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Muscle Architecture and Maximal Strength between Male Practitioners of Functional Fitness Training and Strength Training

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ABSTRACT

International Journal of Exercise Science 16(7): 1142-1153, 2023. Functional Fitness Training (FFT) is a very popular training method in recent years. However, the combination of aerobic and strength components of this training method raised the hypothesis of impaired strength and muscle structure when compared to Strength Training (ST). Thus, the study aimed to compare muscle architecture and strength between FFT and ST, and the relationship between muscle architecture and maximum strength performance. Males (28.46 ± 6.03 years), nonathletes, and practitioners for two years in FFT (n = 8) and ST (n = 8), in addition to males classified as physically active (n = 8) were recruited. Muscle architecture of the rectus femoris (RF) and vastus lateralis (VL) of the thigh were evaluated with the aid of B-mode ultrasound and maximum strength in the back squat through the one-repetition maximum test. For muscle architecture, the fascicle length (FL), pennation angle (PAn), and muscle thickness (MT) were evaluated, in addition to the cross-sectional area (CSA). The FL, PAn, MT, and CSA of the RF and VL did not differ between the FFT and ST groups. Similarly, maximum strength did not differ between the FFT (152 ± 23.68 kg) and ST (151.88 ± 14.77 kg) groups. A significant relationship was observed between the PAn of the RF and the maximum strength ($r = 0.862$; $p = 0.006$) of FFT practitioners. The muscle architecture, CSA, and muscle strength do not differ between FFT and ST male practitioners, and PAn of the RF correlates with the maximum force for FFT practitioners.

KEY WORDS: HIFT, resistance training, muscle morphology

INTRODUCTION

Functional Fitness Training (FFT) is a training method that has grown in popularity recently (11). This training method combines components of aerobic, muscle strength, gymnastics, and plyometric exercises, which are performed in a circuit or interval model and at a high intensity (2). FFT-based training programs are primarily responsible for disseminating this training method and the growing scientific research (2,10,25).

Because of different exercises combination, with many of these exercises based on aerobic or muscle strength components, the question was raised about the possibility of an interference effect with the practice of FFT (34). The interference effect is understood as a phenomenon that occurs by the combination of aerobic and strength exercises in the same training session or close sessions and is related to the attenuation of gains in strength, power, and muscular hypertrophy of the lower limbs when compared to the isolated practice of Strength Training (ST) (7,32).

Since the muscle architecture can adapt to different types of training (12), it can be hypothesized that the interference effect could influence muscle morphology. Muscle architecture is a concept applied to the organization of skeletal muscle components such as fascicle length, pennation angle, and muscle thickness, which influence the muscle size, for example, the cross-sectional area (12,19). This muscular plasticity resulting from the training practice gives its practitioner a great performance (16,20) and becomes increasingly specific with the increase in the training level (7).

It is known that ST is capable of generating specific adaptations in muscle architecture (19), and these adaptations can be negatively influenced in the presence of the interference effect (32). If FFT provides the appearance of this effect, the adaptations between these two training methods may differ, which could influence the physical performance of FFT practitioners. Given that this effect may be evident in more trained individuals (7,32), it is unknown whether there is a difference between the muscle architecture of experienced practitioners in FFT and practitioners trained only in ST.

The literature presents the study by Mangine et al. (23) who compared the muscle architecture of experienced FFT practitioners with practitioners who combined ST and Aerobic Training. However, to our knowledge, comparisons with individuals who only practice long-term ST have not yet been reported. Therefore, this study aimed to compare muscle architecture and muscle strength between FFT and ST male practitioners, in addition to evaluating the relationship of muscle architecture with the performance of maximum lower limb strength.

Faced with the possibility of the interference effect, our first hypothesis is that ST practitioners have higher mean muscle thickness and pennation angle values and lower fascicle length values than FFT practitioners. Regardless of the training method, FFT and ST practitioners perform exercises with high overloads that favour muscle hypertrophy, so our second hypothesis is that there will be no difference in cross-sectional area between FFT and ST practitioners. Recently, Pallarés et al. (31) observed that, in general, individuals who trained in full back squats performed better in the maximum strength test when compared to individuals who performed parallel squats. Therefore, our third hypothesis is that FFT practitioners present a greater load in the maximum strength test than ST practitioners.

