©Journal of Sports Science and Medicine (2023) **22,** 582-590
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.582

Research article

Mechanics of The Medial Gastrocnemius–Tendon Unit in Behaving more Efficiently in Habitual Non-Rearfoot Strikers than in Rearfoot Strikers during Running

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Abstract
This study aims to quantify how habitual foot strike patterns would affect ankle kinetics and the behavior and mechanics of the medial gastrocnemius–tendon unit (MTU) during running. A total of 14 runners with non-rearfoot strike patterns (NRFS) and 15 runners with rearfoot strike patterns (RFS) ran on an instrumented treadmill at a speed of 9 km/h. An ultrasound system and a motion capture system were synchronously triggered to collect the ultrasound images of the medial gastrocnemius (MG) and marker positions along with ground reaction forces (GRF) during running. Ankle kinetics (moment and power) and MG/MTU behavior and mechanical properties (MG shortening length, velocity, force, power, MTU shortening/lengthening length, velocity, and power) were calculated. Independent *t*-tests were performed to compare the two groups of runners. Pearson correlation was conducted to detect the relationship between foot strike angle and the MTU behavior and mechanics. Compared with RFS runners, NRFS runners had 1) lower foot strike angles and greater peak ankle moments; 2) lower shortening/change length and contraction velocity and greater MG peak force; 3) greater MTU lengthening, MTU shortening length and MTU lengthening velocity and power; 4) the foot strike angle was positively related to the change of fascicle length, fascicle contraction length, and MTU shortening length during the stance phase. The foot strike angle was negatively related to the MG force and MTU lengthening power. The MG in NRFS runners appears to contract with greater force in relatively isometric behavior and at a slower shortening velocity. Moreover, the lengthening length, the lengthening velocity of MTU, and the MG force were greater in habitual NRFS runners, leading to a stronger stretch reflex response potentially.

Key words: Foot strike pattern, medial gastrocnemius, muscle contraction, ultrasound.

Introduction

The popularity of running has increased sharply by about 57% globally in the last decade(Kakouris et al., 2021). In 2021, running was the biggest fitness trend, and 28.76% of runners began running during the pandemic (Rizzo, 2021). During running, the triceps surae plays an important role in propulsion, and its energy consumption accounts for 22% - 32% of total energy consumption (Swinnen et al., 2019a). Meanwhile, the Achilles tendon contributes up to 35% of the total energy storage and return during running (Ker et al., 1987). Furthermore, the triceps surae-tendon unit behavior and mechanics could influence muscle force generation, power output, and metabolic energy cost during running, i.e., the fascicle contraction velocity was shown to be inversely proportional to muscle force (Seow, 2013), and positively related to energy consumption (Bohm et al., 2019). Thus, foot strike patterns that could alter the behavior and mechanics of muscle-tendon units during running are favorable to running performance.

The non-rearfoot strike pattern (NRFS, forefoot, and midfoot strike pattern), which is widely used by elite long-distance runners (Hanley et al., 2019; Preece et al., 2019), has been recommended to improve the running economy. This was not only because an anterior shift in initial ground contact, associated with a forefoot strike, has been linked to faster running speed (Breine et al., 2014), but also because employing NRFS could allow for greater storage and release of elastic energy from the triceps surae-tendon unit (Preece et al., 2019). In the past 10 years, the kinetic and kinematic differences between NRFS and rearfoot strike patterns (RFS) have been extensively studied. Running with NRFS has a lower peak knee extension moment and greater peak plantarflexion moment and the angle at striking (Almeida et al., 2015; Liebl et al., 2014). Changes in kinematics and kinetics of knee and ankle joints will alter the underlying muscle-tendon unit in terms of activation level, force demand, morphology, and mechanics during running.

Previous studies preliminarily found that the peak medial gastrocnemius (MG) force was greater (Yong et al., 2020), the activation time of the MG was earlier and longer during the stance phase (Ahn et al., 2014; Yong et al., 2014) and the axial transmission velocity of the Achilles tendon (potentially representing the elastic modulus) was greater during running in habitual NRFS runners than in RFS runners (Wearing et al., 2019). Runners who run habitually with larger heel strike angles (the absolute foot segment angle relative to the laboratory coordinate system) had smaller MG cross-sectional areas (Gonzales et al., 2019). This finding indicated that the muscle-tendon unit might respond differently to different foot strike patterns. However, limited information is available regarding the behavior and mechanics of the medial gastrocnemius–tendon unit (MTU, commonly studied as a representation of the triceps surae-tendon unit (Fukunaga et al., 1992). Based on computer simulation and musculoskeletal modelling, studies (Bonacci et al., 2022; Yong et al., 2020) revealed that forefoot striking or barefoot running increased the

Received: 27 March 2023 / Accepted: 28 August 2023 / Published (online): 01 September 2023

MTU work and power. However, the simulation and modelling might not completely reflect the real movement of muscles in vivo. The combination of dynamic ultrasound imaging and traditional biomechanical measurements has been used to study the link between running kinetics and the behavior and mechanics of the muscle-tendon unit in vivo experiments. This method could provide further information on muscle force production cost and propulsion efficiency during running at the muscle level (Bohm et al., 2019; Fletcher and MacIntosh, 2017).

