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Adaptations of Lumbar Biomechanics after Four Weeks of Running Training with Minimalist Footwear and Technique guidance: Implications for Running-Related Lower Back Pain

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Comments

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ADAPTATIONS OF LUMBAR BIOMECHANICS AFTER A FOUR-WEEK RUNNING TRAINING WITH MINIMALIST FOOTWEAR AND TECHNIQUES: IMPLICATIONS FOR RUNNING-RELATED LOWER BACK PAIN

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Highlights (for review)

- A 4-week minimalist style running training was conducted in recreational runners.
- After training, runners exhibited reduced lumbar extension angle during stance.
- After training, runners exhibited reduced lumbar paraspinal muscle activation.
- Changes in lumbar kinematics and muscle activation transferred to normal running.
- No runner reported any adverse effect during the 4-week training.

ADAPTATIONS OF LUMBAR BIOMECHANICS AFTER A FOUR-WEEK RUNNING TRAINING WITH MINIMALIST FOOTWEAR AND TECHNIQUES: IMPLICATIONS FOR RUNNING-RELATED LOWER BACK PAIN

ABSTRACT

Objectives: To investigate the changes in lumbar kinematic and paraspinal muscle activation before, during, and after a 4-week minimalist running training.

Design: Prospective cohort study.

Setting: University research laboratory.

Participants: 17 habitually shod recreational runners who run 10-50 km per week.

Main outcome measures: During stance phases of running, sagittal lumbar kinematics was recorded using an electro-goniometer and activities of the lumbar paraspinal muscles were assessed with electromyography. Runners were asked to run at a prescribed speed (3.1m/s) and a self-selected speed.

Results: For the 3.1 m/s running speed, significant differences were found in the calculated mean lumbar posture (p=0.001) during stance phase, specifically the runners ran with a more extended lumbar posture after minimalist running training. A significant reduction of the contralateral lumbar paraspinal muscle activation was also observed (p=0.039). For the preferred running speed, similar findings of a more extended lumbar posture (p=0.002) and a reduction in contralateral lumbar paraspinal muscle activation (p=0.047) were observed.

Conclusion: A 4-week minimalist running training produced significant changes in lumbar biomechanics during running. Specifically, runners adopted a more extended lumbar posture and reduced lumbar paraspinal muscle activation. These findings may have clinical implications for treating individuals with running-related lower back pain.

Key words: running**;** lower back pain; kinematics**;** EMG

Introduction

Running is one of the fastest expanding participation segments of sports and exercise. In the United States, It was estimated that 19 million people ran more than 100 times in 2011, a 9.3% increase from 2010.(NSGA, 2011) The number of marathon finishers increased by more than 75.5% in the last decade.(Lamppa, 2014) However, the drastic increases in the popularity of running are accompanied by an increase in the number of injured runners. Nielsen et al. reported that over the course of one year, 23.1% of novice runners sustained running-related injuries to the lower extremity or back.(Nielsen, et al., 2014) According to a 2013 survey of running event participants, 10.1% of the runners reported experiencing a running-related lower back injury within the last 12 months.(Yoder, 2013) Walter et al. have shown injuries pertaining to the back and pelvis account for approximately 25-35% of all running-related injuries.(Walter, Hart, McIntosh, & Sutton, 1989) In addition, preliminary data showed that running more than 20 miles per week can increase the odds of persistent LBP five-fold.(Gonzalez, Akuthota, Min, & Sullivan, 2006)

The repetitive impact loading during running is a possible mechanism for developing lower back structural changes and pain in runners.(Cavanagh & Lafortune, 1980; Dimitriadis, et al., 2011; Hamill, Gruber, & Derrick, 2014; Hamill, Moses, & Seay, 2009) Dimitriadis et al. reported transient disc height reduction following 1 hour of running measured using MRI in a static posture. Furthermore, the disc height reduction was greatest in the lumbosacral region identifying a location of higher load absorption.(Dimitriadis, et al., 2011) Garbutt et al. also observed that running speed is positively related to the extent of stature shrinkage measured immediately after running.(Garbutt, Boocock, Reilly, & Troup, 1990) While acute structural changes of the spine are not directly indicative of pain, over time the mechanical stress associated with running's repetitive loading can potentially lead to changes in spinal structure and possibly overuse musculoskeletal symptoms including running-related lower back pain.

