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Original Research

Relationships Between Performance in the Frequency Speed Kick Test, Heart Rate Variability, and Body Composition in Amateur Muay Thai Fighters

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Abstract

International Journal of Exercise Science 18(6): 428-442, 2025. https://doi.org/10.70252/PPGL4101 In martial arts, heart rate variability (HRV) measurements can potentially be used to assess injury risk and susceptibility to fatigue. Muay Thai uses the Frequency Speed of Kick Test (FSKT) to measure kick speed, but it is unknown whether better fitness results in improved autonomic function and body composition, which may affect athletic performance and recovery. We aimed to evaluate the correlations between FSKT, HRV, and body composition measures in amateur Muay Thai fighters. This is a cross-sectional study with 37 Muay Thai fighters. They underwent FSKT-10s and multiple FSKT to measure the kick fatigue index (KFI). In addition, body composition was assessed using bioelectrical impedance analysis and HRV using a heart rate monitor. When comparing the values before and during the FSKT-10s, there was a decrease in the percentage of interval differences of consecutive successive NN intervals greater than 50 ms (pNN50), approximate entropy, and parasympathetic nervous system (PNS) index, with an increase in the sympathetic nervous system (SNS) index. The number of kicks assessed by FSKT-10s positively correlated with fat-free mass (FFM) and low frequency (LF) of the HRV assessment. The KFI correlated negatively with the FFM and PNS index, and positively with the LF and SNS index. When amateur Muay Thai fighters perform the FSKT-10s, there is an acute effect on autonomic modulation with increased sympathetic activation and vagal withdrawal. FFM and sympathetic activation are related to performance and susceptibility to fatigue. These results indicate the importance of assessing HRV in Muay Thai fighters to improve performance.

Keywords: Martial art, autonomic nervous system, exercise

Introduction

Martial arts such as Muay Thai have become increasingly popular in recent years. Muay Thai is a kickboxing style that allows full-contact striking to the head, torso, and legs, using standing

strikes and various clinching techniques.[1] It combines a mixture of upper-limb strikes, such as punches and elbows, and lower-limb strikes, such as kicks and knees. Muay Thai also uses evasion and protection techniques, where fighters use their own bodies to execute sequences of strikes and defenses in a game of attack and counterattack.[2] Muay Thai is considered an "eight-limbed" martial art, with practitioners using eight points of contact with the opponent (i.e., fists, elbows, knees, and feet).[3] The potential benefits associated with practicing this sport include changes in body composition, improved balance control, improved cardiorespiratory fitness, and increased aerobic power, flexibility, agility, and mobility.[4]

In martial arts, success in competition and training depends on overall motor fitness, which results primarily from the development of coordination and flexibility skills, as well as force-speed and force-endurance interactions that affect physical and mental performance.[3] Muay Thai training can lead to significant improvements in strength, flexibility, endurance, and fighting ability.[5] Flexibility is the ability to move a joint through its greatest possible range of motion, and flexibility training is important for performance in Muay Thai because it helps to increase the range of motion of the joints, thereby improving the speed, power, and accuracy of strikes.[6] In this sense, the Frequency Speed of Kick Test (FSKT) has been increasingly used as a performance test to measure the speed and frequency of kicks; it is easy to perform, noninvasive, requires inexpensive equipment, assesses anaerobic capacity, and is easily implemented by coaches.[7,8] The FSKT is typically performed with a punching bag to achieve as many kicks as possible in a given period of time. In addition, the FSKT can be used as an indicator of fitness and as a training target to improve kicking speed and frequency.[6]

Heart rate (HR) is a measure of cardiac activity and its variation depends on several factors, including age, level of physical fitness, and type of physical activity. In this sense, heart rate variability (HRV) is the variation in the interval between heartbeats and can be used as an indicator of the activity of the autonomic nervous system (ANS) to regulate cardiac activity. Exercise contributes to changes that involve neural changes, including adaptations in the central nervous system, baroreceptor activity, and the muscle contraction reflex.[9] Greater variability between heartbeats reflects greater parasympathetic action and consequently better autonomic efficiency, whereas low variability represents greater sympathetic action.[10] Thus, HRV analysis can be useful in evaluating response to training and monitoring cardiovascular health of fighters, and martial arts practice appears to improve autonomic modulation.[11,12] A decrease in HRV may indicate that the athlete is trying too hard and may be at risk for injury, while an increase in HRV may indicate fatigue and be a sign that the athlete needs more rest.[9]

