EFFECTS OF RUNNING HABITS ON MORPHOLOGY AND PLANTAR FLEXION TORQUE OF MEDIAL GASTROCNEMIUS-ACHILLES TENDON UNIT

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This study aims to explore the effects of running habits on the morphology of gMTU (medial gastrocnemius-Achilles tendon unit) and plantar flexion torque, to reveal the adaptive changes of different running habits. Male habitual distance runners with forefoot strike pattern (FFS, n=10), male habitual distance runners with rearfoot strike pattern (RFS, n=10), and male non-runners (NR, n=10) were recruited. The Mindray M7 Super ultrasonography system was used to measure the morphological characteristics of the gMTU. A dynamometer was utilized to determine the plantar flexion torque. One-way ANOVA and Nonparametric Test were used for analysis. The significance level was set as 0.05. Significant differences between groups were detected on muscle fascicle length (FL) ($p < 0.05$), Normalized FL ($p < 0.05$), and pennation angle (PA) ($p < 0.01$), while no significant difference was observed in other parameters. Specifically, the FL and Normalized FL were greater in FFS than NR ($p < 0.05$), while the PA was smaller in FFS than NR ($p < 0.05$). These results suggest that long-term running with FFS pattern could induce a greater contraction velocity and a more efficient force transmitting of the medial gastrocnemius (MG).

KEYWORDS: medial gastrocnemius, foot strike pattern, long-distance running

INTRODUCTION: Running is one of the most popular sports activities around the world. In recent years, with the growing population of runners, the research focusing on running has been increased. Muscle-tendon units (MTU) play an important role in generating strength, storing, and releasing mechanical energy in walking, running, jumping, and other sports. Arampatzis et al (2006) reported that by comparing runners with the different running economies, runners with the highest running economy have the higher energy storage capacity of MTU. At the same time, Muscles morphology and strength have been linked with sports performance and injury occurrence (Timmins et al. 2015). It has been shown that the maximum shortening speed of muscle is related to the muscle fascicle length (FL) and pennation angle (PA) (Wickiewicz et al. 1984). It has also been reported that shorter FL is more prone to injury (Timmins et al. 2015). As the medial gastrocnemius-Achilles tendon unit (gMTU) is one of the most important MTU in the running propulsion phase and the calf muscle strain is one of the common running-related injuries, the morphology of gMTU and the strength of plantar flexor is worth being studied.

As the repetitive load of the lower extremity muscular system during running, the morphology of the gMTU and the strength of plantar flexor might adaptively change inferring by the adaptive changes of morphology of medial gastrocnemius (MG) after 12-week marathon training. Meanwhile, foot strike pattern is a heated discussion topic in recent years. Previous research reported that the kinematics and kinetics of the lower extremity were significantly different between the forefoot and rearfoot runners (Ahn et al. 2014). Muscles morphological and mechanical adaptive changes caused by running foot strike patterns deserve to be studied to better understand how running habits can affect performance and injury risks. Therefore, the purpose of this study was to explore the effects of different running habits on gMTU morphology and plantar flexion torque of the ankle.

METHODS: Ten male habitual distance runners with forefoot strike pattern (FFS), ten male habitual distance runners with rearfoot strike pattern (RFS), and ten male non-runners (NR) were recruited (Table 1).

Table 1. Basic information of participants.

Group	Age (years)	Height (cm)	Weight (kg)	Weekly running volume (km)	Running years
FFS (n=10)	27.50±8.68	175.75±7.69	69.01±6.96	39.50±18.92	5.40±3.47
RFS (n=10)	30.10±5.07	173.00±5.16	69.59±10.11	34.60±13.72	4.00±1.70
NR (n=10)	25.40±1.78	175.00±4.74	68.01±6.48	/	/
p	0.147	0.675	0.910	0.516	0.272

FFS: forefoot strike pattern; RFS: rearfoot strike pattern; NR: non-runners

The shank length was measured from the medial tibial condyle to the medial malleolus of the ankle while the subject was seated with the hip and knee flexed at 90° (0° = fully extended), and the ankle at 90° (the ankle should be perpendicular to the shank). A B-mode ultrasonography system (M7 Super, Mindray, Shenzhen, Guangdong, China) with a linear array probe was used to determine FL, PA, and muscle thickness (MT) of MG and cross-sectional area (CSA), rest length (L_{AT}) of the Achilles tendon (AT). gMTU morphology was determined through measurements conducted while the subject was lying prone on the treatment bed with the hip fully extended (0°), the knee fully extended (0°), and the ankle at 90°.