The recent interest in the body's natural ability to attenuate impact loads during running has led to a resurgence of barefoot and minimalist style running as a means to reduce the risk of running-related injuries.(Perkins, Hanney, & Rothschild, 2014; Rixe, Gallo, & Silvis, 2012; Tam, Astephen Wilson, Noakes, & Tucker, 2014) This running style typically focuses on running barefoot or wearing shoes with minimal heel cushion. Due to the reduced impact attenuation of the footwear, the runners typically adapt a change of foot strike pattern from rear to mid or forefoot and a reduction of peak impact force. In essence, the proposed benefits from running with the minimalist footwear were based on the theory that it promotes a movement pattern that is conducive to lower shock loading during running.(De Wit, De Clercq, & Aerts, 2000; Derrick & Mercer, 2004; Divert, Mornieux, Baur, Mayer, & Belli, 2005; Mercer, Vance, Hreljac, & Hamill, 2002; Robbins & Hanna, 1987)

It has been postulated that the biomechanical adaptations (i.e. foot strike pattern) associated with running barefoot or in minimalist footwear can lead to kinematic changes in the lumbo-pelvic region. For example, Delgado et al. reported decreased overall lumbar range of motion and peak leg impact measured via leg acceleration following an acute foot strike pattern shift from the rearfoot to forefoot.(Delgado, et al., 2013) However, this study had a number of important limitations: first, the effects of foot strike pattern on lumbar range of motions were examined in a single data collection session. The participants were acutely instructed to run using specific foot strike patterns, which may or may not translate to a more permanent movement pattern change. Second, the effect of minimalist running on paraspinal muscle activation was not examined. Excessive paraspinal muscle activation is hypothesized to contribute to increased lumbar spinal loading. Third, in practice, it may be unrealistic and ill-advised to suggest drastic changes in foot strike and running mechanics to injured or at-risk runners. It is clinically more meaningful to understand the progression of responses in lumbar biomechanics to minimalist style running over a longer duration of training.

The purpose of this study was to investigate the effects of a 4-week running training transitioning runners to minimalist footwear and techniques on the lumbar kinematics and paraspinal muscle activation in habitually shod runners. We hypothesized that the runners will exhibit a reduction of lumbar range of motion and paraspinal muscle activation during the stance phase of running after training.

Methods

Subjects

Seventeen volunteers from the local running population was recruited. This sample size was determined *a priori* based on a previous investigation on how change of foot strike pattern affects lumbar posture.(Delgado, et al., 2013) To achieve an 80% power, with α level of 0.05, we calculated a sample size of 13 is needed to detect a difference in a repeated measures study design. Additional 4 subjects were recruited to account for potential attrition. The participants were included if they were: 1) age 18-45 years (Kienbacher, et al., 2015), 2) current recreational runners who run between 10-50 km during a typical week, and 3) habitual shod runners. Participants were excluded from the study if they exhibited any of the following: previous experience with minimalist or barefoot running, any orthopedic surgeries that permanently change the musculoskeletal structure of the lower extremity and spine (i.e. joint replacement, spinal surgery, etc.), any injuries or conditions within the last 8 weeks that prevented their normal running training. Two participants dropped out of the study due to an unrelated injury and a personal reason, resulting in 8 male and 7 female participants who completed the 4-week training program (Table 1).

TABLE 1. Demographic, anthropometric and running characteristics of the participants

	Mean ± SD
Age	24.7 ± 2.6 years
Body mass	70.4 ± 12.7 kg
Height	1.72 ± 0.09 m
Body Mass Index	23.9 ± 2.7 kg/m^2
Sex	7 female, 8 male
Running Training Distance	
Typical week	17.3 ± 5.5 km
Week Prior to Intervention	13.4 ± 7.3 km
Typical Run	5.4 ± 1.8 km

Prior to participation, the objectives, procedures, risks of the study, and rights of the participant were explained to each participant, and an informed consent approved by the Institution Review Board of XXX University was signed by each participant.

