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Motion Control Shoe Delays Fatigue of Shank Muscles in Runners With Overpronating Feet

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Background: The motion control shoe is a well-developed technology in running shoe design for controlling excessive rearfoot pronation and plantar force distribution. However, there is little information on the leg muscle activation with different shoe conditions.

Hypothesis: The motion control shoe can prevent excessive shank muscle activation and delay fatigue.

Study Design: Controlled laboratory study.

Methods: Twenty female recreational runners with excessive rearfoot pronation were tested with running 10 km on a treadmill on 2 days. Participants wore either a motion control running shoe or neutral running shoe on each day. Activities of their right tibialis anterior and peroneus longus were recorded with surface electromyography. The normalized root-mean-square electromyography and median frequency were compared between the 2 shoe conditions.

Results: Significant positive correlations were found between the root-mean-square electromyography and running mileage in both the tibialis anterior and peroneus longus in the neutral shoe condition ($P < .001$). The median frequency dropped in both shoe conditions with mileage, but paired t tests revealed a significantly larger drop in the neutral shoe ($P < .001$ for peroneus longus, $P = .074$ for tibialis anterior).

Conclusion: The motion control shoe may facilitate a more stable activation pattern and higher fatigue resistance of the tibialis anterior and peroneus longus in individuals with excessive rearfoot pronation during running.

Clinical Relevance: The motion control shoe may increase the running endurance, thus reduce overuse injuries, in athletes with unstable feet during long-distance running.

Keywords: running; footwear; shank; electromyography

Excessive rearfoot pronation may cause various overuse injuries in runners such as posterior tibial syndrome (shin splints), plantar fasciitis, and Achilles tendinopathy.⁶ Footwear is essential in running, and the motion control shoe technology was developed to prevent lower leg muscle overuse in runners by limiting rearfoot pronation during landing. The rationale of motion control footwear is based on the normal running biomechanics in heel strikers (ie, runners who land on the lateral border of the heel).^{4,5} The lateral sole of motion control footwear is made of a relatively soft and more compliant material than the medial

sole so that it can deform during landing to decelerate the pronation movement. During midstance, however, the firmer material on the medial sole provides extra support to stop further pronation.

In a study with 3-dimensional kinematic analysis of 25 female runners who had excessive rearfoot pronation,² a motion control shoe reduced rearfoot pronation by an average of 6.5° (95% confidence interval, 4.7°-8.2°). Nevertheless, such pronation control function was not found in the normal cushioned shoe. Furthermore, the motion control function was maintained even after the runners had developed leg muscle fatigue. Motion control footwear was also effective in balancing the uneven plantar load distribution during long-distance running.³

Because most running-related injuries are associated with lower leg muscle imbalances,²¹ it is necessary to examine the activities of those muscles in order to evaluate the efficacy of the foot orthosis^{12,17,18,26} or other design features of the shoe.^{10,14} Heretofore, the effects of the motion control shoe on lower leg muscle activation have not been

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Figure 1. Location of markers: center of heel cap just above the shoe sole, center of heel cap at the insertion of the Achilles tendon, center of Achilles tendon at the height of the medial malleolus, and 15 cm above marker 3 at the center of the leg.

well examined. Therefore, this study aimed to investigate the lower leg muscle activations between different shoe conditions in individuals who had excessive foot pronation.

METHODS

Participants

Twenty female runners with excessive rearfoot pronation of $>6^\circ$ were recruited. The method of kinematics measurement is according to Cheung and Ng.² In brief, the subject wore neutral shoes with 2 light reflective spherical markers attached to the calf and Achilles tendon and 2 other markers on the back of the shoe (Figure 1). The proximal 2 markers formed vector *a* (*V_a*) and the distal 2 markers formed vector *b* (*V_b*). A 3-camera Vicon motion analysis system (Vicon Motion Systems, Oxford, United Kingdom) was used to capture the lower leg movements during the run. The rearfoot angle was defined as the acute intercept angle between these 2 vectors using the formula: rearfoot angle = $\arcsin(|V_a \cdot V_b| / (|V_a| \times |V_b|))$.

All the participants were asymptomatic and healthy in terms of both musculoskeletal and cardiopulmonary aspects and reported no symptoms during tests. They were naive about the motion control footwear technology. Many of them had not heard of motion control shoe design before engaging in this study, and none of them wore an orthotic device.