The ultrasound (US) images of MG were obtained with the subject at rest. The US probe was positioned longitudinally to the muscle fibers and perpendicular to the skin at 30% (MG) of the distance between the popliteal crease and the lateral malleolus. The starting and ending points of AT were determined by the ultrasonic probe enable to measure the length of AT. AT's CSA was measured at the horizontal position of the medial and lateral malleolus on the AT. Three US images of MG and CSA were recorded for each participant.

A dynamometer (Con-Trex Mj, Schnaittach, Germany) was utilized to determine the plantar flexion torque during maximal voluntary isometric contraction (MVIC). The participants were asked to lay prone on the dynamometer with their ankle in the neutral position, knee fully extended, thigh fixed. They were instructed to perform an MVIC. Each test was conducted for 5 s and repeated thrice.

Ultrasonography images were analyzed by Image J software (NIH, Bethesda, MD, USA). The best fascicle in each image was used for FL and PA analysis. FL was considered as the length of the fascicular path between superficial and deep aponeuroses. When the ends of the fascicles were outside the ultrasound image, FL was estimated as recommended in previous studies. PA was calculated as the angle between the muscle fascicle and the deep aponeuroses. MT was defined as the distance between the deep and superficial aponeuroses and was calculated through the mean value of 5 parallel lines drawn at right angles between the superficial and deep aponeuroses along with each ultrasonography image. Normalized FL and L_{AT} were divided by the shank length. The CSA of the AT was also measured using ImageJ software. The peak plantar flexion torque (T_{MAX}) of the ankle was directly collected from the dynamometer and then normalized to body weight (dividing by the bodyweight).

SPSS v26 (IBM Statistics, Chicago, USA) was used to perform statistical analyses. The Shapiro-Wilk test was used to test the normality of data results, in which one-way ANOVA was used for Variables following the normal distribution, otherwise, Nonparametric Tests (Kruskal-Wallis test) were used. The significance level was set to 0.05. η^2 was used to quantify the size of the effect.

RESULTS: Significant differences between groups were detected on FL ($p < 0.05$), Normalized FL ($p < 0.05$), and PA ($p < 0.01$), while no significant difference was observed in other parameters (Table 2). The FL (Figure 1a) and Normalized FL (Figure 1b) were greater in FFS than NR ($p < 0.05$), while the PA (Figure 1c) was smaller in FFS than NR ($p < 0.05$).

Table 2: Morphological differences of gMTU under different running habits.

Variable	FFS (n=10)	RFS (n=10)	NR (n=10)	*p-value*	η^2
L_{AT} (cm)	20.43±2.27	20.23±1.73	21.57±2.41	0.413	0.063
shank length (cm)	33.72±2.44	34.08±2.05	34.88±1.99	0.641	0.032
Normalized L_{AT}	0.61±0.05	0.60±0.07	0.62±0.07	0.726	0.023
Normalized FL	0.36±0.48	0.18±0.03	0.16±0.01*	0.015	0.237
T_{MAX} (Nm·kg^{-1})	1.56±.039	1.35±0.30	1.41±0.34	0.345	0.076
MT (mm)	16.82±1.49	17.28±2.43	18.88±1.90	0.065	0.183
FL (mm)	67.26±12.74	62.52±7.64	55.92±2.04*	0.029	0.187
PA (°)	16.22±1.94	18.92±2.83	19.25±2.40*	0.008	0.280
CSA (mm^2)	55.82±11.52	56.13±8.29	51.95±6.95	0.387	0.068

Note: *Indicates a significant difference between FFS and NR ($p < 0.05$)
FFS: forefoot strike pattern; RFS: rearfoot strike pattern; NR: non-runners