This study aimed to quantify the potential differences in the ground reaction forces (GRF), ankle kinetics, and MTU behavior and mechanics between runners with NRFS and RFS. Based on the greater plantarflexion and greater knee flexion angle at touchdown in NRFS runners (Almeida et al., 2015), we hypothesized that compared with habitual RFS runners, NRFS runners had 1) greater peak ankle moment and power; 2) lower fascicle length at striking, shortening/change length and contraction velocity and greater peak MG force; 3) greater MTU lengthening and MTU shortening length and power; 3) foot strike pattern related to the MTU behavior and mechanics.

Methods

Participants

The sample size was calculated in G*power (Version 3.1.9.6, Kiel University, Kiel, Germany). Cohen's *d* was calculated by the MG fascicle contraction length between the forefoot and rearfoot striker reported by Swinnen et al. (2019b) which compared the kinematics of MG in two different foot strike patterns and speeds. A priori power analysis was conducted in G*power (Version 3.1.9.6, Kiel University, Kiel, Germany). The sample size was 11 in each group for the independent *t*-test ($\alpha = 0.05$, $1-\beta = 0.8$, Cohen's $d = 1.256$).

Fifteen male participants were recruited for each group. One participant in NRFS was excluded because of the unclear ultrasound image of MG. Thus, the RFS group had 15 runners (age: 34 ± 10.23 yrs; height: 175.15 ± 5.14 cm; mass: 67.32 ± 9.74 kg; weekly running distance: 40.30 ± 19.68 km) and the NRFS group had 14 runners (age: 32.27 ± 8.45 yrs; height: 172.71 ± 4.29 cm; mass: 69.96 ± 8.86 kg; Weekly running distance: 42.53 ± 20.91 km). The inclusion criteria were as follows: 1) weekly running distance in the last three months of ≥ 20 km; 2) never suffering from neurological disease and pain and injury in triceps surae and Achilles tendon; 3) having no lower limb injuries in the last 3 months; and 3) having kept the habitual foot strike pattern for at least 1 year. The habitual running speed of participants generally ranged from 9 - 15 km/h depending on the running distance, with a predominant concentration around 12 km/h. All participants signed an informed consent form approved by the ethics committee of of Shanghai University of Sport (No. 102772021RT085).

Procedure

Initially, the length of the MG fascicles (the path between the superficial and deep aponeuroses) and the length of the shank (from the medial tibial condyle to the medial malleolus of the ankle) were measured. These measurements of fascicle length and shank length were taken with the participants in a prone position with their ankles in a neutral position and the sitting position with the ankle in the neutral position and the hip and knee flexed at 90° respectively (Deng et al., 2021).

All participants were asked to wear traditional running shoes that were identified and provided by the experimenter for standardization (heel-toe drop: 10 mm, midsole cushioning material: EVA foam, with both air cushions in the forefoot and heel area). The subjects conducted a 5-minute warm-up run on a treadmill with the habitual foot strike pattern. Running video was obtained by mobile phones in slow motion mode to preliminary ensure the self-reported habitual foot strike patterns.

A total of 36 reflective markers were attached to the lower extremities of the participants (Figure 1). The probe (12L5A, frequency: 12 MHz) was fixed to the MG belly of the dominant leg by using a self-made foam model and bandages (Figure 1). The exact location of the probe was at 30% of the distance between the popliteal crease and the malleolus (Monte et al., 2020) and adjustment was made according to the degree of parallelism between superficial and deeper aponeurosis. Since the MG is more easily imaged by ultrasound in vivo and could be accurately measured than other muscles of the triceps surae, it was chosen in the current study to compare with previous studies (Cigoja et al., 2021).

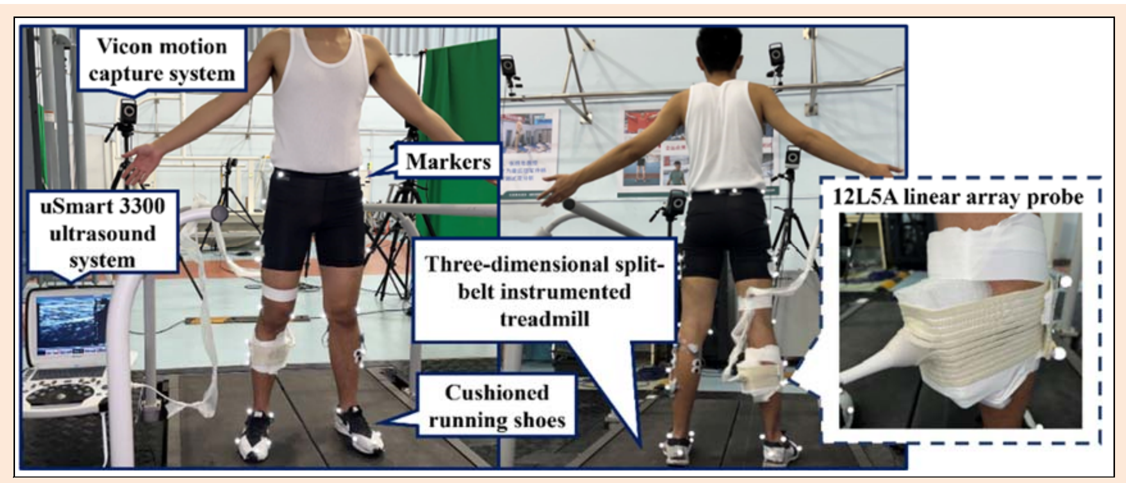

Figure 1. Experimental setup and probe placement.