This study was reviewed and approved by the ethics review committee of Hong Kong Polytechnic University

TABLE 1
Age, Running Experience, Body Mass Index,
and Rearfoot Pronation of Study Participants

Participant Characteristic	Mean \pm Standard Deviation
Age, y	25.8 \pm 3.7
Running experience, y	4.6 \pm 2.4
Body mass index, kg/m ²	20.54 \pm 1.27
Rearfoot pronation angle, deg	13.9 \pm 1.34

and all the participants gave their written informed consent before the tests. Their age, running experience, and body mass index are presented in Table 1.

Test Shoe

Two shoe models were tested in this study—the Adidas Supernova (Adidas AG, Herzogenaurach, Germany) control was the motion control shoe and the Adidas Supernova cushion was the neutral shoe (Figure 2). The design and construct of these shoe models are highly comparable except for the midsole. The midsole of the Supernova control is composed of 2 materials with different hardnesses so that it can minimize foot pronation during landing and weight transfer. The Supernova cushion, however, has a single midsole material that reduces the impact loading rate but does not control foot pronation. Previous reports have revealed no detectable difference in the kinematics profile between barefoot running and running with a neutral shoe.^{24,25}

Experimental Procedures

Treadmill running at a speed of 8 km/h without inclination was used in this study. The speed was selected because it was similar to the training speed of the subjects. All the subjects ran for 10 km in 2 sessions with 1 week apart. In each session, the subjects wore either test shoe models in a randomized sequence, which was achieved by



Figure 2. Adidas Supernova control (left) and Supernova cushion (right).

throwing dice. An odd number indicated the use of motion control shoe in the first session.

It is important to define the instance of touch-down loading and toe-off in determination of a gait cycle. A previous study³⁰ had used a foot switch (eg, F-scan [Tekscan Inc, Boston, Massachusetts]) to identify the running steps and loading response during the whole-stance phase. However, in consideration that our participants had to run for a long distance and the foot switch may not withstand the repeated loading, a new method was used to determine the instance of loading. A load cell (Tedeia-Huntleigh, Inc, Darmstadt-Eberstadt, Germany) was positioned at the right rear base of a leveled treadmill and when a participant exercised on the treadmill, an analog level of alternate high and low waves indicated right and left steps, respectively, interlaced by a signal-free airborne phase.

A pilot test involving 6 participants running for 2 minutes was conducted. Identification of the last 10 steps was measured by both F-scan and the load-cell setup. The 95% limits of agreement¹ between these 2 measurements in step determination was 0.03 ± 0.00345 seconds.

Electromyographic (EMG) Recording Procedures

The right tibialis anterior (TA) and peroneus longus (PL) were tested in this study in light of their roles as the major stabilizing muscles of the subtalar joints,^{11,22} where most rearfoot pronation happens. The EMG activities of these muscles were recorded using the DelSys (DelSys Inc, Boston, Massachusetts) double-differential Ag-AgCl surface electrodes with an interelectrode distance of 10 mm. The common mode rejection ratio of the system was 92 dB. To reduce skin impedance, before applying the electrodes, the overlying skin was carefully prepared by shaving, lightly abrading with fine-grade sandpaper, and thoroughly cleansing with alcohol to reduce the skin-electrode interface impedance to below 5 k Ω .¹³ The electrode on TA was applied at one-fourth to one-third the distance between the distal patella and lateral malleolus and lateral to the tibia, whereas the PL electrode was applied at 5 to 7 cm distal to the lateral head of fibula along the lateral shin.¹⁵

The EMG reference electrode was placed over the patella. To prevent movement artifacts, connecting wires of the electrodes were secured to the skin with adhesive tapes and the leads were braided to minimize electromagnetically induced interference.²⁸

The EMG signal was 1-k amplified (1000 \times) (Bagnoli-4 Main Amplifier [DelSys]) and sampled at a rate of 1000 Hz using a data-acquisition program (EMGworks Acquisition [DelSys]). Before sampling, the EMG signals were analog band-pass filtered (high pass, 20 Hz; low pass, 450 Hz) to minimize noise and movement artifacts in the low-frequency region, and to eliminate aliasing and other artifacts in the high-frequency region. The resulting power spectrum was quantified by calculating the median frequency (MF) for each of the raw EMG data.

