercises (21). For the LM, similar EMG activations were reported for different types of exercises that closely resembled those adopted in the current study (18, 40, 53). Collectively, our results are in line with the literature that clinically meaningful improvements in lumbar stabilizing muscles activation can be achieved via exercise training in general. However, improvement in longissimus fatigability, despite showing statistical significance, is unlikely clinically meaningful since the changes in MFS by 0.046 (0.023 × 2 time points) after 8-week training were too small to overcome the MDC (95% CI) ranging from 0.11 to 0.17 (10). The lack of improvement in longissimus fatigability parallel with previous studies examining the training effect of lumbar extensor (26, 39), stabilization (26), and general lower limb exercises (36). Interestingly, improvement in iliocostalis fatigability in the LE group is about clinically meaningful, with MFS changes of 0.11 (0.055 × 2 points) after 8 weeks. This finding contradicted a previous study reporting no change in muscle
fatigability after a 12-week lumbar extensor isoinertial exercise intervention (36). Differences in exercise protocol (isometric vs isoinertial) and EMG electrodes placement (parallel vs 45° to the spine) (36) may explain the lack of agreement between the previous and present study. In summary, the results from the present study suggest that lower limb exercises are equally effective as back exercises in improving lumbar stabilizing muscle activation in runners with cLBP. On the other hand, lumbar extensor muscle fatigability was responsive to lumbar extensor exercises but not lower limb or lumbar stabilization exercises.

Running step length as the only running gait parameter significantly changed by exercise training in current study increased by 9.856 cm (2.464 cm × 4 time points) by the end of the 6-month follow-up in the LL group, which was similar to LE group but significantly more than LS group. Since the running speeds on treadmill are rather stable over time (TABLE 2), increased step length would have resulted in reduced their step frequency given that speed is a product of step length and step frequency. Taking fewer steps to complete the same distance may have reduced the number of impacts on the spine during the ground contact (5), contributing to reduced pain and improved running capability reported by the participants. While the OptoGait system has been shown valid and reliable for measuring spatiotemporal parameters during walking (29, 30), there is no established MDC to determine the clinical relevance of any observed changes during treadmill running. Nevertheless, it is clear that lower limb exercises lead to the greatest increase in running step length among our participants.

There are a few limitations to the current study. First, the low attendance of supervised exercise session [mean 5.6 (4-7) visits out of 16] was less than the minimal
frequency of once a week for successful treatment in cLBP patients (3). Home exercise compliance rate was much better [mean 29.3 (13-52) sessions], suggesting that any improvements observed were most likely attributed to home exercises rather than supervised training. In the literature, home exercise compliance rather than formal physiotherapy session attendance was found correlated to the reductions in pain and self-reported disability in cLBP patients (34). Future studies can investigate whether home exercise alone is sufficient to successfully treat cLBP conditions. Second, only spatiotemporal gait variables during a treadmill test were measured. Since altered trunk posture during running in cLBP population has been reported, (48), additional kinematics and kinetic data will be useful for a more comprehensive biomechanical evaluation of running gait. Lastly, the current findings should be applied with caution to older, less active individuals since our participants were younger [age = 27.3 (5.5) year], recreational runners.

CONCLUSION

Lower limb exercise therapy has shown to be a promising approach to the clinical management of non-specific cLBP in recreational runners. Compared with conventional back exercises, lower limb exercise therapy was more effective in improving key rehabilitation outcomes including self-rated running capability, knee extension strength, and running step length. All exercise therapies were equally effective in reducing running induced pain and improving back muscle function.

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Conflict of Interest

This study was funded by the National Institute of Education Academic Research Fund. The funding source did not play a role in the investigation. We affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

The results of the present study do not constitute endorsement by ACSM.

The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.
Reference


FIGURE 1. The study flowchart of participants.
FIGURE 2. Lower limb exercises during supervised sessions and home exercises.

Supervised sessions included resistance training exercises: hip abductors (a), hip extensors (b), leg press (c). Home exercises comprised single leg squat (d) and wall-sit exercise (e).
FIGURE 3. Lumbar extensors exercises

For the first week of training, participants performed leg raise in a 4-point kneel position with the lumbar spine in a neutral position (a). In the second week, participants performed contralateral leg and arm raises (b). A 0.5-kg of ankle weight was added at week 3 and a 0.5-kg of wrist weight was added at week 4. Subsequently, an increment of 0.5 kg every week for the ankle and 0.5 kg every three weeks for the wrist were suggested to participants (c). Prone back extension (d) was introduced to replace the 4-point kneeling exercises in week 5 only during the supervised exercise sessions but not for the home exercises (i.e. participants continued with their contralateral leg and arm raises with ankle and wrist weights at home).
FIGURE 4. Lumber stabilization exercises