The static model was captured after the subjects were acclimatised to the split-belt instrumented treadmill (Bertec, United States, length: 175 cm × width: 50 cm, sampling frequency: 1000 Hz). A formal running test was then conducted. The participants were asked to run with their habitual foot strike pattern at a speed of 9 km/h on the instrumented treadmill (Bohm et al., 2021). The GRF, trajectories of reflective markers, and MG ultrasonic images were collected synchronously for 10 s at the end of 5 minutes of each running trial when the speed of the treadmill and foot strike pattern was stabilized determined by observation with high-speed videos (Cigoja et al., 2021).

Synchronization was achieved by triggering the external foot switch connecting the ultrasound (United States, uSmart 3300, sampling rate: 22Hz) and Vicon motion capture system (Vicon, United Kingdom, sampling frequency: 200Hz). The ultrasound method is a relatively mature technology, whose reliability and validity have been proven and reported by a previous study (Monte et al., 2020). Meantime, a reliability test was conducted in the pilot experiment using the intraclass correlation coefficient (ICC) of multiple measurements taken by the same experimenter. The results showed good reliability of the MG behavior measurements collected and calculated using ultrasound during running (ICC = 0.834 - 0.958).

Data processing

The static fascicle length was acquired from the ultrasonic images by Image J software (version 1.46r, NIH, USA). The reflective markers' coordinates were filtered by a Butterworth fourth-order, low-pass filter at a 7 Hz cut-off frequency, and GRF data were filtered at a cut-off frequency of 50 Hz (Zhang et al., 2021). The ankle joint moment was calculated via inverse dynamic with V3D software (C-Motion, Inc., United States, version: v5). The five steps at initial collection were used for analysis. All data were extracted for the dominant limb.

Foot strike angle

The foot strike angle, the angle between the ground and the line connecting the markers of the first metatarsophalangeal joint and the heel, was used to define the foot strike pattern (RFS: angle > 8°; NRFS: angle < 8°) (Altman and Davis, 2012).

GRF

The vertical GRF included the peak impact force (only occurred when running with RFS) and the 2nd peak GRF (occurred when running with RFS and NRFS). The GRF was used to determine the foot striking (GRF > 30 N) and the toe-off moment (the previous frame of GRF less than 30 N after striking)(Swinnen et al., 2022). The stance phase (period from touchdown to toe-off) was divided into the early stance phase, middle stance phase, propulsion period, and late stance phase (0% - 20%, 20% - 55%, and 55% - 85%, 85% - 100% of the stance phase, respectively) (Welte et al., 2021). GRF was normalized by body weight.

Behavior of MG and MTU

The ultratrack (version: 4.1, measurement precision: 0.001 m) was used to track the ultrasound video collected during running to obtain the muscle fascicle length during running (Farris and Lichtwark, 2016). The fascicle length was defined as the fascicular path between superficial and deep aponeuroses. If a muscle fascicle could not be completely captured in the images, then an extension line was made manually according to the superficial/deep aponeuroses and the fascicle to determine the missing part(Franchi et al., 2018) (Figure 2). The muscle fascicle lengths of the touchdown and toe-off frames were the fascicle lengths at the initial contact and toe-off moment determined by GRF (Figure 2).

The changing amount of muscle fascicle length during the stance phase was determined by calculating the difference between the muscle fascicle length at the initial contact and toe-off moment (Figure 2, L_{strike}-$L_{toe\text{-}off}$). Meanwhile, the fascicle shortening length was measured as the difference between the maximum and minimum muscle fascicle length during the stance phase. Both were normalized by the static muscle fascicle length(Monte et al., 2020). Additionally, to further examine muscle behavior during different phases of the stance, the changing amount of muscle fascicle length in the early, middle stance phases, propulsion phase, as well as the late stance phase, was calculated. Specifically, the changing amount of muscle fascicle length of different periods was the difference in muscle fascicle length between the start and end frames of the corresponding phase was calculated (Figure 2, L_{strike}-$L_{e\text{-}m}$, $L_{e\text{-}m}$-$L_{m\text{-}t}$, $L_{m\text{-}t}$-L_p, L_p-L_l).