To compare different stages of running, the total 10-km running distance was equally divided into 10 recording

checkpoints. Because the total running time was 75 minutes, each checkpoint therefore lasted for 7.5 minutes. To reduce the data acquisition and storage problem, the EMG data were only collected during the last minute of each recording checkpoint and all the recording checkpoints were included for analysis.

Before each running session, every participant performed a maximum voluntary isometric contraction (MVC) for both the TA and PL according to the method of Yang and Winter.²⁹ Each muscle contraction was held for 8 seconds and the actual window for measurement was confined to the last 4 seconds.¹⁷ This procedure was repeated for 3 times and the mean root-mean-square (RMS) EMG value of the 3 repetitions represented the MVC EMG value. In each recording point of the running tests, the RMS values of electromyography from all the running steps were averaged and normalized against the MVC EMG value. The MF of electromyography was also obtained by taking the average of the values from each step within each checkpoint.

Statistical Analysis

Repeated-measures analysis of variance was used to test the effects of footwear and mileage on the normalized RMS EMG values of both muscles. Because 20 (10 recording points and 2 shoe models) pairwise comparisons would be performed, Bonferroni adjustment was applied by reducing α to .0025 so as to control type I error. For significant analysis of variance results, the post hoc Wilks Lambda test was used to identify the data pairs that were significantly different from one another. Furthermore, the relationships between mileage and electromyography were examined with the Pearson correlation. For the fatigue profile, the corresponding MF difference between checkpoint 1 and checkpoint 10 was analyzed using paired *t* tests. The α value for the paired *t* test was set at .05.

RESULTS

Significant differences in the normalized RMS EMG values of the TA and PL muscles were found with different footwear conditions ($P < .001$) and across mileage ($P < .001$). The mean values across all checkpoints of TA activation with the neutral shoe testing condition was around 10.5% higher than that of the motion control shoe condition. For the PL activation, the result revealed a 9.6% higher activity in the neutral shoe than in the motion control shoe condition (Figure 3). Regardless of the shoe condition, EMG activities in both muscles increased with the running mileage. When compared with the baseline value at the first recording point, the TA and PL recruitment increased beginning with the fourth ($P = .004$) and second ($P < .0001$) checkpoints, respectively, in the neutral shoe condition. In the motion control shoe condition, the TA and PL activities increased beginning with the tenth ($P < .0001$) and eighth ($P < .0001$) checkpoints, respectively.