METHODS

Participants
Volunteers who met the following inclusion criteria were selected: male, adults (> 18 years), practitioners of FFT, ST, and physically active individuals (PA) to compose the control group. Those who had injuries or physical limitations, used anabolic-androgenetic steroids, athletes, or who trained with the competition's aim were excluded.

For volunteers practicing FFT, we followed the criteria of Mangine et al. (23). Participants should have at least two years of experience with the modality and practice at least 3 weekly sessions. For the ST group, participants should have at least 2 years of weight training practice and strengthen lower leg muscles at least twice a week. In the PA group, participants should be classified as active or very active according to the international physical activity questionnaire (24) and not practice FFT or ST.

All participants considered eligible were informed about the risks and benefits of the study, and each participant provided written consent. This study was conducted in accordance with the Declaration of Helsinki, and the ethical standards of the International Journal of Exercise Science (28). All procedures were previously approved by the ethics and research committee of the Federal University of Santa Catarina (n° 51849421.6.0000.0121)

For the sample size, information on the muscle architecture of the rectus femoris and vastus lateralis from previous studies was collected (8,22,23) and the effect size was calculated. Thus, considering the test's statistical power of 80%, effect size of 0.78, and significance level of 5%, a minimum number of 21 participants was obtained.

Twenty-four males were included in the study (28.46 ± 6.03 years; 162 ± 6.73 cm): PA (n = 8), FFT (n = 8), and ST (n = 8). Regarding the physical training of the volunteers, the PA group was made up of running, cycling, and soccer practitioners, who practiced these activities for approximately 4.6 years, with a frequency of 4 times a week, with a duration of 100 minutes each session. Participants in the FFT group had 3.6 years of experience with this training method, with a frequency of 5 weekly sessions and a duration of 82.5 minutes for each session. Participants in the ST group had been practicing weight training for 4.5 years, with a frequency of 5 sessions per week, and a duration of 67.5 minutes in each training session. The characterization of the participants is presented in Table 1.

Table 1. Characterization of the participants.

Anthropometric characteristics	PA (n = 8)	FFT (n = 8)	ST (n = 8)
Age (years)	29.25 ± 8.24	27 ± 4.6	29.13 ± 6.12
Height (cm)	173 ± 7.11	173.76 ± 7.55	175.91 ± 3.76
Body mass (kg)	66.25 ± 6.95*	78.44 ± 9.6	82.50 ± 8.69
Fat percentage (%)	11.50 ± 2.45	12.48 ± 4.5	12.89 ± 4.08
Fat-free mass (kg)	58.25 ± 5.02*	68.36 ± 6.09	71.68 ± 6.19
1RM test (kg)	87 ± 6.9*	152 ± 23.68	151.88 ± 14.77

PA, physically active; FFT, Functional Fitness Training; ST, Strength Training; cm, centimeters; kg, kilograms; min, minutes. *Mean values lower than those of FFT and ST, $p < 0.05$.

Protocol

Experimental design: For this cross-sectional study, three visits were made to the Biomechanics Laboratory. All study procedures were explained on the first visit, the consent form was signed, and the entire evaluation protocol was familiarized. The following evaluations were performed on the second visit: anthropometric, ultrasound, and maximum strength. On the third day, data reproducibility was performed in the ultrasound evaluations, and maximum strength. If the participant was not feeling well during a data collection day, the collection was rescheduled. All evaluations were performed at an interval of 48 hours.

Anthropometry: Total body mass was assessed with the participant wearing appropriate clothing and in an orthostatic position on a digital scale (Filizola®, Brazil), while height was assessed using a stadiometer (Sanny®, Brazil). An experienced rater with level 2 certification from the International Society for the Advancement of Kinanthropometry (ISAK) measured the participants' skinfolds. Subscapular, triceps, suprailiac, and medial calf skinfolds were collected. With this information, the body density of the participants was calculated using the equation by Petroski and Pires Neto (33), which allowed the calculation of the percentage of fat using the Siri equation (36). Fat-free mass was calculated using the equation by Vanitallie et al. (38).

Ultrasound: Muscle morphology was acquired through B-mode ultrasound images (model LOGIQ S7 Expert, General Electric, GE Healthcare, USA), on the dominant side of the participants, defined as the leg chosen to kick a ball (26). All images were acquired by an evaluator with 700 hours of experience in image acquisition and image processing was performed by an evaluator with 312 hours of experience in image analysis.