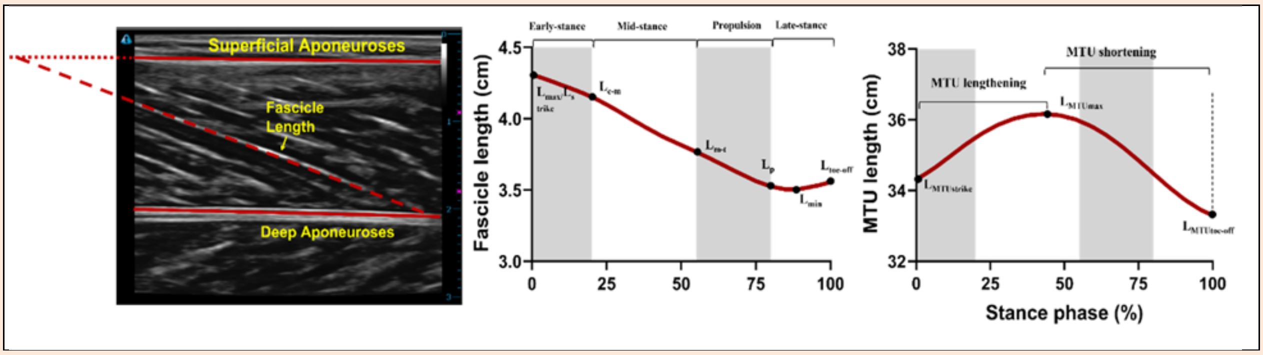

Figure 2. Ultrasound image of the medial gastrocnemius and calculation of the medial gastrocnemius (MG) and the medial gastrocnemius–tendon unit (MTU) behavior. L_{strike}, $L_{e\text{-}m}$, $L_{m\text{-}t}$, L_p, and $L_{toe\text{-}off}$ are the fascicle length of touchdown, the end of the early stance phase and the start of the mid-stance phase, the end of the mid-stance phase and start of propulsion phase, the end of propulsion phase and toe-off moment. L_{max} and L_{min} are the maximum and minimum fascicle lengths. $L_{MTUstrike}$, $L_{MTUtoe\text{-}off}$, and L_{MTUmax} are the length at touchdown, toe-off, and the maximum length of the medial gastrocnemius-tendon unit (MTU).

The MTU length during running was calculated according to the regression equation of Hawkins and Hull (1990) The MTU of touchdown and the toe-off moment and the maximum MTU length in the stance phase during running were taken for analysis (Figure 2). The calculation formula was:

$$L = C0 + C1\alpha + C2\beta + C3\beta^2 + C4\varphi$$

where L is the MTU length; $C0$ to $C4$ are regression coefficients; α, β, and Φ are the angles of the hip, knee, and ankle joint of the sagittal plane, respectively; and the shank length was used to multiply with MTU length to have a somewhat subject-specific MTU length.

The contraction length of MTU was the difference between the MTU length of the toe-off moment and its maximum length (Figure 2, L_{MTUmax}-$L_{\text{MTUtoe-off}}$). The stretching length was the difference between the MTU length of the touchdown moment and its maximum length (Figure 2, L_{MTUmax}-$L_{\text{MTUstrike}}$) (Monte et al., 2020).

The average muscle fascicle shortening velocity in the stance phase during running was calculated by dividing the change amount of muscle fascicle length by the time of the stance phase (Figure 2). During running, the instantaneous contraction velocity of the muscle fascicle in the stance phase was derived from the fascicle length in the stance phase. After the derivation, the peak value was the peak shortening velocity of the muscle fascicle (Monte et al., 2020).

The peak shortening velocity of MTU was the maximum value of the first derivative of MTU length in the stance phase. The peak lengthening was the minimum value of the first derivative of the MTU length in the stance phase.

MG force formula was:

$$F_{\text{MG}} = k \cdot (M / L_{\text{AT}})$$

where k = 0.16, representing the ratio of MG to the cross-sectional area of triceps surae (Kubo et al., 2022); M is the plantar flexion moment during running; and L_{AT} is the Achilles tendon arm obtained based on the polynomial algorithm of Lyght et al. (2016) to calculate the muscle-tendon moment arm of triceps surae and the Achilles tendon images as follows (Rugg et al., 1990):

$$Y = -0.00591+0.0475X-0.00855X^2$$

where Y is the muscle-tendon moment arm of the triceps surae, and X is the ankle angle (rad).

Muscle power was calculated by equation (Swinnen et al., 2019b):

$$P_{\text{MG}} = F_{\text{MG}} \times V_{\text{MG}}$$

where P_{MG} is the MG power, F_{MG} is the sequence data of MG force during the stance phase and V_{MG} is its corresponding muscle fascicle shortening velocity. The peak value of the stance phase was taken.

MTU shortening and lengthening power were calculated by the following equations (Swinnen et al., 2019b):

$$P_{\text{MTU-shortening}} = F_{\text{MG}} \times V_{\text{MTU-shortening}}$$

$$P_{\text{MTU-lengthening}} = F_{\text{MG}} \times V_{\text{MTU- lengthening}}$$

where $P_{\text{MTU-shortening}}$ and $P_{\text{MTU-lengthening}}$ are MTU shortening and lengthening power, respectively; F_{MG} is the sequence data of MG force during the stance phase; $V_{\text{MTU-shortening}}$ and $V_{\text{MTU- lengthening}}$ are the corresponding muscle fascicle shortening and lengthening velocity; F_{MG} is the sequence data of MG force during the stance phase.