One of the major benefits associated with Muay Thai training is the change in body composition, including an increase in fat-free mass (FFM), which in turn can affect strength, muscular endurance, aerobic power, flexibility, and agility. This improvement in body composition may lead to exercise-related adaptations that are dose-dependent, and therefore the results of Muay Thai training may vary depending on the intensity of the exercise.[2,13] In addition to the percentage of FFM and fat mass in Muay Thai athletes, it is important to evaluate body water as it plays a fundamental role in several physiological functions.[14] Improvements in dietary habits must be sought to help these athletes achieve a balanced ratio of nutrients to improve their

quality of life.[15] Dehydration in Muay Thai athletes can be caused by several factors, including excessive sweating during training, lack of adequate fluid replacement before and during physical activity, and hot weather conditions, as well as specific pre-fight dehydration protocols. Nutrition is another aspect that should always be evaluated in Muay Thai fighters, as it can affect the performance, recovery, and overall health of fighters.[15]

Muay Thai fighters rely heavily on the use of the roundhouse kick due to its effectiveness and impact on the final score. Therefore, different timings of full force strikes are used during training as a method of increasing kick power.[16] In this sense, training load assessment is fundamental in Muay Thai, as it helps to ensure that fighters are adequately prepared for competition, thus avoiding overuse and injury. Training load assessment allows coaches and athletes to monitor training volume, intensity, and duration and make adjustments as necessary. This may include changes in the number and intensity of training sessions, as well as the addition of specific training exercises that may have a strong impact on body composition and autonomic modulation, with a greater risk of injury and fatigue. Although previous studies have shown that Muay Thai training can improve strength and flexibility[5,6] as well as modify body composition[2,13], no previous studies have assessed HRV before and during a performance test in this population. Indeed, neural adaptations that occur during training may increase parasympathetic nervous system (PNS) activation and decrease sympathetic nervous system (SNS) activation, thereby increasing HRV.[17] Although some studies have evaluated cardiac autonomic modulation in martial arts fighters, they have not focused on the acute effects of training[9] or used direct measures of HRV[18]. Our hypothesis is that the better the physical fitness, the better the cardiac autonomic modulation and body composition. Therefore, this study aimed to evaluate the correlations between FSKT, HRV, and body composition measures in amateur Muay Thai fighters.

Methods

Participants

This is a cross-sectional study with a convenience sample that consecutively evaluated 37 amateur Muay Thai fighters, aged ≥18 years, between February and May 2024. Athletes' motor fitness assessment and baseline measurements of body composition and HRV were performed at Academia AAZIZ, Curitiba, Brazil. Muay Thai fighters with at least 6 months of training were included. The following exclusion criteria were used: history of diabetes, hypertension, kidney disease, liver dysfunction, and neoplastic disease; use of any medication to control blood pressure or heart rate; history of alcohol or drug abuse; and inability to perform performance tests.

This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science*.[19] The study was conducted in accordance with the tenets of the Declaration of Helsinki. All participants gave informed consent before the start of the study. The protocol was approved by the Research Ethics Committee of the Augusto Motta University Center under CAAE-77325224.4.0000.5235. The protocol was registered on ClinicalTrials.gov under the number NCT06338501.

Protocol

We use bioelectrical impedance analysis (BIA), a non-invasive, low-cost approach widely used in sports, to assess body composition.[20-23] BIA was performed with a whole-body tetrapolar device (Sanny®, BIA 1010, Brazil) using an electrical frequency of 50 kHz. Prior to BIA, the participant was instructed to fast for 4 hours, to avoid physical activity for 12 hours before the test, and to avoid the use of oils and lotions on the skin. To perform the BIA, the participant was asked to remove any metal objects he was wearing, such as earrings, bracelets, watches, and piercings. The participant was then placed in the supine position so that four electrodes could be placed on the right side, two of which were detector electrodes placed on a line between the radial and ulnar styloid processes on the dorsum of the wrist and the line between the medial and lateral malleoli on the dorsum of the foot. Two other source electrodes were superimposed on the head of the third metacarpal on the dorsum of the hand and the third metatarsal on the dorsum of the foot.[20] The following parameters were calculated: body fat; FFM; total body water (TBW); and basal metabolic rate (BMR). These variables were calculated directly from the equipment, taking into account the ethical group's own equations obtained in male athletes.[21,22]