Instrumentation

All testing was done with the participants running on a treadmill (PrecorC956; Woodinville, WA, USA). Lumbar sagittal range of motion was captured using an electrogoniometer (SG150/B Series; Biometrics Ltd., Newport, UK) connected to a wireless transceiver (Delsys Trigno Biaxial Goniometer Adapter; Delsys Inc., Natick, MA, USA). The center of the electrogoniometer was positioned over the spinous processes of the 3rd lumbar vertebrae. Sagittal plane lumbar range of motion was captured at 2000 Hz. Electromyography (EMG) signals of the paraspinal muscles were captured using a wireless surface EMG system (Trigno Wireless System; Delsys Inc., Natick, MA, USA). Sampling frequency of the EMG signal was 2000 Hz.

EMG preparation consisted of shaving the location to remove any hair, cleansing the site with an alcohol swab, and abrading the site with a rough, dry paper towel until the skin becomes flush in color. The EMG sensors were attached using double-side tape. Pairs of surface EMG sensors were placed bilaterally over the palpated lumbar paraspinal muscle bellies approximately 2-5 cm from the spinous process of the 3rd lumbar vertebrae. The electrodes were placed in parallel with the fiber direction of the lumbar paraspinal muscle in accordance to the established surface EMG protocol (Merletti, Rau, Disselhorst-Klug, Stegeman, & Hagg, 2016; Zipp, 1982)

Foot strike incidents were monitored using 2 thin film pressure sensors (Model 402; Interlink Electronics Inc. Camarillo, CA, USA) placed inside of the shoes connected through a Delsys wireless transceiver (Delsys Trigno 4-Channel FSR Sensor). The sensors were attached to the bottom of the foot. The pressure sensor was round and 12.7 mm in diameter with a thickness of 0.45 mm. Foot pressure data was sampled at 2000 Hz for the rearfoot and 148 Hz for the forefoot. The difference in sampling frequency was due to a hardware limitation. Since the duration of a stance phase when running at the speeds used in this study (2.8-3.5 m/s) was observed to be 350-500 ms, we determined that the 148 Hz sampling frequency for the forefoot pressure sensor would still provide sufficient temporal resolution (6.76 ms) to identify the instant of toe-off with high degree of accuracy. EMG, lumbar kinematics, and foot strike pressure data were time-synchronized through a trigger module (Delsys Trigger Module; Delsys Inc., Natick, MA) to a motion capturing computer (Nexus 1.8, Vicon Motion Systems Ltd., Oxford, UK).

Procedure

Each participant was tested in 3 sessions (PRE, MID, POST); the PRE session was conducted on the day prior to the beginning of the 4-week training program; the MID was at the 2-week point; the POST assessment was completed at the end of the training (4-week). During each session, the testing began by measuring the runner's height and weight, followed by instrumentation.

Maximal voluntary isometric contraction (MVIC) of back extension was conducted with the subject in a prone position. The MVIC amplitude of the lumbar paraspinal muscles was used to normalize the muscle activation level. The subject was secured to a treatment table using straps. The tightness of the straps was adjusted to elicit a neutral (lack of hyperextension) alignment during the back extension against the strap. Two investigators provided additional stabilization of the legs as the participant performed two 5-second MVIC trials.

Following the MVIC trials, the goniometer was attached to the participant in a relaxed standing posture (Figure 1). The lumbar flexion/extension angle in this resting standing position was defined as neutral (0°). The electrogoniometry procedure was established in a prior study.(Delgado, et al., 2013) The two pressure switch sensors were attached to the plantar surface of the foot of the dominant leg (defined as the preferred leg to kick a ball with).

FIGURE 1. Placement of the EMG electrodes and the electrogoniometer

Biomechanical Testing

The testing began with a warm-up in which the participants walked on the treadmill at 1.33 m/s for 1 minute, the speed increased 0.22 m/s at the end of every minute until the runner reached the prescribed running speeds. If the runner reported discomfort during this period, the investigators stopped to make necessary adjustments before the runner resumed the warm-up.