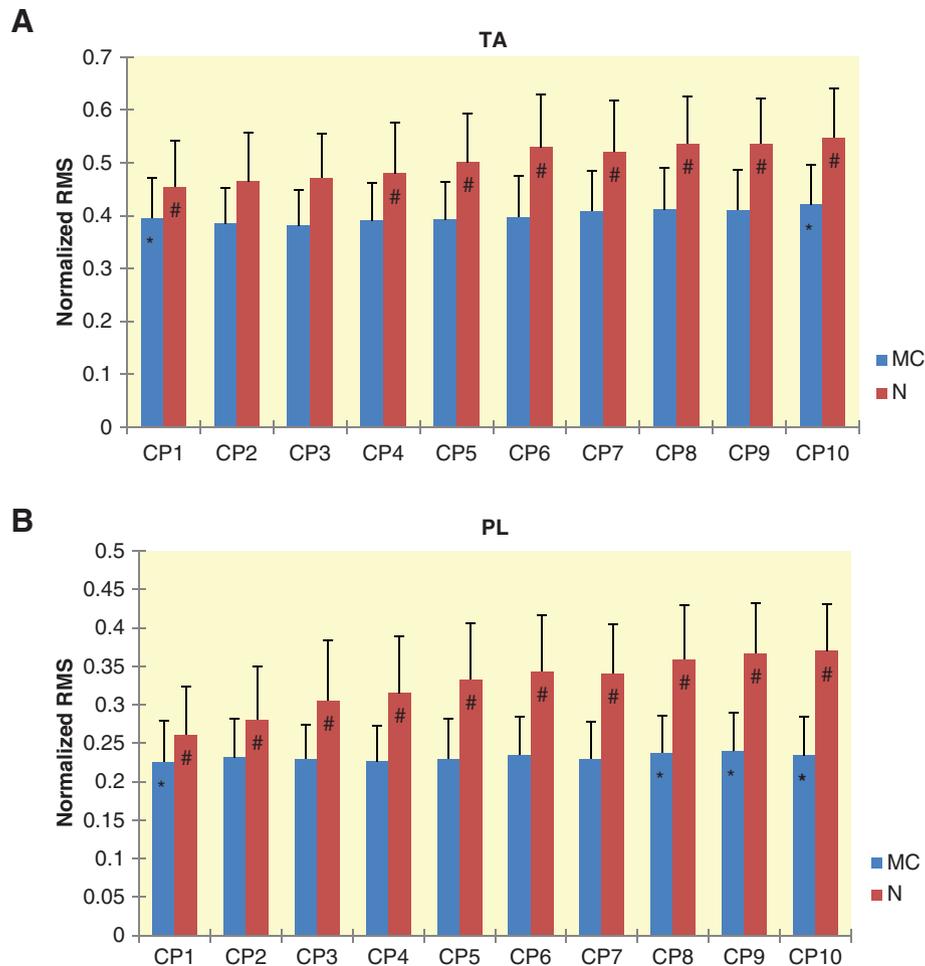


Figure 3. Normalized root-mean square electromyography (RMS EMG) of the tibialis anterior (TA) and peroneus longus (PL) in motion control (MC) and neutral (N) shoe conditions at different checkpoints (CPs). The error bars represent standard deviations and the number sign (#) indicates significant difference in the neutral shoe condition of that particular CP when compared with the same shoe condition at CP 1. The asterisk (*) indicates a significant difference in the motion shoe condition of that particular CP when compared with the same shoe condition at CP 1.

Significant correlations were found between the change in TA RMS EMG values of both shoe conditions with running mileage (Pearson correlation = 0.148 for motion control shoe; 0.329 for normal cushion shoe), whereas for the PL muscle, such a correlation was only revealed in the neutral shoe condition (Pearson correlation = 0.444). As a whole, the correlations were more evident in the neutral shoe than the motion control shoe condition (Table 2).

There was a significant downward shift ($P < .001$) in MF comparing the first and the last checkpoint in the 10-km running bout. Comparing the 2 shoe conditions, a significantly larger shift in MF was found in the PL during the neutral shoe testing condition (MF drop = 11.60 Hz; $P < .001$). For the TA, however, the difference between shoe conditions was insignificant ($P = .074$), although a larger amplitude of MF decrease was observed in the neutral shoe testing condition (MF drop = 12.94 Hz; $P = .074$) (Table 3).

DISCUSSION

This study compared the lower leg muscle recruitment with and without fatigue in recreational runners who have excessive foot pronation when running with different footwear. The results revealed that motion control footwear was able to maintain more stable activity in the TA and PL muscles and delay fatigue of these muscles with prolonged running better than neutral cushioned footwear.

The participant pool for this study was homogeneous in terms of gender, running skill level, and foot type. Previous studies^{7,8,16} suggested that there might be differences in the biomechanics of running between men and women. Recruitment of participants from a single gender would therefore minimize the variance due to gender despite the limitation on the generalizability of this study to both genders.

TABLE 2
Correlation Between the Change in RMS EMG
in the TA and PL and Running Mileage^a

	Motion Control	Neutral
TA	0.148 ($P = .037$)	0.329 ($P < .001$)
PL	0.066 ($P = .35$)	0.444 ($P < .001$)

^aRMS EMG, root-mean-square electromyography; TA, tibialis anterior; PL, peroneus longus.

TABLE 3
Drop in Median Frequency in the TA and PL
With Different Shoe Conditions^a

	Motion Control	Neutral	<i>P</i>
TA	5.51 ± 6.59 Hz	12.94 ± 13.93 Hz	.074
	CP 1: 75.59 Hz	CP 1: 74.66 Hz	
	CP 10: 70.08 Hz	CP 10: 61.72 Hz	
PL	2.10 ± 4.44 Hz	11.60 ± 5.96 Hz	<.001
	CP 1: 69.18 Hz	CP 1: 77.76 Hz	
	CP 10: 67.08 Hz	CP 10: 66.17 Hz	

^aTA, tibialis anterior; PL, peroneus longus; CP, checkpoint.

According to a previous report,⁵ recreational or novice runners were more prone to injuries than professional runners. Therefore, the testing with nonprofessional runners could make the study more clinically relevant. Furthermore, as there are more recreational runners in the society than professional runners and they are usually not supported by coaches or running clubs, the findings in this population would therefore have a larger societal relevance and impact.