Immediately after the BIA, the ten seconds Frequency Speed of Kick Test (FSKT-10s) was performed. To perform the FSKT-10s, the athlete was asked to stand in front of the support equipped with a training trunk (boxing dummy) at a distance of 90 cm. The athlete was previously instructed to alternate the Bandal Tchagui technique for 10 seconds at the highest possible speed and force. Then the evaluator gave a command signal and the athlete began to perform the kicks, alternating between the right and left legs. We used a stopwatch to measure the time and a counter to record the number of kicks performed. The results were expressed in kicks per minute.[4,6,23]

We also performed the multiple Frequency Speed of Kick Test (FSKT-mult) to measure the kick fatigue index (KFI). After a 1-minute rest, the athlete restarted the FSKT-mult test, which consists of 5 sets of 10 seconds with 10 seconds recovery. The number of kicks in each 10-second set was counted. The KFI calculation took into account the number of kicks performed during the FSKT-mult and was calculated as follows: KFI (%) = (best kick - worst kick / best kick) x 100.[6,23]

HRV was assessed using a heart rate monitor (V800, Polar OY, Finland) before and during the FSKT-10s. The normal-to-normal RR (NN) intervals recorded by the heart rate monitor were exported to the Kubios HRV software (University of Finland, Kuopio, Finland) for HRV analysis by time domain, frequency domain, and Poincaré plot nonlinear analysis. Time domain analysis measurements were as follows: mean NN intervals; maximum HR; standard deviation of all NN intervals (SDNN), which captures overall HRV and reflects circadian heart rhythm; the square root of the mean squared differences between consecutive NN intervals (rMSSD), which correlates with PNS activity; percentage of interval differences of consecutive NN intervals greater than 50 ms (pNN50), representing primarily vagal activity; and triangular interpolation of NN intervals histogram, representing global autonomic activity. Measurements in the frequency domain analysis were as follows: total power (TP, 0.04-0.15 Hz), which reflects global autonomic activity; low frequency range (LF, 0.04-0.15 Hz) which is a marker primarily for SNS activity; high frequency range (HF, 0.15-0.40 Hz), which reflects modulation of PNS efferent

activity by ventilation; and LF/HF ratio, which reflects autonomic balance, with higher values indicating SNS predominance. The power of the LF and HF components was also evaluated in standard units (nu). The following Poincaré plot nonlinear measures were evaluated: standard deviation of the instantaneous variability beat-to-beat (SD1), which describes short-term variability (representing parasympathetic modulation); standard deviation of long-term continuous NN intervals) (SD2) which describes long-term variability (representing global cardiac autonomic activity); SD2/SD1 ratio; and approximate entropy (ApEn), which detects changes in a time series and indicates ANS complexity. We also evaluated the PNS index which is calculated in the Kubios HRV software from measurements of mean NN intervals, rMSSD, and Poincaré plot index SD1, and the SNS index which is calculated in the Kubios HRV software from measurements of mean HR, a geometric measure of HRV reflecting cardiovascular system stress, and Poincaré plot index SD2. Recording and analysis were performed according to the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology.[24]

Statistical Analysis

Statistical analysis was performed using SPSS statistical software version 26 (IBM Corp., Armonk, NY, USA). The normality of the data distribution was checked using the Shapiro–Wilk test and graphical analysis of histograms. Descriptive analysis was presented in the form of tables. The observed data were expressed using measures of central tendency and dispersion appropriate for numerical data. The variation between the two moments (before and during the FSKT) was evaluated using the Wilcoxon signed rank test. In addition to null hypothesis significance testing, we addressed the magnitude and practical significance of the results using effect sizes.[25] Thus, we also calculated effect sizes using Cohen's *d* with the following interpretations for highly trained subjects: <0.25 = trivial, 0.25-0.50 = small, 0.50-1.0 = moderate, >1.0 = large.[26] Spearman's correlation (r_s) and determination coefficient (R^2) with their respective 95% confidence intervals (CI) were used to test the strength of the associations for FSKT-10s, KFI, BIA, and HRV before FSKT-10s. To calculate the CI for Spearman's rank correlation coefficient (r_s), the Fisher transformation was used.[27] The r_s cut-offs of 0.1, 0.3, 0.5, 0.7, and 0.9 were considered small, moderate, large, very large, and nearly perfect, respectively.[28] The significance level was set at 5%.