The procedures for acquiring images for the cross-sectional area (CSA) were conducted as described by Lacerda et al. (21). This technique for assessing CSA was validated by Noorkoiv et al (29) by comparing the extended field-of-view ultrasound method with computed tomography (ICC: 0.95 - 0.99). First, the greater trochanter and the lateral epicondyle of the femur were identified and the femur length was measured, then, starting from the proximal region of the thigh, points 40, 50, 60, and 70% of the femur length were identified. Thus, the participants' anterior thigh region was marked in each of these percentages for image acquisition. After 5 minutes of rest on a stretcher (5), two images were acquired in each of the percentages in the extended view mode with a 5 cm transducer. The settings used were: frequency of 10 MHz, image capture depth of 7 cm, and gain of 60 dB. Water-based gel was applied to the transducer head to achieve acoustic coupling, and extra care was taken to avoid muscle strain. Rectus femoris and vastus lateralis CSA were manually demarcated using ImageJ public domain software (V.1.52; National Institute of Health, USA). The average of the four percentages for each muscle represented the CSA for the statistical analysis.

For muscle architecture, the same settings reported above were used. Then, the transducer was positioned longitudinally to the femur, oriented parallel to the muscle fascicles, and perpendicular to the skin (15). Two images were acquired at 50% of the femur length for the rectus femoris and vastus lateralis. Muscle thickness was determined as the distance between the muscle's deepest and most superficial aponeurosis (6). For the acquisition of muscle thickness, five measurements were taken along the image (one at each end, one central, and two intermediates), then the average between them was calculated. The fascicle length was estimated using the Fini and Komi equation (13) and understood as the length of the fascicular path between the superficial and deep aponeurosis. The pennation angle was defined as the angle between the deep aponeurosis and the fasciculus.

Maximum force: The back squat exercise was used to assess maximum strength through the one-repetition maximum test (1RM). The 1RM test protocol was performed according to Vigotsky et al. (39) and the test was performed on the Smith machine (Freestyle, Righetto) to ensure the safety of the participants. The participants were asked to perform the parallel squat and, for the reproducibility of the data, the height of the safety device of the Smith machine, as well as the positioning of the participants' feet were marked.

Before the test, a 5-minute warm-up was performed on an ergometric bicycle, followed by a specific warm-up on the Smith machine at 50% and 80% of the estimated 1RM. Then, the maximum load was determined in a maximum of 5 attempts with a 5-minute interval between them. After each successful attempt, the load was increased (or decreased in the case of an unsuccessful attempt) according to what the investigators and the participant considered feasible. The maximum load lifted was used for analysis, but the weight of the equipment bar was disregarded from the final load.

Statistical Analysis

Values are reported as mean ± standard deviation. The normal distribution of data was evaluated using the Shapiro-Wilk test. One-way ANOVA followed by post hoc Bonferroni was used to assess group differences. Effect size (ES) of comparisons was calculated and classified according to Hopkins (18): 0.0–0.2, trivial; 0.21–0.6, small; 0.61–1.2, moderate; 1.21 –2.0, large; and 2.1–4.0, very large. Pearson's correlation evaluated the relationship between the maximum load in the 1RM test and muscle architecture measurements. The magnitude of correlations was determined using the scale based on Cohen's classification (14): small ($r^2 = 0.01$), medium ($r^2 = 0.09$), and large ($r^2 = 0.25$). The adopted significance level was 5%, and the analyzes were performed in the statistical package for social sciences (IBM SPSS Statistics, USA). For data reproducibility, the Intraclass Correlation Coefficient (ICC), the typical error (TE), and the 95% confidence intervals (CI) were calculated.

RESULTS

Participants in the PA group had lower body mass ($F = 7.904$; $p = 0.003$; FFT, $p = 0.028$; ST, $p = 0.003$) and lower fat-free mass ($F = 11.155$; $p = 0.006$; FFT, $p = 0.008$; ST, $p = 0.001$) when compared to the other groups. Participants in the FFT and ST groups did not differ among themselves for any of the general characterization measures (Table 1).