Treadmill running was used in this study in consideration that the setup has the advantages of (1) providing a speed-controlled environment for long-distance running and (2) being able to simulate the general trend of the new generation of exercising in a fitness club. As there may be potential kinematics and EMG differences compared with outdoor running,²⁷ caution is thus needed when applying the results of this study to other conditions.

The RMS EMG findings revealed an increased activation level in the TA and PL in the neutral shoe running condition, and there are also significant correlations between the change in RMS EMG values of both muscles and mileage of running with this type of footwear. For the motion control shoe, however, the EMG activation levels of both muscles were more stable throughout the running bout.

Excessive rearfoot motion may be controlled by either a foot orthosis or a motion control shoe, but the design features of these are different. Motion control footwear adopts different medial and lateral midsole hardness that allows more time for loading response during landing, thus a longer duration for the foot stabilizers to work. This design feature would result in an overall decrease in muscle activity. In contrast, foot orthoses provide extra support to the

foot arches so that the muscles can contract in a more efficient position. Therefore, lower muscle activation was expected in the motion control shoe condition, whereas orthosis might facilitate muscle activation. To the best of our knowledge, this is the first report on shank muscle activation with motion control footwear. The following discussion about foot orthosis is aligned with this speculation.

A study by Nawoczinski and Ludewig¹⁸ comparing individuals wearing sandals alone and sandals with orthoses revealed that the TA EMG values increased with orthotic conditions. Murley and Bird¹⁷ had similar findings in testing the lower leg EMG activities of 15 runners with rearfoot overpronation problems. The maximum EMG amplitude was higher with an orthosis than barefoot walking. The reason for the increased muscle activities with orthoses may be due to the fact that orthoses may induce a new sensory input^{12,17,18} for runners. This new sensory input may trigger additional muscle work in the runners. A study by Santilli et al²³ revealed that athletes with rearfoot instability exhibited different patterns of EMG activation when running with a new pair of running shoes. The authors explained that an immediate increase of EMG intensity was the result of a short-term sensory stimulation of the orthosis on the foot structure. This stimulation would vanish when the runners have adapted to the sensation. Such a sensory stimulation may not happen in a motion control shoe because, according to a previous study,² the participants were not able to differentiate the function of the motion control shoe from the normal cushioned shoe.

Previous studies have reported that reduction in MF is an indication of localized muscle fatigue.^{9,19,20} The present findings revealed that MF had dropped in both muscles after running with motion control or neutral shoe conditions (Table 3), but the drop was significantly more in the neutral shoe condition than the motion control shoe condition for PL ($P < .001$) and a similar trend was also observed for TA ($P = .074$). These findings suggest that the PL, and possibly TA, had developed more fatigue in the neutral shoe testing condition throughout the 10 km of running. As both the TA and PL are important dynamic stabilizers that control rearfoot pronation,^{11,22} fatigue of these muscles might lead to further increase in pronation with running mileage.² Therefore, a motion control shoe that helps delay muscle fatigue in the PL and TA would be beneficial for long-distance running in maintaining stability of the foot. These results suggest that motion control footwear may promote runners' performance by increasing the endurance and delaying the onset of leg muscle fatigue.

There are some limitations in this study that need to be considered when interpreting the findings. First, the use of treadmill running may not simulate the actual overground running. The inclusion of only a single gender, and the fact that all the participants were asymptomatic novice recreational runners, would limit the generalizability of the findings. Furthermore, during the data collection, the aerobic threshold, speed, and race record were not measured. However, all the participants reported the testing speed of 8 km/h to be a suitable constant speed to finish a 10-km distance. This might partly indicate that the runners were comparable in their levels of performance.

This study has addressed the possible advantages of motion control footwear in providing more favorable activation pattern of the TA and PL, so as to guard against stabilizing muscle fatigue for individuals with rearfoot overpronation. It is highly recommended that further investigation be conducted in symptomatic individuals to test the efficacy of the motion control shoe for symptom control.

CONCLUSIONS

We conclude that a motion control shoe could enhance more stable activation and fatigue endurance of the TA and PL than a neutral shoe during a 10-km running bout in recreational runners who have rearfoot overpronation problems. The exact clinical implication of this finding needs to be further investigated.

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