



Muscle power and muscle hypertrophy of the lower limbs among practitioners of functional fitness training and strength training

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Abstract

Purpose The practice of Functional Fitness Training (FFT) combines aerobic and muscle strength exercises that can lead to adaptations different from those observed with the isolated practice of Strength Training (ST). Thus, this study aimed to compare lower limb power and hypertrophy in different muscle portions between FFT and ST practitioners.

Methods In this cross-sectional study, men experienced (≥ 2 years) in FFT ($n = 8$; 27 ± 4.6 years) and ST ($n = 8$; 29.13 ± 6.12 years) participated. Additionally, physically active men were recruited for the control group ($n = 8$; 25 ± 8.24 years). For muscle power, jump height and peak power output (PPO) normalized by body mass were evaluated, and for hypertrophy, the cross-sectional area (CSA) was evaluated in 4 different portions of the vastus lateralis with the aid of B-mode ultrasound.

Results It was observed that the CSA did not differ between the FFT and ST groups, and showed higher values in relation to the control group. Jump height was higher ($p = 0.003$) for the FFT group (53.5 ± 2.4 cm) compared to the control group (45.7 ± 3.6 cm), and did not differ in relation to the ST group (50.8 ± 5.7 cm; $p = 0.058$). PPO showed no statistical difference ($p = 0.39$) between groups (control, 50.5 ± 6 W kg^{-1} ; FFT, 54.1 ± 5.8 W kg^{-1} ; ST, 50.6 ± 5.6 W kg^{-1}).

Conclusion Vastus lateralis hypertrophy does not differ between men experienced in FFT and ST. The practice of these training methods does not seem to differ in relation to muscular power, although there are indications that those of FFT perform better than those of ST.

Keywords HIIFT · Resistance training · Muscle morphology · Muscle plasticity

Abbreviations

CSA	Cross-sectional area
ES	Effect size
FFT	Functional fitness training
IC	Confidence intervals
ICC	Intraclass correlation coefficient
PA	Physically active
ST	Strength training

Introduction

Functional Fitness Training (FFT) is a training method that has gained many supporters in recent years, mainly because of exercise programs that are based on this training method. The FFT is characterized by emphasizing multi-joint movements through the combination of aerobic exercises (cycling, rowing, running) and muscular strength (weight lifting and derivatives, body weight, and plyometric exercises) designed to improve the parameters of the general physical fitness of its practitioners [1, 2].

In this scenario, some studies have been developed to better understand the effects of FFT. In the systematic review by Dominski et al. [3], for example, the authors evaluated 26 studies that addressed the topic of injuries associated with the practice of FFT. In this study, the incidence of up to 36 injuries per 1000 h of training was observed, with the shoulder being the main part of the body affected, and the

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training experience being one of the associated factors. In the systematic review by Sharp et al. [4] longitudinal studies were evaluated, and the authors observed that the practice of FFT provides positive effects for aerobic conditioning when compared to Concurrent Training (CT). However, in relation to muscle strength and power, the authors did not observe differences between the groups, raising the discussion of the possibility of the interference effect, which has been studied in the CT, also being found with the practice of the FFT.

This possibility of the effect of interference with the practice of FFT had already been suggested in the systematic review by Schlegel [5]. The concept of this effect was presented with the seminal study by Hickson [6] that combined strength and aerobic exercises in the same training session and observed the impairment in muscle strength gains of the lower limbs when compared to the practice of isolated Strength Training (ST). Based on these results, several studies have been developed and it has been observed that this effect can also compromise muscle power gains of the lower limbs [7], being more evident in individuals with a higher level of training (i.e. trained individuals) [8, 9]. In this context, if the practice of FFT provides the appearance of the interference effect, then experienced practitioners of this training method may have compromised muscle power.

In addition to the impairment of physical performance, in the recent study by Lundberg et al. [10] it was shown that the muscle fiber may be influenced by the interference effect. The authors discussed that it is possible that this influence could be associated with alterations in muscle architecture, such as an increase in the muscle pennation angle. In the literature it is shown that the organization of these architectural components can influence the muscle cross-sectional area (CSA) [11], therefore, if the interference effect influences the organization of these components, then it can influence the adaptations of the whole muscle (i.e. CSA).

