ACUTE EFFECTS OF FOOT STRIKE PATTERN TRANSITION ON TRICEPS SURAE AND TIBIALIS ANTERIOR MUSCLE ACTIVITIES DURING RUNNING

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This study aimed to investigate the acute effects of transitioning foot strike patterns on muscle activity in the lateral gastrocnemius (LG), medial gastrocnemius (MG), soleus (SOL), and tibialis anterior (TA) muscles during running. Fifteen healthy male runners with habitual rearfoot strike pattern (RFS) were recruited to complete running with RFS and the forefoot strike pattern (FFS) tests at 9 km/h. The electromyography (EMG) and ground reaction force were collected synchronously. The paired *t*-tests were used to examine the differences in the root mean square (RMS). The results revealed that the mean RMS for the triceps surae was higher in FFS than in RFS and the muscle co-activation ratio was higher in RFS than in FFS during the pre-activation phase. Overall, the acute transitioning to FFS could change muscle activation mode during running.

KEYWORDS: foot strike pattern, electromyography, muscle co-activation

INTRODUCTION: Running as one of the most popular sports in daily life has many benefits. The choices of foot strike patterns can greatly affect the sports performance. With the deepening of research in recent years, many runners and scholars had focused on the biomechanics of forefoot strike pattern (FFS). According to existing research, compared to the more familiar rearfoot strike pattern (RFS) runners, which using FFS have the advantage of lower loading rate and knee extension moment, and higher ankle plantarflexion moment and muscle activation (Daoud et al., 2012; Yang et al., 2020). Based on these findings, many runners accustomed to RFS began to transition to FFS in pursuit of better sports performance.

Muscle activation affected kinematics and kinetics in some extent. According to previous research, the major muscle groups of the calf are important components in influencing human running economy and performance, and are important in storing and releasing energy. It has been found that the muscle-tendon units of the ankle joint are able to play a more active role during running compared to other lower limb joints (Takahashi et al., 2016), and the elastic energy provided by the triceps surae muscle-tendon units through rebound and stretch can account for up to 35% of total body energy consumption (Swinnen et al., 2019). Therefore, the four most important muscles during ankle dorsiflexion and plantarflexion movements, i.e., the triceps surae and tibialis anterior muscles and their tendons, are the main structures in the human body for releasing and storing energy during running (Yong et al., 2020). So research on the degree of muscle activation in the major muscle groups of the ankle joints is necessary.

The purpose of this study was to explore the acute effects of foot strike patterns on the root mean square (RMS) of the major plantar flexors and dorsiflexors and the co-activation for providing the theoretical basis and feasibility of the gait retraining during running.

METHODS: A total of fifteen healthy male participants (mean ± SD age 37.0 ± 16.0 years, body height 1.72 ± 0.07 m, body mass 62.8 ± 7.8 kg and weekly running volume 55.0 ± 35.0 km) were recruited, who were accustomed to wearing cushioned running shoes in RFS over 3 years. Inclusion criteria were runners who running more than 20 km per week for the past three months and having no cardiovascular or neurological disease, no triceps surae pain or injury, and no severe lower extremity injuries within the past three months.

The participants were asked to use their habitual running foot strike patterns to perform a 5 min warm-up run on the treadmill. Participants' habitual foot strike patterns were determined by taking videos, based on criteria from Kovacs et al. (2023). RFS was defined as when the heel is the first region to contact the ground, and FFS was defined as when the ball of the

foot contacts the ground prior to the heel. A treadmill equipped with a three-dimensional force platform (Bertec, USA, 1000 Hz) was used to collect data of vertical ground reaction force (vGRF) during running. The participants were first tested with the RFS and then transitioned to FFS according to the criteria of FFS mentioned above at 9 km/h (Sano et al., 2015). A 16-channel EMG system (Noraxon, USA, 2000 Hz) was also used to synchronously collect EMG signals from LG, MG, SOL, and TA. The GRF and EMG data were acquired synchronously for 10 s each after the foot strike pattern was stabilized.
The EMG signals were preprocessed by using MR3.18 (Noraxon, USA, version 3.18) with 20-400Hz band-pass filter. The EMG signal amplitudes were normalized to the mean of the peaks for each muscle and the RMS window was selected to be 100 ms.
The GRF data were viewed by using Visual 3D (C-Motion, USA, version 3.21). The threshold of the touchdown and toe-off moment was 30 N. The stance and swing phases were determined based on the toe-off and the touchdown moment. The pre-activation phase was defined as 50 ms before touchdown (Ruan & Li, 2010), and five consecutive steps were selected to calculate the average RMS. The formula of muscle co-activation ratio is as follows:

$$CO_{Ankle} = \frac{RMS_{TA}}{(RMS_{SOL} + RMS_{MG} + RMS_{LG})/3}$$

The experimental data were statistically analyzed by using SPSS Statistics 26 (IBM, USA, version 26). The Shapiro-Wilk test was used to determine parameters conformed to a normal distribution, then a paired-samples *t*-test was used to quantify whether there was a significant difference between the RMS and muscle co-activation ratios in these two foot strike patterns. All data conformed to a normal distribution. The significance level was set at 0.05.

RESULTS: There was a significant difference in RMS of the MG during the stance phase (p<0.05) and LG during the swing phase (p<0.05) between RFS and FFS, specifically, both RMS were higher in FFS than in RFS (p<0.05, Figure 1, Table 1). The RMS in the TA in RFS tended to be higher than in FFS during the pre-activation phase. There was a significant difference in muscle co-activation ratios during the pre-activation phase, which was higher in RFS than in FFS (p<0.05, Figure 1, Table 2).