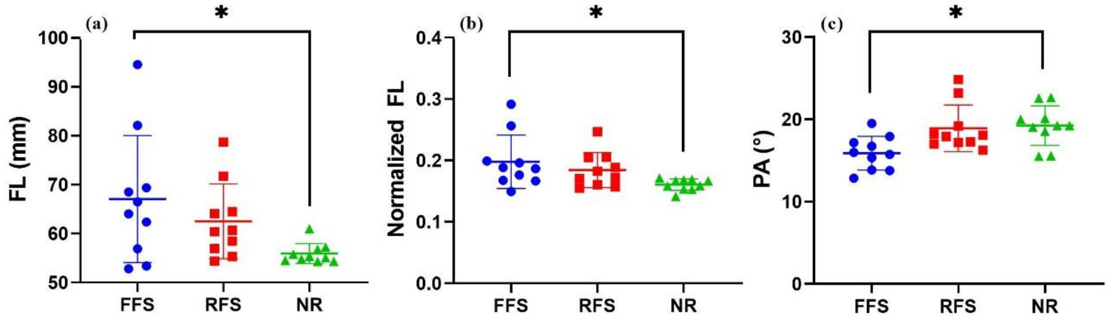

Figure 1: Effects of running habits on the FL (a), Normalized FL (b), PA (c) of MG.
Note: *Indicates $p < 0.05$.
FFS: forefoot strike pattern; RFS: rearfoot strike pattern; NR: non-runners

DISCUSSION: The purpose of the study was to explore the effects of running habits on gMTU morphology and plantar flexion torque. The results showed there were significant differences between groups on FL ($p < 0.05$), Normalized FL ($p < 0.05$), and PA ($p < 0.01$), while no other significant difference was observed. Specifically, the FL and Normalized FL were greater in FFS than NR ($p < 0.05$), while the PA was smaller in FFS than NR ($p < 0.05$).
The results of thduced working range as a result of fewer sarcomeres in series. This may increase the amount of work being completed on the descending limb of theis study showed that the FL of FFS is longer than NR. We speculated that the longer FL of FFS was caused by the eccentric stimulation of the plantar flexor muscle during running. The plantar flexor muscle of the ankle contracts eccentrically in the early stance phase and then contracts concentrically in the propulsion stage. This is consistent with the research on the increase of FL caused by long-term eccentric training (Kudo et al. 2020). In addition, shorter FL will have a re force-length relationship. Shorter FL may result in an increased potential for muscle damage. So we hypothesized that long-term running with forefoot strike might reduce the incidence of muscle injury.
This study found that compared with NR, FFS has smaller pennation angles. Kawakami (2005) reported the smaller PA, the more conducive to the transmission of contractile force to the tendon. This means that within a certain range, A smaller PA indicated greater force transmitted to the tendon. Therefore, we speculated that FFS had higher efficiency of transmitting force and less energy loss in the propulsion stage. Thus, FFS might have a higher running economy. In the comparison of MT, there is no significant difference between FFS, RFS, and NR, which is similar to previous studies on long-distance runners (Abe et al. 2000). The above indicated that the long-distance running habit did not lead to an increase in muscle thickness. Long-distance runners tend to have slender limbs, especially in the lower limbs, which to some extent supported the result of our study.
The results of this study showed that there was no significant difference in CSA of the Achilles tendon among the three groups, which was similar to the previous study, Hansen et

al. (2003) conducted running training for ordinary people, but there was no significant difference in the CSA of the AT after long-term training. Since the blood vessels in AT are less, the blood supply capacity is poor, and its metabolism rate is slower, the remodeling of AT was speculated to require a longer time and a greater load to adapt.
In this study, there was no difference in morphological and mechanical characteristics between FFS and RFS, which was similar to previous studies. Gonzales et al. (2019) compared the morphology of lower limb muscles between FFS and RFS long-distance runners and found no significant difference in FL and PA of the MG. In addition, although Gonzales et al found that FFS had a higher plantar flexor torque than RFS, the weekly running volume of FFS was significantly higher than RFS, thus, the results might be affected by the running volume.

CONCLUSION: In this study, the effects of running habits on gMTU morphology and plantar flexion torque were explored. The results showed that the FL of MG in FFS was significantly longer than NR, and the PA was smaller than NR while no other significant difference was observed between RFS and other groups. The above suggested that long-term running with forefoot strike pattern led to longer FL and smaller PA of the MG. Therefore, we speculated that long-term running with forefoot strike pattern, the injury rates of Lower limb muscle could be reduced, the speed of muscle contraction and the efficiency of transmitting force could be higher, which provided the possibility to improve the running economy to some extent.

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ACKNOWLEDGEMENTS: This research was funded by the National Key Technology Research and Development Program of the Ministry of Science and Technology of China (2019YFF0302100), the National Natural Science Foundation of China (11772201), the “Outstanding Young Scholar” Program of Shanghai Municipal, and the “Dawn” Program of Shanghai Education Commission, China (19SG47).