In stage 1, participants were instructed to conduct low-load activation of transversus abdominis and lumbar multifidus, isometrically in minimal loading positions of sitting and standing (a-b). In stage 2, integration of the lumbar stabilizing muscle activity into light dynamic functional tasks was added to participant’s exercise programs (c-d). In stage 3, heavier-load functional tasks were progressively introduced to participants with the resistance from the theraband during shoulder external rotation in 90° abduction (e) and with the resistance during shoulder abduction in a single leg stance position (f).
<table>
<thead>
<tr>
<th></th>
<th>All Participants (n = 84)</th>
<th>LL group (n = 28)</th>
<th>LE group (n = 28)</th>
<th>LS group (n = 28)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Age (years)</td>
<td>27.3 (5.5)</td>
<td>28.9 (5.3)</td>
<td>26.1 (4.1)</td>
<td>26.9 (6.4)</td>
<td>.154</td>
</tr>
<tr>
<td>*Body mass (kg)</td>
<td>61.2 (11.8)</td>
<td>61.7 (12.6)</td>
<td>61.7 (10.8)</td>
<td>60.3 (12.1)</td>
<td>.877</td>
</tr>
<tr>
<td>*Body mass index (kg/m²)</td>
<td>21.8 (2.4)</td>
<td>21.7 (2.4)</td>
<td>21.8 (2.4)</td>
<td>21.9 (2.4)</td>
<td>.948</td>
</tr>
<tr>
<td>*Usual running frequency per week</td>
<td>2.6 (0.8)</td>
<td>2.5 (0.8)</td>
<td>2.6 (0.7)</td>
<td>2.5 (0.8)</td>
<td>.772</td>
</tr>
<tr>
<td>*Usual running distance (km) per time</td>
<td>4.1 (2.0)</td>
<td>4.2 (1.8)</td>
<td>3.8 (2.0)</td>
<td>4.3 (2.3)</td>
<td>.657</td>
</tr>
<tr>
<td>*Pain duration (weeks)</td>
<td>65.4 (31.6)</td>
<td>62.0 (35.0)</td>
<td>65.4 (33.1)</td>
<td>68.9 (27.0)</td>
<td>.722</td>
</tr>
<tr>
<td>*†Total supervised sessions attended during 8 weeks</td>
<td>5.6 (2.1)</td>
<td>5.9 (2.3)</td>
<td>5.4 (2.3)</td>
<td>5.4 (1.9)</td>
<td>.629</td>
</tr>
<tr>
<td>*†Total home exercise sessions during 8 weeks</td>
<td>29.3 (11.3)</td>
<td>29.1 (10.0)</td>
<td>28.9 (12.6)</td>
<td>29.9 (11.9)</td>
<td>.947</td>
</tr>
<tr>
<td>*†Total running distance (km) during 8 weeks</td>
<td>40.1 (21.1)</td>
<td>37.5 (21.6)</td>
<td>36.4 (19.2)</td>
<td>46.2 (21.8)</td>
<td>.181</td>
</tr>
<tr>
<td>‡Back pain region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>6 (7.1%)</td>
<td>6 (7.1%)</td>
<td>3 (3.6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>6 (7.1%)</td>
<td>5 (6.0%)</td>
<td>4 (4.8%)</td>
<td></td>
<td>.770</td>
</tr>
<tr>
<td>bilateral</td>
<td>9 (10.7%)</td>
<td>11 (13.1%)</td>
<td>15 (17.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>central</td>
<td>7 (8.3%)</td>
<td>6 (7.1%)</td>
<td>6 (7.1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‡Pain onset</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>gradual</td>
<td>26 (31.0%)</td>
<td>21 (25.0%)</td>
<td>25 (29.8%)</td>
<td></td>
<td>.130</td>
</tr>
<tr>
<td>sudden</td>
<td>2 (2.4%)</td>
<td>7 (8.3%)</td>
<td>3 (3.6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‡History of previous LBP episode/s</td>
<td></td>
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</tr>
<tr>
<td>yes</td>
<td>10 (11.9%)</td>
<td>14 (16.7%)</td>
<td>12 (14.3%)</td>
<td></td>
<td>.588</td>
</tr>
<tr>
<td>no</td>
<td>18 (21.4%)</td>
<td>14 (16.7%)</td>
<td>16 (19.0%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Values are mean (SD). †based on 75 participants (5 loss of contact and 4 injured participants were excluded from the analysis; LL group, n = 26); LE group, n = 24 and LS group, n = 25. ‡Values are counts (% of the total counts). LL = lower limb exercises, LE = lumbar extensor exercises, LS = lumbar stabilization exercises, LBP = low back pain.
TABLE 2. Self-rated outcomes, running gait measurements, and muscle functional characteristics during intervention and follow-ups

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Mid</th>
<th>End</th>
<th>3 months</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPRS-average running</td>
<td></td>
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<tr>
<td>induced pain during the</td>
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<tr>
<td>past 1 week</td>
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<tr>
<td>PSFS-running</td>
<td></td>
<td></td>
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<tr>
<td>Knee extension changes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM percent changes (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TrA percent thickness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>changes (%)</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Flight time (s)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Contact time (s)</td>
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<td></td>
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<td></td>
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<tr>
<td>Step length (cm)</td>
<td></td>
<td></td>
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<tr>
<td>Self-selected running</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>speed (km/h)</td>
<td></td>
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</tbody>
</table>

Values are mean (SD). Data of running gait and muscle characteristics were averaged value of dominant and non-dominant sides. LL = lower limb exercise group, LE = lumbar extensor exercise group, LS = lumbar stabilization exercise group, PSFS = patient specific functional scale, NPRS = numeric pain rating scale, TrA = transversus abdominis, LM = lumbar multifidus, MFS = mean frequency slope. The Pre (pre-intervention) data were based on LL group, n = 28, LE group, n = 28 and LS group, n = 28. The Mid (mid-intervention) data were based on LL group, n = 27, LE group, n = 24 and LS group, n = 25. The 3 months data were based on LL group, n = 26, LE group, n = 24 and LS group, n = 25. The 6 months data were based on LL group, n = 25, LE group, n = 24 and LS group, n = 25.