Statistical analysis

All results were presented as M±SD. Shapiro–Wilk test was used to evaluate the normality of the data distribution. If the data were distributed normally, then an independent *t*-test was used to quantify significant differences in the foot strike angle, ankle kinetics, GRF, MG, and MTU behavior and mechanics under different foot strike patterns. If the data were not distributed normally, then the non-parametric Mann-Whitney U test was used. Cohen's d was calculated for each parameter. Pearson correlation was conducted to detect the relationship between foot strike angle and the MTU behavior and mechanics. A Bonferroni correction was conducted to avoid type I errors for the independent *t*-test and Pearson correlation and adjust the significance level to 0.002. The correlation coefficient ranges from 0 to 1, where a coefficient of 0 to 0.4 indicates a weak correlation, 0.4 to 0.7 indicates a moderate correlation and 0.7 to 1.0 indicates a strong correlation (Schober et al., 2018).

Results

Foot strike angle

The foot strike angles of NRFS and RFS runners all met the criteria for defining foot strike patterns. A significant difference was found in the foot strike angle between RFS and NRFS (Figure 3a).

GRF and ankle kinetics

No significant differences were observed in the 2nd peak GRF and ankle power between habitual NRF and RFS runners (Figure 3b). The peak ankle moments were significantly greater in NRFS than in RFS runners (Figure 3c).

Behavior and mechanics of MG

Except for the fascicle length at touchdown and toe-off, as well as the maximum and minimum fascicle length, peak MG power, and force, all other variables related to the behavior and mechanics of the MG muscle followed a normal distribution. The (standardised) change of fascicle length, the (standardised) fascicle shortening length during the stance phase in habitual NRFS runners were significantly shorter and lower than those in habitual RFS runners ($p < 0.001$, Cohen's $d = 1.80$; $p < 0.001$, Cohen's $d = 2.80$; $p < 0.001$, Cohen's $d = 2.12$; $p < 0.001$, Cohen's $d = 2.17$, Figure 4 and Figure 5e-h). The Pearson correlation analysis showed that the foot strike angle was positively related to the change of fascicle length ($R^2 = 0.678$, $p < 0.001$), and fascicle contraction length during the stance phase ($R^2 = 0.775$, $p < 0.001$). The foot strike angle was negatively related to the MG force ($R^2 = -0.552$, $p = 0.002$) (Figure 6).

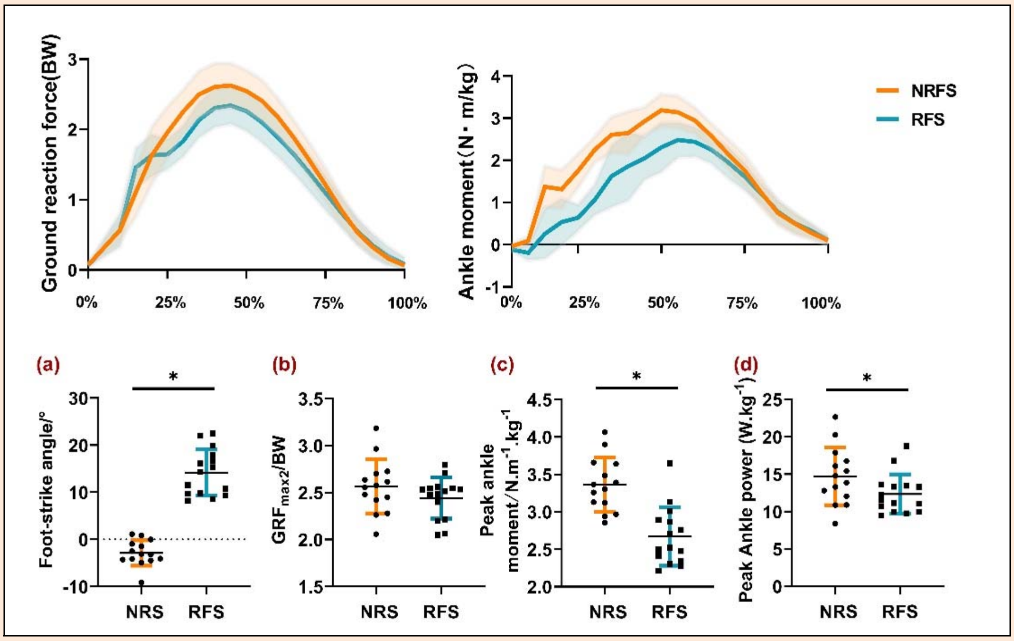

Figure 3. Effect of habitual foot strike patterns on foot strike angles and the 2nd peak GRF and ankle kinetics.
GRF: ground reaction force, NRFS: non-rearfoot striker, RFS: rearfoot striker, * indicates significant differences.

