Effects of Foot Strike on Low Back Posture, Shock Attenuation, and Comfort in Running

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ABSTRACT

DELGADO, T. L., E. KUBERA-SHELTON, R. R. ROBB, R. HICKMAN, H. W. WALLMANN, and J. S. DUFEK. Effects of Foot Strike on Low Back Posture, Shock Attenuation, and Comfort in Running. Med. Sci. Sports Exerc., Vol. 45, No. 3, pp. 490–496, 2013. Purpose: Barefoot running (BF) is gaining popularity in the running community. Biomechanical changes occur with BF, especially when initial contact changes from rearfoot strike (RFS) to forefoot strike (FFS). Changes in lumbar spine range of motion (ROM), particularly involving lumbar lordosis, have been associated with increased low back pain. However, it is not known if changing from RFS to FFS affects lumbar lordosis or low back pain. The purpose of this study was to determine whether a change from RFS to FFS would change lumbar lordosis, influence shock attenuation, or change comfort levels in healthy recreational/experienced runners. Methods: Forty-three subjects performed a warm-up on the treadmill where a self-selected foot strike pattern was determined. Instructions on running RFS/FFS were taught, and two conditions were examined. Each condition consisted of 90 s of BF with RFS or FFS, order randomly assigned. A comfort questionnaire was completed after both conditions. Fifteen consecutive strides from each condition were extracted for analyses. Results: Statistically significant differences between FFS and RFS shock attenuation (P < 0.001), peak leg acceleration (P < 0.001), and overall lumbar ROM (P = 0.045) were found. There were no statistically significant differences between FFS and RFS in lumbar extension or lumbar flexion. There was a statistically significant difference between FFS and RFS for comfort/discomfort of the comfort questionnaire (P = 0.07). There were no statistically significant differences between other questions or the average of all questions. Conclusion: Changing foot strike from RFS to FFS decreased overall ROM in the lumbar spine but did not make a difference in flexion or extension in which the lumbar spine is positioned. Shock attenuation was greater in RFS. RFS was perceived a more comfortable running pattern. Key Words: BACK KINEMATICS, FOREFOOT, INJURY, LORDOSIS, REARFOOT

Preventing injury in the athletic population is of interest (31), especially in the running community. Because running is a popular pastime for both experienced and recreational athletes, attempts are continuously made to find ways to enhance performance and/or prevent injuries. Examples include a change in posture (15) or footwear (22). In addition, overuse injuries from training errors occur, yet these injuries may be preventable (12,14). One of the techniques used in the prevention of injuries is to modify the gait pattern (4), with one particular trend, barefoot running (BF), rising among athletes (36). However, there is growing evidence to suggest that BF creates kinematic and kinetic changes throughout the body (8,24,34), and these should be explored.

Evidence shows that BF changes the foot strike pattern from a rearfoot strike (RFS) to a forefoot strike (FFS) (10,31). This change results in a decrease in impact attenuation at the tibia (4) and in vertical ground reaction force (21). It has also been shown to improve running performance overall (10).

Focusing specifically on the low back while running, there is evidence to suggest that during loading response and stance phase, there are positional changes in the low back and pelvis (33). This leads to the notion that a change in initial contact as a result of using a different foot strike pattern could change the position of the low back during running. Hasegawa et al. (10) suggested that a change in the running pattern from RFS to FFS can create changes across the low back (33). Relative to injury prevention, Nicola and Jewison (28) and Levine et al. (20) stated that an excessive anterior pelvic tilt, which allows for a longer stride length (8,17,28) and is more directly associated with an RFS, results in increased lumbar lordosis.
In addition, Hamill et al. (9) concluded that low back pain (LBP) can be caused by lower extremity stiffness, especially in the knee, and Bishop et al. (2) concluded that lower extremity stiffness can be decreased with BF.