The assessment of CSA is one of the ways to assess muscle hypertrophy [11]. The literature shows that the level of training, age, sex, and type of training method performed can influence the dimensions of muscle CSA [12–14]. Additionally, the literature shows that hypertrophy does not happen in the same way throughout the length of the muscle [11]. In this scenario, not only could the interference effect interfere with hypertrophic gains, but it could also differ throughout the entire muscle. Therefore, if FFT favors the appearance of the interference effect, the adaptations observed in these structures may be different from those observed with the practice of ST.

Although important, to our knowledge, comparisons on CSA taking into account the non-homogeneity of muscle hypertrophy between FFT and ST have not been reported in the literature to date. In addition, the comparison of jump performance between experienced practitioners in FFT and ST is scarce. Thus, the aim of this study was to compare

lower limb power and hypertrophy in different muscle portions between experienced FFT and ST practitioners.

The practice of exercises that emphasize muscle power is common in FFT. Thus, despite the possibility of the interference effect, we hypothesized that FFT practitioners are more powerful than those of ST. However, both training methods include exercises that enhance hypertrophy. Thus, our second hypothesis is that there is no difference in CSA between FFT and ST.

Material and methods

Study design

In this cross-sectional study, men experienced in FFT and ST were recruited, as well as physically active (PA) men to compose the control group. Data collection was carried out with 3 visits to the Biomechanics Laboratory, where experienced researchers conducted the research procedures. On the first visit, the volunteers were introduced to the study, signed the consent form, and were familiarized with the entire evaluation protocol. On the second visit, anthropometry, ultrasound, and lower limb power assessments were performed. Ultrasound and muscle power assessments were again performed on the third visit. All these evaluations were performed at an interval of 48 h.

Participants

For the sample calculation, we considered a test statistical power of 80%, an effect size of 0.78, and a significance level of 5%. The effect size was calculated based on previous studies on muscle morphology [15–17]. Thus, the minimum number calculated was 21 participants.

The study included 24 men, divided into 3 groups: FFT ($n=8$), ST ($n=8$), and PA ($n=8$). Participants were selected according to the following inclusion criteria: male, adults (> 18 years), practitioners of FFT, ST, or being considered physically active by the international physical activity questionnaire [18] to compose the PA group. The following exclusion criteria were adopted: report of injuries or physical limitations, use of anabolic androgenic steroids, and individuals who considered themselves athletes, or trained with the aim of competition.

To consider as experienced practitioners, the criteria of Mangine et al. [17]. FFT practitioners should have at least 2 years of practice and attend 3 weekly sessions. ST practitioners should practice bodybuilding for at least 2 years, with at least 2 weekly training sessions for lower limbs. In the PA group, participants could practice any activity except FFT or ST.

Each participant provided written consent, after presenting the risks and benefits of the study. All research was carried out in accordance with the Declaration of Helsinki, and all procedures were previously approved by the ethics and research committee of the Federal University of Santa Catarina.

Anthropometric assessment

Total body mass and height were measured using a digital scale (Filizola®, Brazil) and a stadiometer (Sanny®, Brazil), respectively.

Ultrasound evaluation

The acquisition of images of the Vastus lateralis was performed with the aid of ultrasound in Brightness mode (model LOGIQ S7 Expert, General Electric, USA). The images were acquired by an experienced evaluator and measured on the participants' dominant limb, defined as the leg chosen to kick a ball [19]. The device was configured with the following specifications: frequency of 10 MHz, image capture depth of 7 cm, and gain of 60 dB. The water-based gel was used during the evaluation, and the pressure on the skin was controlled by the evaluator to avoid muscle deformation. The Vastus lateralis assessment was chosen given its higher CSA and contribution to total quadriceps volume in trained individuals [20].

The acquisition of CSA information followed the procedures reported by Lacerda et al. [21]. First, the length of the femur was measured as the distance between the greater trochanter and the lateral epicondyle of the femur. Then, the evaluation sites corresponding to 40, 50, 60, and 70% of the total femur length were demarcated (Fig. 1). These markings were made in the anterior region of the thigh, with the proximal point at 40% and the distal point at 70%. After these procedures, the participants rested for 5 min [22], and with the aid of a 5 cm transducer, two images were acquired in each of the percentages. For this procedure, a device was attached to the participant's thigh to better guide the evaluator, and the transducer was transversely positioned parallel to the intercondylar line for image acquisition.