During all running trials, the participant wore his or her own running shoes. The participant ran at two speeds: a control speed of 3.1 m/s and a self-selected running speed. For the preferred speed, the participant was blinded to the treadmill display and an investigator changed the speed according to the runner's indication. Runners were instructed to select a speed that felt close to their typical running training speed. Three 20-second trials were collected at each speed.

After the first running data collection session (PRE), participant was fitted with a pair of standardized minimalist running shoes (Brooks® PureDrift; Brooks Sports, Inc., Seattle, WA, USA). The sock liner of the shoes was removed as specified by the manufacturer to nullify the heel-to-toe offset. After the shoe fitting, an investigator explained the training program, which the runner was to adhere to for the next 4 weeks.

Minimalist Running Training Protocol

The participants were instructed to begin by running 10% of their normal running mileage in the minimalist shoes. Every 2 weeks the participants would increase the running distance wearing the minimalist shoes by no more than 10-20% of their total running distance. This was intended to allow the runners to safely do 30-50% of their running in the minimalist shoes by the end of week 4. This program was designed based on the recommendation that minimalist shoe running should be gradually incorporated into a person's normal running regimen to allow the body structures to adapt to the different mechanical stressors.(Robillard, 2010, 2012)

Each participant was given general instructions on minimalist running techniques including maintaining relaxed shoulders, trunk, and a slight bend at the knee throughout the running stride.(Robillard, 2010, 2012) The runners were also recommended to try to land upon the forefoot as gently as possible. However, no explicit feedback regarding each runner's running form was given during any of the data collection sessions. This was done to simulate a common self-initiated transition to the minimalist running shoes which is typically done with little external feedback or guidance.

The runners were asked to keep a running log, including the time of each run, the distance, and which shoes (normal or minimalist) they wore for the run. Each participant was asked to record all of this information in their training log every day for 4 weeks. The runners were asked not to change their normal training mileage. Participants were advised to wear only their normal running shoes or the minimalist shoes provided and not changing to different shoes during the 4-week period. Participants were also instructed to perform a schedule of exercise drills including: the Marble Drill, Jump Drill, and Walk in Place as typically suggested to increase the strength of the feet (Table 2).

TABLE 2. Weekly progression of the minimalist style running training

	Percentage mileage recommended to run in minimalist footwear	Recommended exercise drills to perform
Week 1	10%	Walk in Place 2x/day Marble drill 1x/day
Week 2	20%	Jump drill 2x/day Walk in Place 2x/day Marble drill 1x/day
Week 3	20%-30%	Jump drill 3x/day Walk in Place 2x/day Marble drill 1x/day
Week 4	≥30%	Jump drill 3x/day Walk in Place 2x/day Marble drill 1x/day

In the subsequent testing sessions (MID and POST), the weekly training logs were reviewed. An exit questionnaire was given to each participant after the last testing session (POST). The main question was whether they encounter any pain or injury during the training.

Data Analysis

Changes in running distances wearing the normal and minimalist shoes over the 4-week training period were analyzed. The preferred running speeds in the two types of shoes during the 3 testing sessions were recorded. Lumbar kinematics and muscle activation data were computed during the stance phase of the dominant leg during the running trials. The stance phases were identified with the aid of the foot pressure sensor data; specifically from the initial foot contact to when the forefoot lost contact with the running surface.

For lumbar kinematics, mean sagittal lumbar posture, peak lumbar flexion, peak lumbar extension, and lumbar range of motion were computed. The mean sagittal lumbar posture was the time-averaged lumbar posture during the stance phase; a positive angular value indicates lumbar flexion. Mean lumbar muscle activation during the stance phase was computed for both the contralateral and the ipsilateral paraspinal muscles. The EMG signals from the lumbar paraspinal muscles were first filtered with a 2^{nd} order Butterworth band-pass filter (cut-off frequencies: 35-500 Hz) then full-wave rectified. The mean muscle activation magnitudes were normalized to the highest 500 millisecond average activation magnitude obtained during the MVIC trials, and reported as percentages of the MVIC. This duration was chosen to correspond with the approximate duration of the stance phase (350-500 ms) for the running speeds used in this study. For each running trial, 10 stance phases were identified; the lumbar kinematic and muscle activation magnitude variables were obtained by averaging over the 10 stance phases from each trial. The average values from 3 running trials for each subject were used for statistical analysis.