If a runner’s low back posture could be affected by a change in foot strike pattern, what other factors does this running style affect? Injuries to structures in the low back, such as joints and articular cartilage, have been linked to the propagation of shock throughout the body (19). Shock attenuation, the dissipation of the impact that occurs during initial contact of foot with the ground, is dependent on passive structures of the body and active movement. It can be influenced by running speed, stride length, and state of fatigue (25). If shock attenuation could change by running a different way, then perhaps injury and pain in the low back could change as well. It is believed that with an increase in stride length, an increase in shock attenuation occurs (24) as with RFS (6,31).

Thus, we questioned the relationship between the change in a runner’s foot strike pattern and low back posture, with the primary purpose of the study to determine whether changing the foot strike pattern from RFS to FFS would change lumbar lordosis in recreational/expert runners. The hypothesis was that there would be a change in lumbar lordosis when changing this foot strike pattern. The secondary purpose of the study was to determine whether changing the foot strike pattern from RFS to FFS would decrease shock attenuation in recreational/expert runners. The hypothesis was that there would be an increase in shock attenuation when changing this foot strike pattern. Finally, we sought to determine whether there is a difference in perceived comfort during running while using an RFS and an FFS in recreational/expert runners. The hypothesis was that there would be a perceived change in overall comfort when changing this foot strike pattern.

METHODS

Sample. A convenience sample in which subjects were enrolled nonconsecutively was used to obtain 48 volunteer participants. These individuals were recruited using flyers posted in areas likely to be seen by runners in the local community. Subjects were included in the study based on the following criteria: age 18–45 yr (18,32), in good overall health, and a recreational/expert runner with the criteria of running at least four times a month. Exclusion criteria included the following: history of sensory deficits in the lower extremities, unresolved lower extremity injuries (9), unresolved lower back pain, diagnosis of scoliosis, and/or any health conditions that would prevent them from running at the time of data collection. Three volunteers were excluded and two subjects’ data were omitted from analysis because of equipment malfunction, resulting in 24 male and 19 female participants (Table 1).

Instrumentation. Lumbar lordosis was measured in the sagittal plane using an electrogoniometer (1000 Hz, model SG150/B; Biometrics LTD, Ladysmith, VA) (11,13). Instrument precision has been reported to be 0.8°–3.6° (30). Leg and head accelerations at impact were measured using uniaxial accelerometers (1000 Hz, model no. 352C68; PCB Piezotronics, Depew, NY). The reliability and validity for these accelerometers have been reported to be within the frequency and amplitude range of human body motion (3).

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>%</th>
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<tbody>
<tr>
<td>Race/ethnicity</td>
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<tr>
<td>Hispanic Latin or Spanish origin</td>
<td>3</td>
<td>7.0%</td>
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<tr>
<td>Asian/Pacific Islander</td>
<td>4</td>
<td>9.3%</td>
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<tr>
<td>Other</td>
<td>2</td>
<td>4.7%</td>
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</tbody>
</table>

At the moment, please rate how you feel about the current foot strike pattern you are using while running. Below is a list of feelings with respect to the current foot strike pattern while running. For each feeling, please mark the number that best describes you.

<table>
<thead>
<tr>
<th>Feeling</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I enjoy it.</td>
<td></td>
<td></td>
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<tr>
<td>2. I feel unstable.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>3. I feel awkward.</td>
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<td></td>
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<tr>
<td>4. I am very frustrated by it.</td>
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<td></td>
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<tr>
<td>5. I feel balanced.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6. I dislike it.</td>
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<td></td>
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<td></td>
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<tr>
<td>7. I feel discomfort.</td>
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</table>

FIGURE 1—Adapted comfort questionnaire.
A comfort questionnaire was selected and adapted from The Physical Activity Enjoyment Scale (23). The questionnaire was composed of seven questions assessing the subject’s perception of stability, balance, level of frustration, comfort, likeability, and agility when running using each of the two different foot strike patterns (Fig. 1). The questionnaire was based on a seven-point scale with 1 and 7 being opposite extremes and 4 being neutral.