Image analysis was performed by an experienced evaluator who manually demarcated the CSA of the Vastus lateralis using ImageJ software (V.1.52; National Institute of Health, USA). This entire procedure was performed in each percentage and to calculate the total CSA of the Vastus lateralis, the sum of the CSA of all percentages was performed.

Assessment of muscle power

Muscle power was assessed through countermovement jump height and peak power output adjusted. A portable force

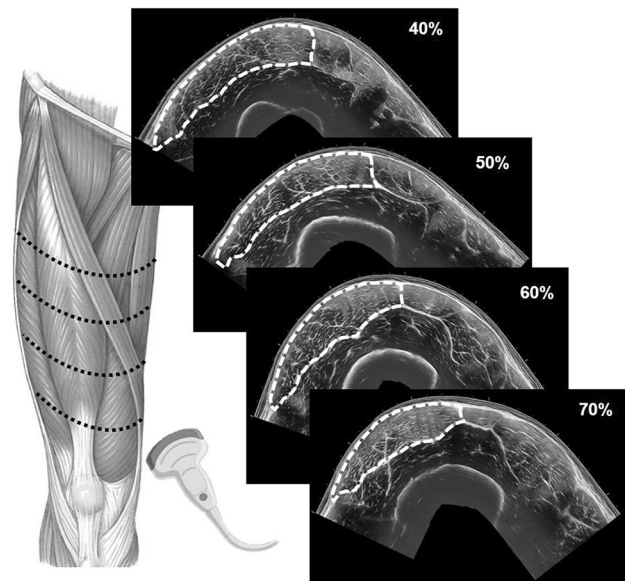


Fig. 1 The percentages along the total femur length where the images were collected to quantify the cross-sectional area

platform (Kistler®, Quattro Jump, 9290AD, Winterthur, Switzerland) was used to assess jump height following the procedures reported by Dal Pupo et al. [23]. First, the participants warmed up on an ergometric bicycle for 5 min, then performed 2 series of 10 jumps on the ground, and performed several jumps with countermovement on the ground and the force platform for technique adjustments. The angle of the knee joint was measured with a goniometer so that all participants performed knee flexion at 90°. To ensure that this flexion was preserved, a device was positioned behind the participants that served as a reference for the depth of the jump in accordance with the 90° angle of the knee joint.

The countermovement jump started from the orthostatic position, in which the participants were instructed to keep the torso as vertical as possible and the hands on the hips. The jump was performed with a countermovement (descending phase) followed by a quick and vigorous extension of the lower limbs' joints (ascending phase), being advised that its execution was performed as high as possible. Each participant performed 3 jumps, with a 1-min recovery interval between them, using the best attempt for analysis.

In the data analysis, the acceleration curve was calculated by dividing the ground reaction force by the participant's body mass. Then, the acceleration curve integral was used to obtain the velocity, and a double integral was performed to obtain the displacement curve. The greatest vertical center of mass displacement was considered as the jump height. The power output was calculated by multiplying the ground reaction force by the velocity, and the highest value was considered the peak power output, which was normalized by the body mass of each participant to minimize the effect

of body mass. Thus, in addition to the height of the jump, the peak power output adjusted was calculated. All these mathematical procedures were performed by an algorithm developed in Matlab software.

Statistical analysis

Values are reported as mean \pm standard deviation. The normal distribution of data was evaluated using the Shapiro–Wilk test. One-way ANOVA with Tukey's post hoc was used to assess differences between groups. Effect size (ES) of comparisons was calculated and classified according to Hopkins [24]: 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. 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) and the 95% confidence intervals (CI) were calculated for the 40% CSA (ICC: 0.98; CI: 0.96–0.99), 50% CSA (ICC: 0.99; CI: 0.97–0.99), 60% CSA (ICC: 0.99; CI: 0.98–0.99), 70% CSA (ICC: 0.98; CI: 0.96–0.99), total CSA (ICC: 0.99; CI: 0.98–0.99), vertical jump height (ICC: 0.99; CI: 0.98–0.99), and peak power output adjusted (ICC: 0.97; CI: 0.95–0.99).