An excellent correlation was observed in all evaluated variables. Fascicle length (ICC: 0.99 (0.98-0.99 CI); TE: 0.24 (0.20-0.30 CI)), pennation angle (ICC: 0.99 (0.98-0, 99 CI); TE: 0.31 (0.26-0.39 CI)), muscle thickness (ICC: 0.99 (0.98-0.99 CI); TE: 0.02 (0.02-0.03 CI)), CSA (ICC: 0.99 (0.98-0.99 CI); TE: 0.29 (0.24-0.36, CI)), and 1RM test (ICC: 0.99 (0.98-0.99 CI); TE: 0.96 (0.75-1.35 CI)).

All muscle architecture information is presented in Figure 1. A significant interaction was observed for the rectus femoris's fascicle length ($F = 3.737$; $p = 0.041$). Participants of the PA group had similar values of fascicle length of the rectus femoris in relation to FFT ($p = 0.05$; ES = 0.22) and ST ($p = 0.152$; ES = 1.23). No significant differences were observed for any rectus femoris muscle architecture variable between the FFT and ST groups. No significant interaction was observed for the fascicle length of the vastus lateralis ($F = 0.17$; $p = 0.84$). The ES for fascicle length was "trivial" (FFT: 0.05; ST: 0.19) between the training groups and the PA group. About FFT and ST groups, a "small" ES was observed (ES = 0.27).

A significant interaction was observed for the rectus femoris's pennation angle ($F = 12.47$; $p < 0.001$). The FFT group ($p = 0.003$; ES = 1.76) and the ST group ($p < 0.001$; ES = 2.93) had a higher pennation angle compared to the PA group. No significant interaction was observed for the pennation angle of the vastus lateralis ($F = 1.30$; $p = 0.29$). The ES for pennation angle was "small" (FFT: 0.46) and "moderate" (ST: 0.75) between the training groups and the PA group. In relation to FFT and ST groups, a "small" ES was observed (ES = 0.36).

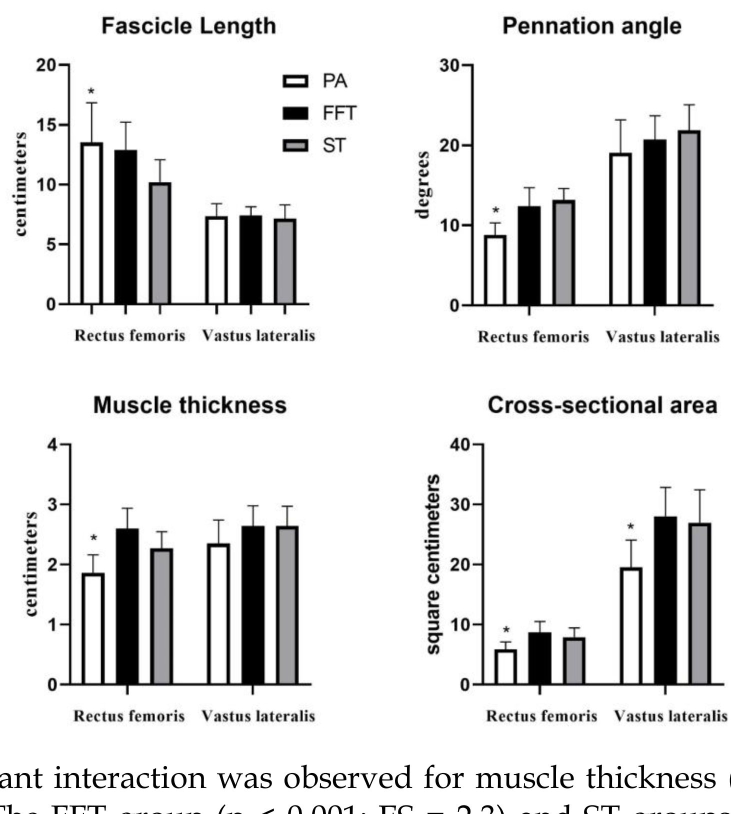

Figure 1. Muscle Architecture and Cross-sectional area between the Physically Active (PA), Functional Fitness Training (FFT), and Resistance Training (RT) groups. *Difference between Physically Active and other groups, $p < 0.05$.