**Procedures.** Upon the appointment, written informed consent, approved by the affiliated institution (IRB protocol number: 1105–3831), was obtained, and consenting subjects completed a brief questionnaire to provide demographic and anthropometric information and determine eligibility. Eligible participants were then randomly assigned to run RFS or FFS during the data collection. Subjects were asked to warm up on the treadmill with their shoes on using a self-selected speed and their preferred foot strike pattern. The warm-up consisted of a 2-min jog followed by a 1-min run and finished with another 2-min jog, with “run” connoting a faster speed than “jog.” During the 1-min run time, the self-selected foot strike pattern was observed and recorded. Foot strike patterns were classified visually on the basis of foot segment inclination relative to the support surface as one of two possible patterns: FFS or RFS (21). Subjects who used a midfoot pattern with

![Figure 2](http://www.acsm-msse.org)

**FIGURE 2**—Placement of an accelerometer on the anterior medial aspect of the distal 1/3 left tibia (*top*), securing the open helmet housing an accelerometer on the anterior portion of the head (*middle*), and placement of an electrogoniometer spanning the spinous process of the second lumbar vertebrae (*bottom*).
0° of inclination (21) were classified as FFS runners. At least two raters with previous training in recognition of foot strike pattern observed and agreed on the self-selected foot strike pattern.

Subjects were then instructed on how to run using two different foot strike patterns, FFS and RFS. The FFS pattern was taught with the verbal cueing consisting of 1) “try to run on your toes” and 2) “do not let your heels touch the ground.” The RFS pattern was taught with the verbal cueing consisting of 1) “try to run with your heels hitting the ground” and 2) “try to run with your heel hitting the ground first.” Each subject was allowed to practice the different foot strike patterns on the treadmill until they felt they could use these patterns correctly (38).

The accelerometers were then attached to the subject while standing barefoot upright on even ground. One was placed on the anterior medial aspect of the distal 1/3 left tibia (16), taped down with athletic tape, and reinforced lightly with an elastic strap. An open helmet with a taped accelerometer on the anterior portion was then strapped to the head. The spinous process of the second lumbar vertebrae was identified and marked with a surgical marker. The electrogoniometer was applied to the low back across the L2 segment and reinforced with Leukotape across both sides of the joint line (Fig. 2). Standing barefoot on the treadmill, the subject was asked to relax with arms at the side while natural lumbar lordosis data were recorded.

Each subject ran barefoot on the treadmill at a self-selected pace and a self-selected pattern of foot strike while the running speed and foot strike pattern were documented. This self-selected speed was used for all subsequent trials. The subject was then told to run with the first randomly assigned foot strike pattern followed by the other until they felt they could reproduce the respective patterns during data collection. At that point, the foot strike patterns were observed again to ensure that the subject was able to demonstrate proper technique. The comfort scale was then explained to the subject. Next, one investigator showed a card to the subject specifying which foot strike pattern to run first with the second investigator (collecting the data) being blinded to the foot strike pattern. The investigator collecting data was unaware of the subject’s random assignment until the end of data collection when data were appropriately coded and saved to the computer. Condition 1 was completed using the first randomized foot strike pattern for 90 s. After completing the comfort questionnaire, condition 2 was completed using the second randomized foot strike pattern (for 90 s) followed by completion of the comfort questionnaire.

Data extraction. BioWare software (version 4.0.x; Kistler Instruments Corp.; Winterthur, Switzerland) was used to capture synchronous electrogoniometer and accelerometer data. The accelerometer data were used as a reference for stride cycles (the time between left foot initial contact to left foot initial contact). Fifteen consecutive stride cycles per condition were selected during the middle of data capture for subsequent analysis. For each stride, the peak left leg and head acceleration values were obtained and used to calculate shock attenuation using the following formula: \[ \left(1 - \frac{\text{head peak}}{\text{leg peak}}\right) \times 100 \] (26). Thus, a larger value was indicative of greater impact attenuation (25). For each foot strike pattern, the average shock attenuation of the 15 strides per subject was calculated and evaluated statistically (Fig. 3).