Results

Participants in the FFT group (27 ± 4.6 years; 173.76 ± 7.55 cm; 78.44 ± 9.6 kg) had been practitioners for 3.6 years and trained 5 times a week with an average duration of 82.5 min for each session. Participants in the ST group (29.13 ± 6.12 years; 175.91 ± 3.76 cm; 82.50 ± 8.69 kg) had been weight training for 4.5 years, performing 5 weekly sessions, with an average duration of 67.5 min. While participants in the PA group (25 ± 8.24 years; 173 ± 7.11 cm; 66.25 ± 6.95 kg) practiced different activities (running, cycling, and soccer) for 4.6 years, with 4 sessions weekly and average duration of 100 min each session. The average values of the weekly frequency and duration of the training session allowed an approximate calculation of the training volume. It was observed that FFT practitioners had a training volume of 433 min/week, while ST practitioners had 329 min/week.

A significant interaction was observed in CSA comparisons at 40% ($F=7.006$; $p=0.005$), 50% ($F=6.440$; $p=0.007$), 60% ($F=4.538$; $p=0.023$), and 70% ($F=7.089$; $p=0.004$) of the total femur length (Fig. 2). For all percentages, the FFT group had higher CSA values compared to the PA group (40%, $p=0.007$, ES: 2.25; 50%, $p=0.007$, ES: 2.2; 60%, $p=0.03$, ES: 1.44; 70%, $p=0.01$, ES: 1.97). For the ST group, higher CSA values were observed at 40% ($p=0.01$,

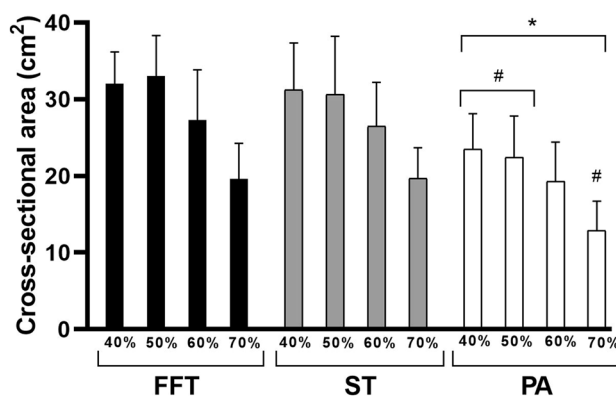


Fig. 2 Vastus Lateralis' cross-sectional area comparisons in different portions (proximal to distal) between Functional Fitness Training (FFT), Strength Training (ST), and Physically Active (PA) groups. *Significant difference between FFT and PA. #Significant difference between ST and PA

ES: 1.56), 50% ($p=0.03$, ES: 1.31), and 70% ($p=0.01$, ES: 1.97) in relation to the PA group, however, no significant difference was observed between these groups in the 60% CSA ($p=0.057$, ES: 1.4).

The FFT ($p=0.007$, ES: 1.83) and ST ($p=0.01$, ES: 1.53) groups had higher total CSA values when compared to the PA group. Both total CSA and all percentages did not show significant differences between the FFT and ST groups (Table 1).

Jump height was higher for the FFT group than the PA group ($p=0.003$, ES: 3.13), and did not differ significantly between the ST and PA groups ($p=0.058$; ES: 1.21) (Table 1). Regarding the FFT and ST groups, no significant differences were observed ($p=0.414$, ES: 0.78). The comparison between FFT and PA showed a very large ES, while the comparison between ST and PA showed a large ES. Between the FFT and ST groups, moderate ES was observed.

Peak power output adjusted showed no significant difference between groups ($p>0.05$) (Table 1). However, in the comparison between FFT and PA a moderate ES was observed ($p=0.45$; ES: 0.61), while in the comparison of ST and PA a trivial ES was observed ($p=0.99$; ES: 0.01). Between the FFT and ST groups, moderate ES was observed ($p=0.47$; ES: 0.61).