Statistical Analysis

One-way repeated measures ANOVA tests were used to compare the participants' preferred running speeds, lumbar kinematic, and muscle activation variables during the 4-week training program (PRE, MID, and POST). Biomechanical data obtained from the 3.1 m/s and the preferred running speeds were analyzed separately. Post-hoc comparisons with Bonferroni correction were conducted when the main effect was significant. All statistical procedures were conducted using SPSS® 22.0 (International Business Machines Corp. New York, USA). Significance level was set at 0.05.

Results

The reported weekly mileage per footwear condition during the 4-week protocol is presented in Table 3. The percentage of total running distance in the minimalist shoes gradually increased from 18.8% to 54.9% during the 4 weeks. A significant difference was detected in the preferred running speed (p=0.007) that at the MID the preferred running speed was significantly slower than at PRE (PRE vs. MID, 3.25±0.33 vs. 3.13±0.31 m/s, p=0.016). No other differences in running speed were detected.

TABLE 3. Recorded weekly distance ran by participants in minimalist and their normal running shoes.

	Week 1	Week 2	Week 3	Week 4
Running Distance (km)				
Total in minimalist shoes	3.6 ± 3.4	4.2 ± 2.2	7.1 ± 2.9	7.8 ± 4.0
Average per run in minimalist shoes	2.6 ± 2.0	3.8 ± 2.0	4.3 ± 1.4	4.7 ± 1.5
Total in normal shoes	14.5 ± 7.4	12.5 ± 6.4	9.8 ± 6.3	6.4 ± 3.8
Average per run in normal shoes	6.3 ± 2.5	5.4 ± 2.1	5.8 ± 4.8	5.1 ± 3.6
% of total distance in minimalist shoes	18.8%	31.3%	42.1%	54.9%

During the prescribed 3.1 m/s running speed, significant differences were detected in mean lumbar posture, peak flexion, peak extension, and contralateral paraspinal muscle activation between the 3 testing sessions (Table 4). Post-hoc comparisons showed that the mean lumbar posture was significantly less flexed when compared to before training (PRE vs. POST, 1.9±15.3° vs. -6.0±13.3°, $p=0.001$). Peak lumbar flexion angle was significantly lower after training (PRE vs. POST, 8.6±15.7° vs. -0.3±13.7°, $p<0.001$; MID vs. POST, 7.6±15.1° vs. -0.3±13.7°, $p=0.001$). Peak lumbar extension angle increased significantly after training (PRE vs. POST, 4.8±14.3° vs. 6.7±11.8°, $p<0.001$; MID vs. POST, 6.7±11.8° vs. 12.6±12.4°, $p=0.033$). There was no significant change in the overall lumbar range of motion before, during, and after training. The contralateral lumbar paraspinal muscle activation significantly differed among the 3 time points. Post-hoc comparison showed that there was a significant reduction of muscle activation after two weeks of training (PRE vs. MID, 47.0±34.0% vs. 24.9±8.2%, $p=0.049$). No significant difference in muscle activation was observed in the ipsilateral paraspinal muscle.

TABLE 4. Comparison of lumbar kinematic and paraspinal muscle activation pre, mid, and post the 4-week training.

	3.1 m/s running speed				Preferred running speed			
	PRE	MID	POST	*p* value	PRE	MID	POST	*p* value
Mean lumbar posture (degree)	1.9 ± 15.3	0.4 ± 13.0	-6.0 ± 13.3*	0.001	2.3 ± 15.5	0.9 ± 13.9	-5.7 ± 14.2*	0.002
Peak lumbar flexion (degree)	8.6 ± 15.7	7.6 ± 15.1	-0.3 ± 13.7*†	<0.001	9.1 ± 16.3	8.0 ± 15.4	-0.3 ± 14.7*†	<0.001
Peak lumbar extension (degree)	4.8 ± 14.3	6.7 ± 11.8	12.6 ± 12.4*†	0.005	4.4 ± 14.7	6.7 ± 12.5	12.4 ± 13.5*†	0.007
Overall lumbar ROM (degree)	13.3 ± 2.4	14.3 ± 6.1	12.3 ± 4.4	0.496	13.5 ± 2.4	14.7 ± 6.0	12.1 ± 4.6	0.325
Contralateral lumbar muscle activation (% of MVIC)	47.0 ± 34.0	24.9 ± 8.2*	29.4 ± 11.3	0.039	41.6 ± 28.6	23.4 ± 6.2	30.3 ± 11.6	0.047
Ipsilateral lumbar muscle activation (% of MVIC)	26.5 ± 15.8	17.0 ± 4.1	25.5 ± 17.2	0.225	28.8 ± 22.5	16.7 ± 3.8	25.9 ± 17.8	0.262