Electrogoniometer data were extracted for each stride cycle. Data between each foot strike were analyzed for minimum (lumbar flexion) and maximum (lumbar extension) values in degrees. For each foot strike pattern, the overall range of motion (ROM) was defined as the difference of these two minimum and maximum average values.

STATISTICAL ANALYSIS

All statistical analyses were performed using SPSS, version 19 (IBM, Chicago, IL). The level of statistical significance was set to \( \alpha < 0.05 \). Paired sample \( t \)-tests were used to analyze the differences between the biomechanical variables (lumbar spine ROM, amount of flexion and extension, shock attenuation, and peak leg acceleration) in FFS and RFS running pattern. A nonparametric Wilcoxon signed-rank test was used to compare differences in comfort questionnaire responses between the two foot strike conditions.

RESULTS

Lumbar spine motion. Analysis of the lumbar spine motion revealed statistically significant differences between FFS and RFS lumbar ROM, \( t(42) = -2.069, P = 0.045 \) (RFS

![FIGURE 3—Exemplar acceleration time histories of the leg and head for RFS (top) and FFS (bottom). Circles identify data extracted.](image-url)
TABLE 2. Comfort questionnaire responses by condition.

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Condition</th>
<th>Question 1</th>
<th>Question 2</th>
<th>Question 3</th>
<th>Question 4</th>
<th>Question 5</th>
<th>Question 6</th>
<th>Question 7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>FFS</td>
<td>4.1</td>
<td>4.4</td>
<td>3.9</td>
<td>5.1</td>
<td>4.5</td>
<td>3.9</td>
<td>3.4</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>RFS</td>
<td>4.9</td>
<td>4.7</td>
<td>4.2</td>
<td>5.5</td>
<td>4.8</td>
<td>4.7</td>
<td>4.6</td>
<td>4.7</td>
</tr>
<tr>
<td>SD</td>
<td>FFS</td>
<td>1.80</td>
<td>1.74</td>
<td>1.92</td>
<td>1.80</td>
<td>1.67</td>
<td>1.93</td>
<td>1.73</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>RFS</td>
<td>1.55</td>
<td>1.95</td>
<td>1.85</td>
<td>1.61</td>
<td>2.00</td>
<td>1.78</td>
<td>1.81</td>
<td>1.50</td>
</tr>
<tr>
<td>Z value</td>
<td>FFS</td>
<td>-1.876</td>
<td>-0.742</td>
<td>-0.408</td>
<td>-1.008</td>
<td>-0.665</td>
<td>-1.723</td>
<td>-2.710</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>RFS</td>
<td>0.061</td>
<td>0.458</td>
<td>0.603</td>
<td>0.314</td>
<td>-0.506</td>
<td>0.005</td>
<td>0.007</td>
<td>0.119</td>
</tr>
</tbody>
</table>

NA, not applicable.

$x = 22.1^\circ \pm 5.1^\circ$, FFS $x = 20.9^\circ \pm 4.6^\circ$). There was no statistically significant difference between the FFS and RFS lumbar extension, $t(42) = 1.367, P = 0.179$ (FFS $x = 14.9^\circ \pm 6.4^\circ$, RFS $x = 15.2^\circ \pm 6.7^\circ$) or flexion, $t(42) = -0.327, P = 0.745$ (FFS $x = 5.9^\circ \pm 6.0^\circ$, RFS $x = 6.8^\circ \pm 6.1^\circ$).