Discussion

The present study aimed to compare lower limb power and hypertrophy in different portions of the vastus lateralis muscle between experienced FFT and ST practitioners. As main findings, no difference was observed in vertical jump height, peak power output adjusted, and vastus lateralis CSA between FFT and ST practitioners. Based on these results,

Table 1 Information on morphology and physical performance

	PA (n=8)	FFT (n=8)	ST (n=8)	F	p
Cross-sectional area (cm ²)	78.2 ± 18.1 [#]	112 ± 19.3	107.9 ± 21.8	6.93	0.005
Jump height (cm)	45.7 ± 3.6	53.5 ± 2.4*	50.8 ± 5.7	7.21	0.004
Peak power output adjusted (W kg ⁻¹)	50.5 ± 6	54.1 ± 5.8	50.6 ± 5.6	0.97	0.39

Data presented as mean ± standard deviation. PA, Physically Active; FFT, Functional Fitness Training; ST, Strength Training. [#]Smaller cross-sectional area than the FFT and ST group. *Jump height greater than that of the FA and without difference in relation to the ST

our first hypothesis was rejected, as no significant differences were observed for the vertical jump. However, our second hypothesis was accepted, since similarity of the CSA between the two training methods was observed.

The regular application of mechanical stresses to the skeletal muscles provides an increase in CSA, which is considered a reliable measure to assess muscle hypertrophy [11]. Although all study participants practiced physical exercise, participants in the FFT and ST groups had the highest values for CSA, with no difference between them, showing that both methods seem to be efficient for hypertrophic gains. These results highlight that regardless of the type of training, muscle strength exercises favor similar hypertrophic gains among experienced FFT and ST practitioners. On the other hand, the physical activities performed by the participants in the PA group also favored hypertrophic gains, however, to a lesser extent when compared to the other groups.

Additionally, the CSA characteristic observed in our study is in line with previous findings in the literature regarding the distribution of this measure along the length of the femur. The disposition of the CSA area of the quadriceps muscles in strength-trained men had already been reported by Narici et al. [25, 26], who observed that the vastus lateralis has its greatest CSA close to 50% of the total length of the femur, and its dimensions decrease as it approaches the knee joint. This configuration may be associated with muscle structures that are not homogeneous throughout the entire muscle, such as the pennation angle of the fasciculus [27], and which are influenced by the specific activation of certain muscle regions during exercise [28]. Therefore, there seems to be no impairment in CSA due to an interference effect with the long-term practice of FFT, since there were no differences in this measure between FFT and ST practitioners.

These results corroborate the recent findings published in the meta-analysis by Schumann et al. [7], who observed that the interference effect does not seem to compromise total muscle hypertrophy. However, a close examination of the individual studies revealed that there were inconsistencies in the literature regarding the interference effect and muscle hypertrophy. Lundberg et al. [10] noted that studies used muscle fiber size as an outcome measure for hypertrophy, and this could influence overall muscle conclusions.

Thus, after performing the second meta-analysis, Lundberg et al. [10] observed that the combination of strength and aerobic exercises can attenuate the hypertrophy of muscle fibers compared to the isolated practice of ST, however, this commitment is not necessarily translated into differences in total muscle hypertrophy. Thus, although we did not observe a difference in CSA between the FFT and ST groups, the possibility that the interference effect induces differences at the level of muscle fibers remains open, since these evaluations were not performed in the present study.

As for muscle power, our results differ from those reported in the literature. Adami et al. [29] evaluated FFT and ST athletes, while Souza et al. evaluated FFT and ST practitioners with 1 year of experience. Adami et al. [29] observed that the strength group, composed of weightlifting athletes, presented higher adjusted power than the FFT athletes. In the study by Souza et al. [30], it was observed that FFT practitioners had higher jump height than ST practitioners. Contrary to these studies, our results showed that the FFT group did not differ statistically from the ST group, in terms of adjusted peak power and jump height.

In these aforementioned studies, some considerations need to be reported. Participants evaluated in the study by Adami et al. [29] were athletes, which influences the different exposures over the years of training when compared to practitioners of a training method as in our study. Additionally, the practice of Weightlifting provides training stimuli of high load and high speed different from the practice of ST. Thus, the practice of this sport modality promotes neural adaptations such as improvement in the firing rate, recruitment, and synchronization of motor units, which favor better performance in the vertical jump [31] which would explain the difference between our findings.

Our results, however, are similar to those reported by Souza et al. [30]. The authors performed a cross-sectional study and compared practitioners with 1 year of experience in FFT and ST in different physical tests. For the power of the lower limbs, the authors evaluated the countermovement height and did not observe a significant difference between the groups, although those from the FFT had higher values (41.08 cm) than those from the ST (35.85 cm). In our study, FFT participants had higher values for muscle power

variables compared to ST participants, however, without significant difference between them.