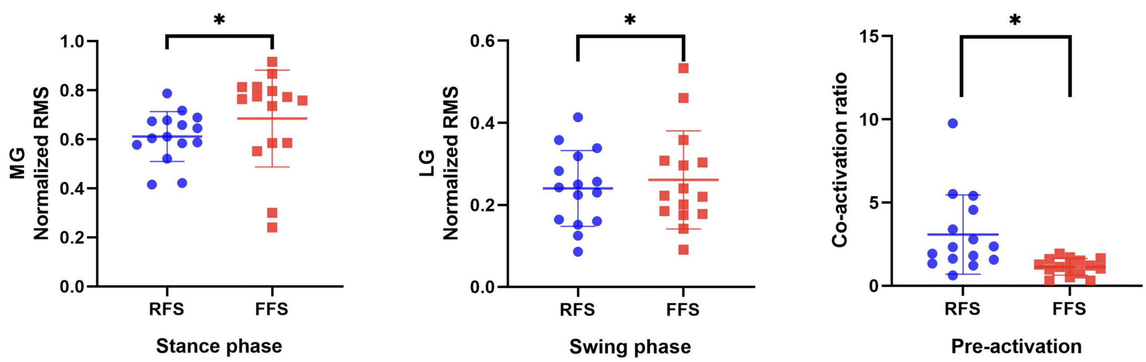

Figure 1: Differences of RMS and co-activation ratios in different foot strike patterns.
Note: *Indicates significant difference between FFS and RFS (p < 0.05).
FFS: forefoot strike pattern; RFS: rearfoot strike pattern

Table 1: EMG activity during forefoot and rearfoot strike running.

Phases	Muscles	Normalized RMS		
		RFS	FFS	*p-value*
Pre-activation	MG	0.323±0.189	0.524±0.294	0.268
	LG	0.375±0.214	0.440±0.230	0.151
	SOL	0.370±0.150	0.457±0.271	0.315
	TA	0.828±0.260	0.493±0.237	0.074
Stance phase	MG	0.575±0.175	0.667±0.242	**0.003***
	LG	0.631±0.089	0.699±0.115	0.576
	SOL	0.618±0.085	0.741±0.051	0.790
	TA	0.404±0.088	0.454±0.203	0.314
Swing phase	MG	0.206±0.062	0.268±0.077	0.832
	LG	0.240±0.092	0.261±0.119	**0.026***
	SOL	0.204±0.073	0.186±0.075	0.366
	TA	0.646±0.088	0.518±0.153	0.168

Note: *Indicates significant difference between FFS and RFS ($p < 0.05$).
FFS: forefoot strike pattern; RFS: rearfoot strike pattern

Table 2: Muscle co-activation ratios during forefoot and rearfoot strike running.

Phases	Co-activation ratio		
	RFS	FFS	*p-value*
Pre-activation	3.08±2.38	1.13±0.50	**0.015***
Stance phase	0.67±0.16	0.65±0.28	0.321
Swing phase	3.17±0.99	2.34±0.96	0.993

Note: *Indicates significant difference between FFS and RFS ($p < 0.05$).
FFS: forefoot strike pattern; RFS: rearfoot strike pattern

DISCUSSION: The purpose of this study was to investigate the acute effects of transitioning foot strike patterns on muscle co-activation and muscle activity in the major plantar flexors and dorsiflexors (i.e., LG, MG, SOL, TA) during running. Significant differences in RMS was found in the MG during the stance phase and in the LG during the swing phase, all of which were higher during the FFS than during the RFS. There was a significant difference in muscle co-activation ratios during the pre-activation phase, which were higher in RFS than in FFS.

The result of higher muscle co-activation ratios during the pre-activation phase in RFS indicated that there were significant differences in the muscle activation modes of these two foot strike patterns before touchdown. In RFS, runners had to do dorsiflexion of the ankle joint before touchdown for heel striking, so the activation of the tibialis anterior muscle was higher at this time. However, in FFS, the ankle joint of the runners was more kept plantarflexed before touchdown, so a significant difference could be observed in the pre-activation phase.

In this study, higher RMS of MG during the stance phase in FFS was found, it was similar to the results of the previous study that MG possessed higher muscle activity during the stance phase (Swinnen et al., 2019). In a previous study of differences between habitual RFS and FFS runners, the authors found that metabolic energy costs of the triceps surae did not differ between foot strike patterns, and that FFS runners had greater MG muscle force in initial contact phase than RFS athletes (Swinnen et al., 2019). So it is reasonable to hypothesize that MG had greater muscle force during FFS when energy costs were similar, perhaps this will be an area for future research.

This study also found that most of the RMS of different muscles during different gait phases did not show significant differences, which was similar to the findings of Kovacs et al. (2023). But the individual differences in RMS in this study were obvious, suggesting that the acute transition from RFS to FFS may have different intervention effects for different individuals, which provided a possible guide for the individualized development of future training plans. However, Wearing et al. (2019) also found there was nearly 1.3 times higher joint loading at

the ankle joint when running in FFS than in RFS, so a progressive training program is essential when attempting to make the transition in foot strike patterns to effectively prevent sports injuries.
Several limitations need to be addressed. Running for less than 1min at a 9km/h speed may correspond to a lower exercise load for the participants and not cause significant differences of muscle activation. Longer running duration and distances and higher running speeds should be used in the future to minimize the associated effects, and the comparisons with novices and habitual RFS runners should be considered.

CONCLUSION: In this study, the results revealed that the mean RMS for the triceps surae was higher in FFS than in RFS and the muscle co-activation ratio was higher in RFS than in FFS during the pre-activation phase. The acute transitioning of foot strike patterns could change muscle activation mode during running.

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