**Shock attenuation and leg impact.** There was a statistically significant difference between FFS and RFS for shock attenuation, $t(42) = -9.026, P < 0.001$ (FFS $x = 56.5^\circ \pm 17.1^\circ$, RFS $x = 73.4^\circ \pm 10.9^\circ$). There was a statistically significant difference in the peak leg acceleration between FFS and RFS, $t(42) = -8.301, P < 0.001$, with a lesser leg acceleration peak in FFS (FFS $x = 22.1^\circ \pm 5.1^\circ$, RFS $x = 3.8^\circ \pm 1.8^\circ$, RFS $x = 22.1^\circ \pm 5.1^\circ$, FFS $x = 6.1^\circ \pm 2.2^\circ$).

**Comfort questionnaire.** The mean and SD values for the comfort questionnaire are given in Table 2. Wilcoxon signed-rank test results revealed that there was a statistically significant difference between the two running conditions for comfort/discomfort (question 7), $Z = 2.710, P = .007$, in favor of RFS (FFS $x = 22.1^\circ \pm 5.1^\circ$, FFS $x = 4.6^\circ \pm 1.8^\circ$, FFS $x = 22.1^\circ \pm 5.1^\circ$, FFS $x = 3.4^\circ \pm 1.7^\circ$). There was no statistically significant difference between questions 1–6 or the average score of all questions.

**DISCUSSION**

The primary purpose of the study was to determine whether changing the foot strike pattern from RFS to FFS would change lumbar lordosis in recreational/experienced runners. The original recruitment criteria for this study were very broad, including running at least four times per month. Across the group, the average mileage per month was 10–15 miles, and more than 60% of the participants reported running more than twice per week. In addition, none of the participants classified themselves as elite runners. As well, less than 10% of the study participants reported previously using FFS during running. Thus, the study sample was much more homogenous than the study inclusion criteria specified.

**Lumbar spine motion.** Results indicated that a change in foot strike pattern from FFS to RFS decreased the overall sagittal ROM in the lumbar spine during running in recreational/experienced runners. When running with an RFS, there was an overall greater excursion in the lumbar spine. However, the change in foot strike did not make a difference in the amount of flexion or extension in which the lumbar spine is positioned. Even though the amount of overall ROM excursion increased in RFS, the position of the lumbar spine was neither more extended nor flexed when compared with running FFS. The results support the null hypothesis that there would be no change in lumbar lordosis.

Schache et al. (33) showed different positional changes in the low back and pelvis during midstance and toe off in running. When initial foot contact was changed in running, the positional change of the lumbar spine was not necessarily in favor of flexion or extension but rather in overall ROM as confirmed by the present study. This change in overall lumbar ROM may be accounted for by the shorter stride length that occurs when running FFS compared with RFS (31). A change in stride length creates changes in the pelvis (8), and positional changes in the pelvis correspond with lumbar lordosis changes (7).

The most probable reason for this study not finding a difference in flexion and extension in the lumbar spine is that no true difference exists. With a change in foot strike, the lower extremities including the knee and hip joints may accommodate (8,24) sufficiently to allow the lumbar spine to remain in a relatively similar position. Another explanation for this finding may be what is occurring in the body in terms of shock. It is beneficial from an injury prevention aspect if lesser impact has to be absorbed (35). Lumbar lordosis acts as a shock-absorbing structure in the body (34), and with more lordosis, there is a greater ability to absorb shock (1). Because the FFS pattern resulted in lesser leg shock at contact, there is less force that needs to be absorbed by the lumbar spine and other body segments, decreasing the need to accommodate shock by exaggerating lumbar lordosis.