*indicates a significant difference from PRE condition.

†indicates a significant diffidence from the MID condition.

For the preferred running speed, significant differences were detected in mean lumbar posture, peak lumbar flexion, peak lumbar extension, and contralateral paraspinal lumbar muscle activation between the 3 testing sessions (Table 4). Post-hoc comparisons showed that the mean lumbar posture was significantly less flexed when compared to before training (PRE vs. POST, 2.3±15.5° vs. -5.7±14.2°, p=0.002). Peak lumbar flexion angle was significantly lower after training (PRE vs. POST, 9.1±16.3°

vs. -0.3±14.7°, p<0.001). The peak lumbar extension angle increased significantly after training (PRE vs. POST, 4.4±14.7° vs. 12.4±13.5°, p<0.001; MID vs. POST, 6.7±12.5° vs. 12.4±13.5°, p=0.046). There was no significant change in the overall lumbar range of motion before, during, and after the training. The contralateral lumbar paraspinal muscle activation significantly differed among the 3 time points. The post-hoc comparison detected a trend of reduction in contralateral paraspinal muscle activation after two weeks of training (PRE vs. MID, 41.6±28.6% vs. 23.4±6.2%, p=0.072). No significant difference in muscle activation was observed in the ipsilateral paraspinal muscle.

Discussion

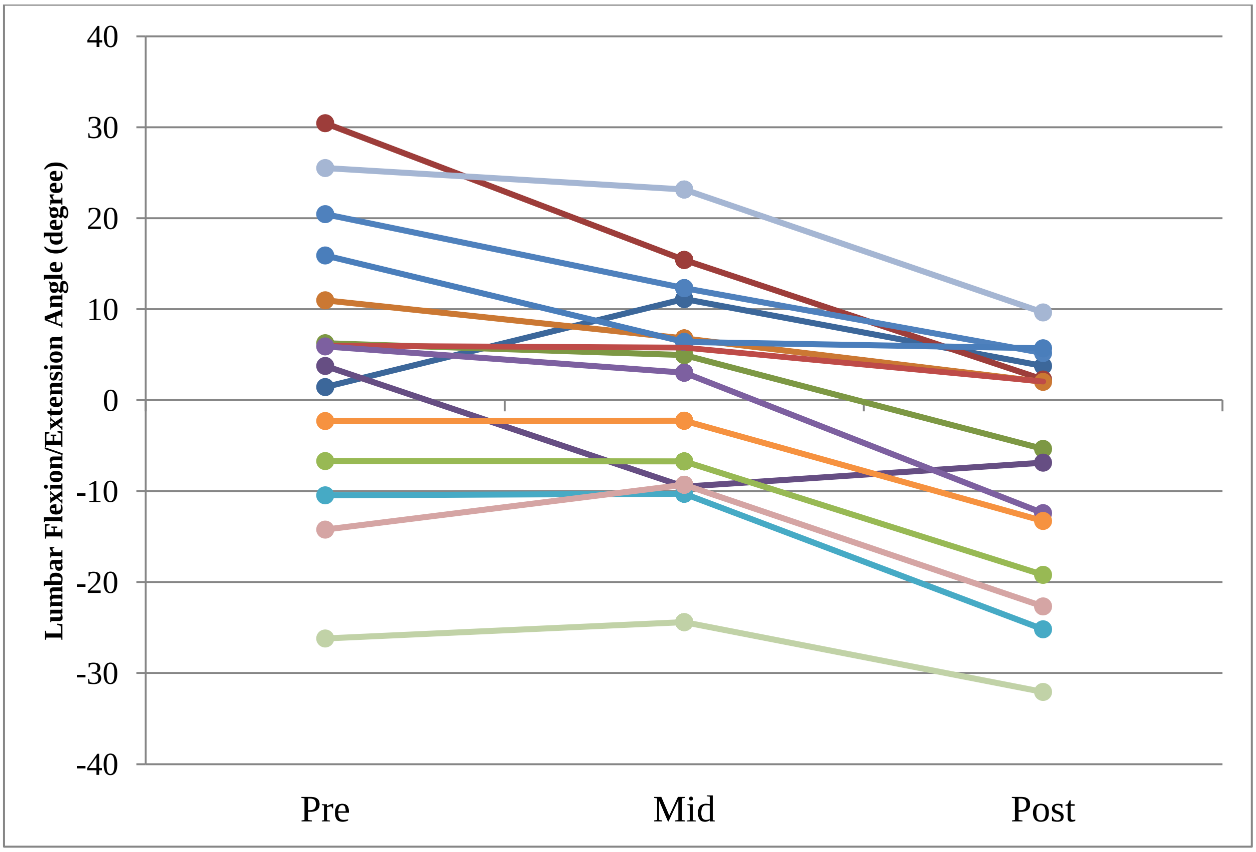
Biomechanical evaluations aimed at identifying risk factors, prevention, and treatment strategies pertinent to running-related injuries have traditionally focused on the more common injuries such as knee pain and tendinopathy. In comparison, research regarding the biomechanics of lumbar spine during running is lacking. This is an important void in the current knowledge base that needs to be addressed, because lower back dysfunctions are relatively common in distance runners.(Gonzalez, et al., 2006; Walter, et al., 1989; Yoder, 2013) Also, preliminary evidence suggested that dysfunction or weakness of the lumbar-pelvis-hip musculoskeletal complex can lead to injuries in other parts of the body.(Brumitt, 2011; Hammill, Beazell, & Hart, 2008)