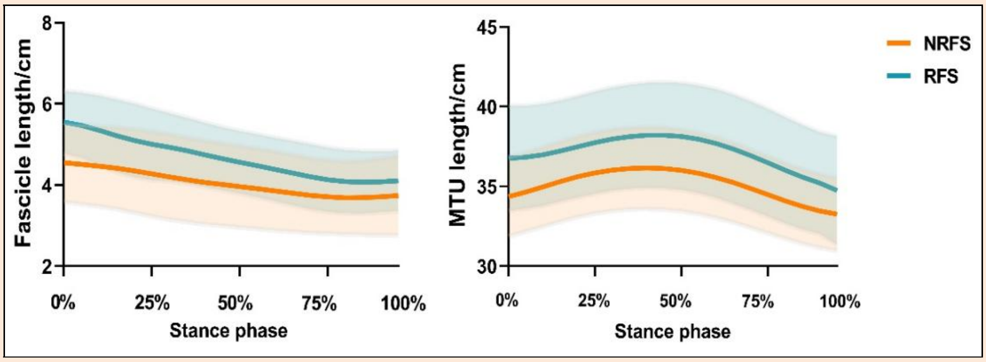

Figure 4. Curve of the medial gastrocnemius fascicle length and the muscle tendon–unit (MTU) length habitual non rearfoot strike pattern (NRFS) and rearfoot strike pattern (RFS) during the stance phase.

The peak and average fascicle shortening velocities of habitual NRFS runners were significantly lower than those of habitual RFS runners (p = 0.001, Cohen's d = 1.38; p < 0.001, Cohen's d = 1.59, Figure 5i, j). The peak MG force was significantly greater during the stance phase in habitual NRFS runners than in habitual RFS runners (p < 0.001, Cohen's d = 1.38; Figure 5k). However, no significant difference was found in fascicle length at touchdown and toe-off moment, minimum fascicle length, change in fascicle length in early stance, middle stance, propulsion, and late stance phase, and MG power between habitual NRFS and RFS runners.

Behavior of MTU

For the behavior of MTU, MTU shortening/lengthening length and velocity, peak MTU lengthening power did not follow a normal distribution. The MTU lengthening length, peak velocity, and power of habitual NRFS runners were significantly greater than that of habitual RFS runners (p = 0.001, Cohen's d = 1.38; p < 0.001, Cohen's d = 1.24, p < 0.001, Cohen's d = 1.91, Figure 7a, d, f). The MTU shortening length was significantly greater in habitual NRFS runners than in habitual RFS runners (p < 0.001, Cohen's d = 1.79, Figure 7b). However, no significant difference was found in MTU length at toe-off, the peak shortening velocity, and power between habitual NRFS and RFS runners. The Pearson correlation analysis showed that the foot strike angle was positively related to the MTU shortening length (R^2 = 0.730, p < 0.001). The foot strike angle was negatively related to MTU lengthening power (R^2 = -0.801, p < 0.001) (Figure 7).

Discussion

This study aimed to quantify the differences in the GRF, ankle kinetics and MG/MTU behavior, and mechanics during running between habitual NRFS and RFS runners based on dynamic ultrasound imaging and motion analyses to understand force production cost and propulsion efficiency difference during running. Most hypotheses were supported, except for the observed absence of differences in MG power, MTU shortening power between habitual NRFS and RFS runners.

Normalized MG contraction length, peak/average shortening velocity during the stance phase were found to be smaller in habitual NRFS runners in this study. Likewise, Swinnen et al. (2019b) reported that MG fascicle contraction length and average contraction velocity were greater in RFS runners than in NRFS runners. We also found the foot strike angle was positively related to the change of fascicle length and fascicle contraction length during the stance phase. From the perspective of running efficiency, the MG contraction length and shortening velocity were positively related to energy consumption and negatively related to running economy with increasing ATP turnover (Bohm et al., 2019; Cigoja et al., 2022). Even without changing the foot strike pattern, rearfoot strikers who land with a flatter foot, or in other words, reduce the foot strike angle, may experience a reduction in the energy consumption caused by MG contractions to some extent. Moreover, the Hill equation reports that the muscle shortening velocity is inversely proportional to muscle force (Seow, 2013). In this study, it was shown that the ankle peak plantarflexion moment was greater in NRFS runners. Thus, the MG of NRFS runners was likely to contract with greater force in relatively isometric behavior and at a slower shortening velocity. This finding potentially indicated that MG contracted efficiently in NRFS runners based on the MG behavior and mechanics. However, Ahn et al. (2014) and Yong et al. (2014) reported that during FFS, although no significant difference was found during the early stance phase, pre-activation of the MG occurs earlier and at higher levels than RFS. We cannot deny that this mode might partly attribute to greater peak MG force during the stance phase in FFS/NRFS. The increase in muscle activity at the pre-activation phase has led to an elevation in energy expenditure, to some extent counteracting the part of energy saving resulting from changes in MG behavior.

Besides higher and longer pre-activation, generating greater force in NRFS runners could also be explained by the muscle force amplification function of MTU. The mechanics of MG could be governed by the compliance of the series elastic element (Bohm et al., 2019). In this study, the shortening and lengthening length and the lengthening velocity of MTU were observed to be greater in NRFS runners with lower MG contraction length and velocity, supporting the above speculation. Namely, the whole MTU of NRFS runners showed a greater ability to elongate during the stance phase compared to RFS runners. It was reported that the longest and fastest stretch meant the stretch-shortening cycle (SSC)-based mechanisms may therefore contribute more (Held et al., 2022). Meanwhile, the firing rate of spindle and Golgi tendon afferents were positively related to the MTU elongation velocity, length, and muscle force (Frigon et al., 2021). When employing an NRFS or reducing the foot strike angle, there was an increase in the MTU lengthening length and velocity, leading to a stronger stretch reflex response in NRFS potentially.