A significant interaction was observed for muscle thickness ($F = 11.4$; $p < 0.001$) of the rectus femoris. The FFT group ($p < 0.001$; ES = 2.3) and ST groups ($p = 0.04$; ES = 1.41) had higher muscle thickness than participants in the PA group. No significant interaction was observed for the vastus lateralis muscle thickness (F = 1.70; p = 0.20). The ES for muscle thickness was "moderate" (FFT: 0.79; ST: 0.8) between the training groups and the PA group. In relation to FFT and ST groups, a "trivial" ES was observed (ES = 0).

A significant interaction was observed for rectus femoris CSA (F = 7.329; p = 0.004). Participants in the FFT and ST groups had higher CSA of the rectus femoris when compared to participants in the PA group (FFT, p = 0.004, ES = 1.84; ST, p = 0.04, ES = 1.47). No significant differences were observed between FFT and ST groups (p = 0.93, ES = 0.4). A significant interaction was observed for vastus lateralis CSA (F = 6.933; p = 0.005). Participants in the FFT and ST groups had higher CSA of the vastus lateralis (FFT, p = 0.008, ES = 1.8; ST, p = 0.02, ES = 1.48) compared to PA group participants. No significant differences were observed between FFT and ST groups (p = 1, ES = 0.2).

A significant interaction between groups was observed for maximum strength (F = 40.723; p < 0.001). Participants in the FFT (p < 0.001; ES = 3.72) and ST groups (p < 0.001; ES = 5.62) achieved a greater load than the participants in the PA group. Between the training groups, no difference was observed for the maximum load in the 1RM test.

The relationship between maximum strength and muscle architecture variables is presented in Table 2. A significant relationship was observed only for the pennation angle of the rectus femoris and maximum strength performance for participants in the FFT group. However, the fascicle length of the rectus femoris presented a "medium" ES for the FFT (r^2 = 0.3), and ST (r^2 = 0.4) groups, "large" and "small" ES as observed for the FFT (r^2 = 0.7) and ST (r^2 = 0.02) groups, respectively, and the muscle thickness presented a "medium" ES for the FFT (r^2 = 0.3) and ST (r^2 = 0.3) groups. For the vastus lateralis, "small" ES of the fascicle length was observed for the FFT (r^2 = 0.1) and ST (r^2 = 0.2) groups, respectively. For the pennation angle, "small" ES and "medium" ES were observed for FFT (r^2 = 0.2) and ST (r^2 = 3) groups, respectively, and the muscle thickness presented "small" ES as observed for the FFT (r^2 = 0.02) and ST (r^2 = 0.002) groups.

Table 2. Relationship of maximum strength and muscle architecture variables.

		Rectus femoris			Vastus Lateralis		
		MT	FL	PAn	MT	FL	PAn
1RM test		Functional Fitness Training					
	r	0.54	-0.55	0.862	0.17	-0.34	0.4
	p-value	0.16	0.15	0.006	0.68	0.4	0.32
		Strength Training					
	r	0.58	0.62	-0.17	-0.05	-0.5	0.51
	p-value	0.12	0.1	0.67	0.9	0.2	0.2

MT = muscle thickness; FL = fascicle length; PAn = pennation angle

DISCUSSION

The objective of the present study was to compare muscle architecture and muscle strength between FFT and ST male practitioners, in addition to evaluating the relationship of muscle architecture with the performance of maximum lower limb strength. The main findings of this study were that FFT and ST male practitioners do not differ from each other regarding the muscle architecture of the rectus femoris and vastus lateralis, as well as they do not differ regarding the performance of maximum strength in the back squat exercise. In addition, only FFT practitioners' pennation angle of the rectus femoris presented a relationship with maximal strength performance. Therefore, we rejected the first and third hypotheses, because muscle architecture and maximum strength did not differ between the FFT and ST groups, and we accepted the second hypothesis because the groups did not differ in relation to CSA.

The practice of muscle strength exercises provides hypertrophic gains that can be inferred by different structural measures (37). Among these measures, there is muscle thickness, which is associated with CSA (35). In this sense, the higher muscle thickness values observed in the FFT and ST groups may be related to the increase in muscle dimensions (i.e., muscle hypertrophy) that was acquired through mechanical stress imposed by constant overloads over the years of training of these participants (9,20).

These overloads imposed with the practice of strength exercises can also influence the pennation angle. It is believed that these stimuli lead to an increase in contractile material in the limited area of the aponeurosis, which affects the increase in the pennation angle (12,27). This scenario would explain the greater pennation angle of the rectus femoris and vastus lateralis observed in the FFT and ST groups.