Although Souza et al. [30] do not present possible explanations for this finding, we believe that the absence of significant differences in our study can be explained by some determining factors for a good performance in the vertical jump that was reported in the study by Morin et al. [32]. The authors present factors such as the individual impulsion distance, which is equivalent to the depth of the squat during the countermovement jump, the ideal load, which can be the body mass itself, and the force–velocity profile. The latter can be understood as the balance between the ability to produce force and the speed of execution of the movement.

In this scenario, controlling the squat depth in our study allows us to discard the first factor presented by Morin et al. [32]. Likewise, the fact that we have normalized peak power output means that we discard the influence of body mass on muscle power. However, one factor that was not measured in our study was the strength-speed profile of the participants. Individuals who performed the jump more slowly may have a longer time during the impulse phase, reflecting a lower mechanical power output. Thus, although no statistical difference was observed for the peak power output adjusted, the highest values observed in the FFT group and the ES results show that FFT practitioners can be more efficient in performing the vertical jump and, possibly, present greater muscular power than the individuals of the other groups.

This higher peak power output adjusted value may have contributed to the higher jump height value observed in the FFT group. However, the constant practice of vertical jumps, similar to the countermovement jump, may have influenced the better performance of FFT practitioners. Bobbert and Van Soest [33] suggested that a resistance training program that aims to improve vertical jump should be accompanied by exercises that improve the efficiency of the neuromuscular system. For the authors, stronger muscles do not necessarily result in greater jumping capacity, since this ability depends on other adjustments such as coordination, timing, and movement technique [33, 34].

Specifically, between the FFT and ST groups, another factor may have influenced the lack of difference between groups. Among the participants in the ST group, some reported practicing or having practiced for many years different activities such as combat sports and volleyball, but in a non-competitive way. These sports modalities are characterized by great efforts performed in a short period, which makes muscle power considered a determining factor of performance [35, 36], therefore, these activities may have influenced the results of the ST group.

Although our study has added new information regarding muscle power and hypertrophy in different training methods, some limitations need to be reported. The study is cross-sectional, which prevented the control of

all intervening variables that could potentially influence the result. The lack of control of the training and exercise variables prevented us from relating the observed adaptations to the characteristics of each type of training. Some participants in the ST group reported practicing or having practiced for many years other activities, which may have influenced the results of muscle power.

Among the positive points of the study, there was the possibility of evaluating experienced practitioners (> 2 years) in two types of training widely practiced today, which would be very expensive and not very logistical in the case of longitudinal studies. The recruitment of participants was random, regardless of the training center, which makes the results more pragmatic and closer to the reality of the population. In addition, it was possible to compare muscle characteristics between FFT and ST, not only as a global measure but as segmented along a muscle. In practical aspects, the prescription of FFT sessions for ST practitioners can be a strategy to provide dynamic sessions that escape the traditional ST prescription routine. This strategy will not compromise vastus lateralis adaptations and may help improve muscle power performance. Especially for beginners, the practice of FFT and ST can improve muscle power performance and provide muscle adaptations. In the sports scenario, FFT athletes can improve their adaptation in the vastus lateralis muscle with the addition of specific ST sessions.

The existence of the interference effect in the FFT group can influence biological markers and structures, and differentiate FFT and ST practitioners. Thus, future studies could assess the effect of interference on FFT and ST through biochemical markers related to hypertrophy, in addition to the analysis of muscle fibers. This analysis could bring interesting answers about the theme. Longitudinal studies should be explored in order to observe the different adaptations experienced by FFT and ST practitioners. In this scenario, uncontrolled variables in our study can be resolved. For example, the equalization of the training volume and the identification of which exercises are prescribed in each training method can increase the understanding of the adaptations of these training methods.

Conclusion

Muscle hypertrophy along the entire vastus lateralis muscle, assessed using CSA, does not differ between men experienced in FFT and ST. In addition, there are indications that the practice of FFT favors greater performance of muscle power in the lower limbs, although no difference was observed in relation to practitioners of ST.

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Authors' contribution Silas de Oliveira and Antônio Moro contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Silas de Oliveira, Grazieli Zapello, Débora Khins, and Gabriela Fischer. The first draft of the manuscript was written by Silas de Oliveira and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no potential conflict of interest.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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