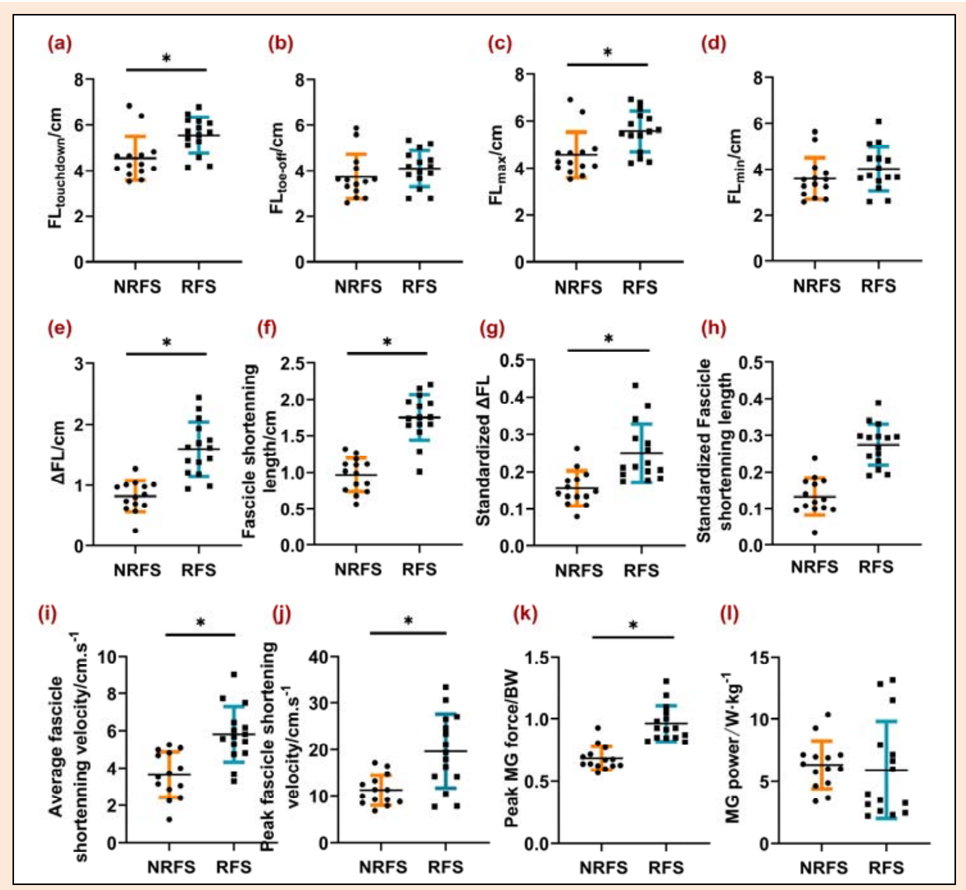

Figure 5. Effect of habitual foot strike patterns on the behavior of the medial gastrocnemius (MG) of the stance phase. FL: fascicle length, NRFS: non-rearfoot striker, RFS: rearfoot striker, * indicates significant differences.

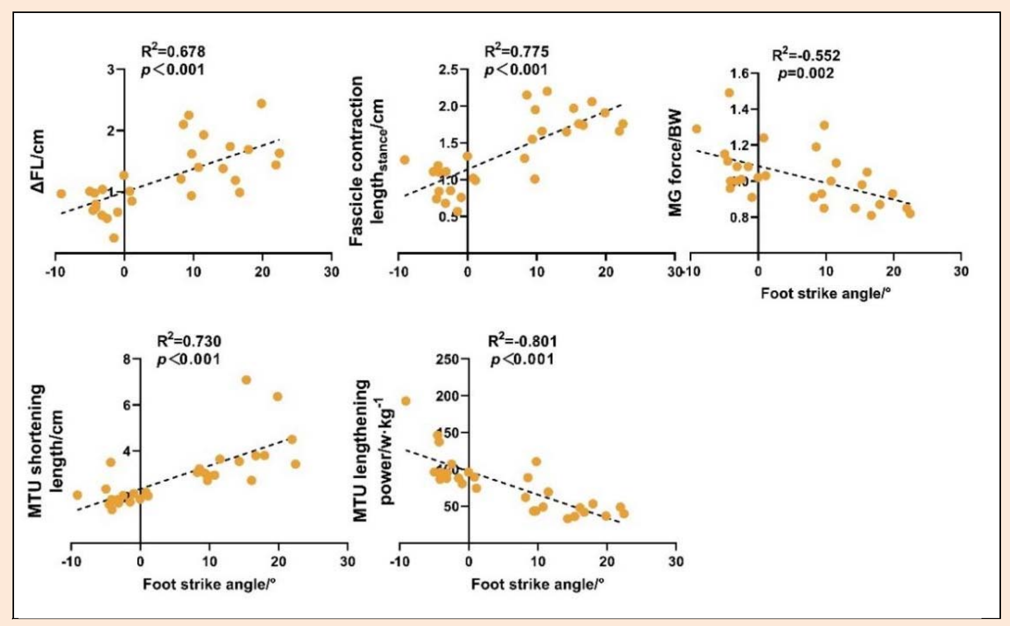

Figure 6. Correlations of foot strike angle with the mechanics and behavior of MTU.