Based on an *a priori* type I error of $\alpha = 0.05$ (two-tailed), the power analysis showed that significant effects were detected in the comparisons between HRV parameters obtained before and during the FSKT-10s. The power varies between 91% and 98%; therefore, the sample size was adequate to obtain significant results.[29]

Results

Of the 37 amateur Muay Thai fighters eligible for the study, 3 were excluded for the following reasons: history of hypertension ($n = 2$) and discontinuation of FSKT-mult ($n = 1$). The mean age was 27.9 ± 7.7 years and all participants were male. Based on body mass index (BMI), 15 (44%) were eutrophic, 12 (35%) were overweight and 7 (21%) were obese. The median number of kicks

in the FSKT-10 was 20 (17–26), while the KFI assessed in the FSKT-mult was 20 (14–29) %. Anthropometric data and BIA parameters are shown in Table 1.

Table 1. Anthropometric Data and Bioelectrical Impedance Analysis Parameters in the Studied Sample (*N* = 34).

Variable	Value
Anthropometry	
Age (years)	27.9 ± 7.7
Weight (kg)	81.9 ± 17.8
Height (m)	1.75 ± 0.08
BMI (kg/m²)	26.6 ± 5
Bioelectrical impedance analysis	
Body fat (%)	12 (11–14)
FFM (%)	88 (87–90)
TBW (%)	64 (63–65)
BMR (kcal)	1966 (1767–2146)

The values shown are mean ± SD, median (interquartile range) or number (%). BMI: body mass index; BMR: basal metabolic rate; FFM: fat-free mass; TBW: total body water.

With regard to HRV, we observed higher values at rest, i.e. before the FSKT-10s, for the following parameters: mean NN intervals [762 (628–890) vs. 402 (382–422), p <0.001, Cohen's d = 3.05]; pNN50 (%) [29 (11–49) vs. 9.8 (5–24.3), p = 0.0007, Cohen's d = 1.47]; ApEn [1.03 (0.73–1.20) vs. 0.42 (0.31–0.66), p <0.001, Cohen's d = 1.85]; and PNS index [0.71 (-0.31–2.22) vs. -1.01 (-2.46–0.03), p = 0.005, Cohen's d = 1.29]. However, we observed higher values during the FSKT-10s for the following parameters: maximum HR [117 (98–117) vs. 195 (181–208), p <0.001, Cohen's d = -2.85], SD2/SD1 [1.15 (0.99–1.33) vs. 1.43 (1.21–1.77), p <0.001, Cohen's d = -1.75]; and SNS index [0.51 (-0.73–1.26) vs. 6.88 (5.2–7.6), p <0.001, Cohen's d = -3.25]. Comparisons between HVR parameters obtained before and during FSKT-10 are shown in Table 2.

We evaluated the correlations between the FSKT kicks and the other study variables with HRV measured before the FSKT-10s (rest) (Table 3 and Figures 1 and 2). The number of kicks assessed in the FSKT-10s was significantly correlated with FFM (%) (r_s = 0.408, 95% CI: 0.160–0.898, R^2 = 0.167, p = 0.016, moderate correlation) and LF (ms²) (r_s = 0.484, 95% CI: 0.175–0.706, R^2 = 0.235, p = 0.003, moderate correlation). The KFI assessed in the FSKT-mult was significantly correlated with FFM (%) (r_s = -0.419, 95% CI: -0.663–-0.095, R^2 = 0.176, p = 0.013, moderate correlation), LF (ms²) (r_s = 0.653, 95% CI: 0.405–0.811, R^2 = 0.427, p <0.001, large correlation), PNS index (r_s = -0.400, 95% CI: -0.728–-0.150, R^2 = 0.160, p = 0.020, moderate correlation) and SNS index (r_s = 0.405, 95% CI: 0.157–0.732, R^2 = 0.164,p = 0.017, moderate correlation). It is worth mentioning that the correlation between the number of kicks evaluated in the FSKT-10s and the KFI was weak and not significant (r_s = 0.279, 95% CI: -0.065–0.563, R^2 = 0.078, p = 0.11) small correlation).