Our primary finding was that the runners gradually adopted a more extended lumbar posture over the 4 weeks of training. During running, lumbar flexion has been shown to dominate the initial loading phase of stance followed by more extension from midstance to toe-off.(Saunders, Schache, Rath, & Hodges, 2005; Schache, Blanch, Rath, Wrigley, & Bennell, 2002; Schache, Blanch, Rath, Wrigley, & Bennell, 2005;

Schache, et al., 2001) Lumbar flexion during the initial loading phase is thought to aid in the attenuation of the impact forces.

In order to provide effective intervention to runners with running-related lower back pain, it is important to establish how different running styles may affect spinal mechanics. Changes in lumbar kinematics in response to foot strike pattern during running were first reported by Delgado et al.(Delgado, et al., 2013) The authors reported a small reduction (from 22.1 to 20.9°) in overall lumbar range of motion after acute changes of foot strike pattern. Contrary to their findings, we observed no changes in the lumbar range of motion, but an overall tendency of most runners adopting a more extended lumbar posture after running training with minimalist footwear and technique instruction. Specifically, the runners in our study generally exhibited a gradual reduction in peak lumbar flexion angle over the course of the training (Figure 2). The discrepancy in the results perhaps stemmed from the different methodology. In the previous study the peak lumbar spinal angles were recorded over combined swing and stance phases, while in this study we focused on the stance phase. Also, we did not explicitly instruct the runners on the foot strike location during the running trials, but allowed the runners to naturally adapt to running with the minimalist footwear over time.

FIGURE 2. Changes of mean lumbar posture during the stance phase of running for each participant Pre, Mid, and Post the 4-week training



The observed more upright running posture after training was accompanied by reduced contralateral paraspinal muscle activation. Previous studies have shown that the greatest activation of the lumbar paraspinal muscle group occurs during forward trunk flexion and is reduced during extension.(Kienbacher, et al., 2015) The observed reduction in the contralateral muscle activation during stance is compatible with the reduced need to stabilize the lumbar spine against gravity in the more upright posture and the potential reduction of impact shock after training.