Specifically for the vastus lateralis, the absence of difference between groups for fascicle length may be related to the organization of pennation angle and muscle thickness. In the model presented by Jogerson et al. (19), the increase in muscle size may be accompanied by an increase in contractile material in parallel in the muscle fascicle. In this scenario, there would be no longitudinal increase, however, a radial increase in the fascicle, accompanied by an increase in the pennation angle of this structure. Therefore, this configuration would provide the absence of changes in the fascicle length, associated with the increase in pennation angle and muscle thickness, as observed in the FFT and ST groups.

The reorganization of the components of the muscle architecture can lead to an increase in CSA, which is related to muscle hypertrophy (17). Hypertrophy can be operationally defined as an increase in the axial CSA of a muscle fiber or whole muscle (35). The increase in CSA results from the combination of concomitant or subsequent changes in muscle architecture, fiber type, and neural factors, which can influence the capacity to produce maximum force (37). Thus, we believe that the arrangement of the muscle architecture of the rectus femoris and vastus lateralis may have contributed to the higher CSA values in the FFT and ST groups in relation to the PA group.
As for the maximum strength performance, we observed that the practitioners of the FFT and ST groups reached high loads in the 1RM test. These results are in agreement with the literature

that presents a good maximum effort performance as a result of the practice of these two types of training. Dexheimer et al. (10) and Meier, Rabel, and Schmidt (25), for example, evaluated males experienced in FFT and reported loads of 151 kg and 152.3 kg, respectively, for maximum strength assessed through the back squat. Similarly, Ormsbee et al. (30) and Alegre et al. (3) evaluated experienced males in ST and reported loads of ~151.4 kg and ~153.8 kg, respectively, after a 1RM test for the back squat.

The performance in the maximum effort test can be related to different factors. For example, the insertion of high loads during training can provide neuromuscular adaptations that contribute to the musculature, increasing its strength production capacity (35). Another factor is related to the similarity of the exercise used in the maximum effort test and the insertion of this exercise during training since the continuous practice of this exercise can favor biomechanical adjustments that provide good performance during the test (4).

Furthermore, some of the muscle architecture components may have contributed to strength gains, given the relationship observed in our study. As previously reported, the addition of sarcomeres may provide lower fascicle length associated with a higher pennation angle (12,19,27). The pennation angle is related to muscle thickness (1), and the combination of these structures can help in the force production capacity. In this sense, the existence of a positive relationship between maximum strength and muscle thickness and pennation angle is understood, as well as a negative relationship between fascicle length and maximum strength performance.

Based on the findings of the present study, the practice of FFT does not seem to negatively influence the muscular adaptations and performance of its male practitioners, when compared to the practice of isolated ST, which weakens the possibility of the existence of an interference effect. Although our study presented relevant information, some limitations were identified and needed to be reported. The study was cross-sectional, which made it impossible to control the different exposures experienced by the participants, which may have influenced some muscle structures. The primary outcome of this study was the muscle architecture; therefore, neural factors were not evaluated, which also influence the production of muscle strength. The ST group did not consist of individuals who exclusively aimed at strength gains, so this may have affected the maximum strength performance of these participants. Additionally, our results are restricted to male practitioners.

On the other hand, our study approached the actual context of different training centers, since it involved experienced practitioners who did not train for competition purposes. The performance test did not grant the participants advantages of any training method, since the back squat exercise is performed in a gym and FFT environments. In addition, comparisons of the muscle architecture of two training methods that are widely practiced nowadays were presented, which can help in the judgment of practitioners and training prescribers regarding the effects of these training methods on the musculature.

We believe that new information can be added to the literature. Therefore, future studies can compare the different training methods regarding the combination of morphological and neural aspects. In addition, to expand information regarding women practitioners of FFT, as well as to evaluate individuals with higher levels of training, such as athletes and competitors.

The conclusion is that muscle architecture and CSA components of the rectus femoris and vastus lateralis muscles do not differ between experienced FFT and ST practitioners. The maximum strength in the back squat also does not differ between practitioners of these two training methods. In addition, the pennation angle of the rectus femoris seems to contribute to force production in FFT practitioners.

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