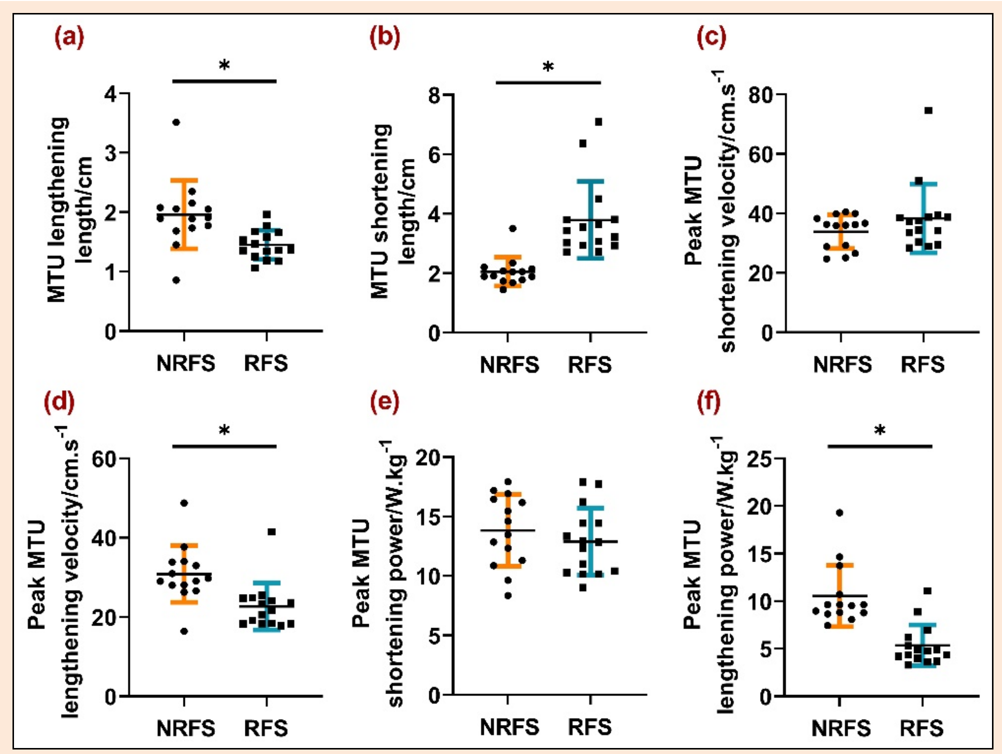

Figure 7. Effect of habitual foot strike patterns on the behavior of the medial gastrocnemius–tendon unit (MTU) of the stance phase. NRFS: non-rearfoot striker, RFS: non-rearfoot striker, * indicates significant difference.

This study has several limitations. First, the running economy was not assessed in the current study, and only inferences were made regarding how MG behavior might affect the running economy. Second, runners may not habitually run with an RFS or NRFS pattern outside lab environments. Third, only one moderate speed was used in this study, future studies could investigate the differences between habitual RFS and NRFS runners at different speeds or self-selected speeds. Finally, the use of an ultrasound probe sampled at 22 Hz might cause us to miss some changes in the fascicle during running. However, the findings regarding fascicle lengths and velocities in our study were consistent with previous research (Swinnen et al., 2022), suggesting that the results would hold validity despite the low sampling rate.

Conclusion

This study demonstrated that when running with NRFS, the MG appears to contract with the MG producing greater force in relatively isometric behavior and at a slower shortening velocity. Moreover, the lengthening length, the lengthening velocity of MTU, and the MG force were greater in habitual NRFS runners, leading to a stronger stretch reflex response potentially.

Acknowledgements

This study was funded by the National Natural Science Foundation of China (12272238;11772201), the National Key Technology Research and Development Program of the Ministry of Science and Technology of China (2019YFF0302100), the "Outstanding Young Scholar" Program of Shanghai Municipal, and the "Dawn" Program of Shanghai Education Commission (19SG47). The experiments comply with the current laws of the country where they were performed. The authors have no conflict of interest to declare. The raw data supporting the conclusions of this article will be made available by the authors upon justified request.

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Key points

- The medial gastrocnemius of habitual non-rearfoot strike pattern runners appear to contract with the MG producing greater force in relatively isometric behavior and at a slower shortening velocity.
- The greater shortening and lengthening length and the lengthening velocity of the medial gastrocnemius-tendon unit of habitual non-rearfoot strikers could potentially lead to a stronger stretch reflex response during running.

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