Appropriate muscle activation during running facilitates adequate coordination between the lumbar spine, pelvis and hip complex, helps to stabilize the spine in response to the ground reaction force during the stance phase of running. However, excessive lumbar paraspinal muscle activation may be a sign of dysfunction, and the increased muscular force can lead to increased loading on the spine. Previous EMG studies of lumbar muscle activation demonstrated that during locomotion, patients with LBP showed continuous activation in contrast to the more phasic activation pattern observed in those without LBP.(Kuriyama & Ito, 2005; van der Hulst, et al., 2010) This indicates that patients with LBP exhibit altered paraspinal muscle activation patterns, perhaps as a guarding response that also increases the stiffness of the spine. Such increased loading from the paraspinal muscle contraction may also be related to the chronic back pain symptoms and interferes with recovery. While we could not definitively imply the observed reduction of paraspinal muscle activation as beneficial, it is possible that such change can be clinically meaningful. Future intervention study on runners with running-related lower back pain is needed to investigate the clinical utility of minimalist running for treating this condition.

Fifteen out of 17 runners were able to complete the training, and none of them reported any running-related injuries during the training period. Our 4-week training intervention protocol was designed around a gradual progression of runners' weekly training mileage in the minimalist shoes. Some previous study protocols were longer at 10-12 weeks.(Miller, Whitcome, Lieberman, Norton, & Dyer, 2014; Ridge, et al., 2013) The extended durations in those studies were necessary for identifying musculoskeletal structural adaptations to the adjusted stress from the altered running pattern. On the other hand, the focus of the current study was to identify movement pattern adjustments rather than structural adaptations. Furthermore, the end point of our program was to allow the runners to incorporate minimalist footwear running into only 30-50% of their total weekly mileage and not a full conversion.

In the current study, the minimalist running training was designed as a supplement to the runner's typical running routine with the inclusion of footwear variability, postural cues and strengthening exercises. In other words, the minimalist style running was used as an exercise drill to induce changes in running movement pattern, which we observed to be transferrable to the runners' normal shod running. This could imply that some learning occurred due to the running training used in this study. We believe that this finding is clinically important as it is often unrealistic to ask a runner to completely shift to a different running style or footwear. In fact, results from a number of previous studies have shown that even successful complete transition to minimalist running can induce potential damage to the foot and lower extremity.(Ridge, et al., 2013; Ryan, Elashi, Newsham-West, & Taunton, 2014) While researchers and clinicians continue to debate about the benefits and injury risks associated with minimalist running,(Jenkins & Cauthon, 2011; Perkins, et al., 2014) it is likely safer to utilize the minimalist style running as a supplemental training to induce beneficial movement pattern changes and not to emphasize a complete transition.

This study has a number of limitations. The biomechanical testing was done on a treadmill, which may not reflect the activities of the lumbar spine and paraspinal muscle during overground running as the treadmill afforded some cushioning. Also, direct measurement of ground reaction force was not done. Since foot strike impact attenuation has been proposed as an important factor to running-related lower back dysfunctions,(Hamill, et al., 2009) future studies should examined the ground reaction impact attenuation and energy absorption of the lower extremity and spinal joints. While surface EMG provide a reliable method of quantifying trunk muscle activity during running locomotion,(Smoliga, Myers, Redfern, & Lephart, 2010) they are unable to differentiate between activity in the different depth of muscles that comprise the lumbar paraspinal group.(Stokes, Henry, & Single, 2003) Lastly, it is important to recognize that individual response to training differs. A recent study has shown that only certain runners respond to barefoot running training in a manner consistent with injury prevention.(Tam, Tucker, & Astephen Wilson, 2016) Future research should focus on the feasibility and the clinical benefits of minimalist style running in clinical populations.

Conclusion

Our results demonstrated that a 4-week running training with minimalist footwear and techniques instruction can induce significance changes to lumbar spine biomechanics during running. Specifically, the participants ran with a less flexed, and more upright lumbar posture after training. Correspondingly, we observed a trend of reduction of the contralateral lumbar paraspinal muscle activation. These effects were observed when the runners ran wearing their regular running footwear. Our findings demonstrated that including minimalist style running into a runners' training may induce beneficial changes to the lumbar kinematics and paraspinal muscle activation during their normal shod running.

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