**Shock attenuation and leg impact.** This study revealed that there was lesser peak leg impact at contact when running with an FFS pattern. This is consistent with current evidence suggesting that running with an FFS would decrease shock when compared with running RFS (6,29,31). Shock attenuation was also observed to be greater with RFS than FFS; there is more shock absorbed throughout the body when running RFS. This may be due to the overall greater foot–ground impact to be generated in RFS, thus increasing the magnitude of shock to be attenuated. This result is consistent with Mercer et al. (24), indicating that an RFS would absorb more shock in the body because of a longer stride length.
Comfort questionnaire. In terms of comfort, the study found that RFS is perceived to be a more comfortable running pattern than FFS for recreational or experienced runners. This may be a result of a lack of familiarity with FFS for the participants who had little time to accommodate. The results could also be due to the subjects feeling uncomfortable simply because of the novel motion (RFS was the preferred foot strike for 84% of the subjects). Williams et al. (38) indicated that familiarity should not have had an effect on the lower extremity mechanics so the accommodation period may have had a larger role. Also, the subjects’ comments during and after data collection were largely concerning the treadmill’s warmth and the feeling of running barefoot in both foot strike conditions. Studies have shown that there are changes in ground reaction forces, rate of proprioception encountered (31), and kinematics when running barefoot versus shod (2, 5, 21, 27), and this may have influenced the results.

The accommodation period may be another alternative explanation for the absence of significant differences in any of the other questions on the questionnaire. The fact that the subjects in this study were not accustomed with running barefoot could also explain this result because both foot strike conditions were performed without shoes. This barefoot phenomenon could have disguised any other differences.

Clinical relevance. Greater overall low back excursion with an RFS pattern may suggest that this pattern creates a greater demand for stability in the lumbar spine. Therefore, this foot strike could possibly not be beneficial for individuals with stability problems, including hypermobility or atrophied lumbar spine musculature. However, the change in ROM did not exceed known error of the measuring device for lumbar ROM, suggesting that the effect may not be clinically significant even though it reached statistical significance. In terms of directional preferences for the lumbar spine, changing the foot strike pattern from RFS to FFS is unlikely to be beneficial according to the current findings.

In addition, excessive loading or shock can lead to degenerative changes and the weakening of shock-absorbing structures of the body including the intervertebral discs (35). Therefore, decreasing the amount of shock that the body encounters could potentially prevent or delay these degenerative changes. It can then be suggested that FFS running could help prevent or delay these degenerative changes over RFS. It has been shown that persons experiencing LBP display a limited ability to attenuate shock (35). Wosk and Voloshin (39) suggested that decreasing the shock that the body is exposed to significantly reduces LBP and improves mobility of patients with LBP. It then follows that an individual with LBP may benefit from running FFS compared with RFS to reduce pain, because FFS was shown to introduce lesser leg impact values at foot contact. Further research is needed to explore this line of inquiry.

One limitation of the study was that subjects ran on a treadmill, which may change the runners’ strategies and biomechanics compared with over ground running (37). Another potential limitation involved the lack of an accommodation period the subjects had for the novel (FFS) running pattern. In addition, choosing BF rather than shod running potentially limits the generalizability of the results to a habitually shod population; however, we performed this experiment with the intent to contribute to the increasingly popular activity of BF running.

Future research investigating the effects of FFS and RFS on individuals with LBP may provide additional insight into whether a change in foot strike pattern would affect low back motion and pain in runners. Although the overall lumbar ROM was found to be significant, the statistical power, computed post hoc, was only 0.520.

CONCLUSION

Results of this study suggested that a change in foot strike pattern from RFS to FFS decreased the overall ROM in the lumbar spine during running but did not make a difference in the amount of flexion or extension in which the lumbar spine was positioned. The peak leg acceleration was greater in RFS than in FFS, and shock attenuation was greater with RFS than FFS. Results also identified that RFS was perceived to be a more comfortable running pattern than FFS for recreational or experienced runners.

To our knowledge, there are no studies directly examining the efficiency of forefoot or midfoot strike patterns on running injuries as compared with rearfoot contact or how it relates to comfort. There is also a paucity of peer-reviewed research comparing injury rates among barefoot, minimally shod, and shod runners. This study leads to the next level of research, that being, investigating the effects of foot strike pattern (adverse or otherwise) in individuals with LBP or other lower extremity issues.

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REFERENCES