Finally, we evaluated the correlations of the FSKT kicks and other study variables with HRV measured during the FSKT-10s (exercise). In this analysis, we did not observe significant correlations between the FSKT-10s, KFI, BIA, and HRV during the FSKT-10s.

Table 2. Comparisons Between Heart Rate Variability Parameters Obtained Before and During the FSKT-10s (n = 34).

Variable	Before FSKT-10s	Durante FSKT-10s	*p*-value	Effect Size (Cohen's *d*)
mean NN intervals (ms)	762 (628–890)	402 (382–422)	**<0.001**	3.05
maximum HR (bpm)	117 (98–117)	195 (181–208)	**<0.001**	-2.85
SDNN (ms)	77 (59–129)	63 (43–111)	0.11	0.48
rMSSD (ms)	93 (59–139)	92 (54–133)	0.47	0.39
pNN50 (%)	29 (11–49)	9.8 (5–24.3)	**<0.001**	1.47
TINN (ms)	556 (388–1142)	538 (358–621)	0.26	0.42
Total power (ms^2)	3255 (1577–8381)	3479 (715–11148)	0.78	-0.18
LF (Hz)	0.077 (0.05–0.10)	0.097 (0.07–0.13)	0.092	-0.72
LF (nu)	49 (39–62)	57 (32–67)	0.84	-0.15
HF (Hz)	0.21 (0.17–0.28)	0.20 (0.16–0.32)	0.85	0.10
HF (nu)	51 (38–60)	43 (33–67)	0.83	0.16
LF/HF	0.96 (0.66–1.62)	1.33 (0.48–2.04)	0.63	-0.23
SD1 (ms)	66 (42–99)	65 (38–94)	0.47	0.37
SD2 (ms)	63 (43–130)	89 (70–151)	0.092	-0.76
SD2/SD1	1.15 (0.99–1.33)	1.43 (1.21–1.77)	**<0.001**	-1.75
ApEn	1.03 (0.73–1.20)	0.42 (0.31–0.66)	**<0.001**	1.85
PNS index	0.71 (-0.31–2.22)	-1.01 (-2.46–0.03)	**0.005**	1.29
SNS index	0.51 (-0.73–1.26)	6.88 (5.2–7.6)	**<0.001**	-3.25

The values shown are mean ± SD, median (interquartile range) or number (%). Bold type indicates significant correlations. ApEn: approximate entropy; BMR: basal metabolic rate; FFM: fat-free mass; HF: high frequency range; HR: heart rate; LF: low frequency range; NN: normal-to-normal; pNN50: percentage of interval differences of consecutive normal-to-normal intervals greater than 50 ms; PNS: parasympathetic nervous system; rMSSD: the square root of the mean squared differences between consecutive normal-to-normal intervals; SD1: standard deviation of the instantaneous variability beat-to-beat; SD2: standard deviation of long-term continuous NN intervals; SDNN: standard deviation of all normal-to-normal intervals; SNS: sympathetic nervous system; TBW: total body water; TINN: triangular interpolation of normal-to-normal intervals histogram; TP: total power.

Table 3. Spearman's Correlation Coefficients for FSKT-10s, KFI, Bioimpedance Impedance Analysis, and Heart Rate Variability Before FSKT-10s (*n* = 34).

Variables	**FSKT-10s**				**KFI**			
	r_s	**95% CI**	**R^2**	***p*-value**	r_s	**95% CI**	**R^2**	***p*-value**
Body fat (%)	-0.294	-0.539–0.014	0.087	0.091	-0.029	-0.363–0.312	0.001	0.87
FFM (%)	**0.408**	**0.160–0.898**	**0.167**	**0.016**	**-0.419**	**-0.663–-0.095**	**0.176**	**0.013**
TBW (%)	-0.144	-0.459–0.204	0.021	0.42	0.004	-0.334–0.341	0.000	0.98
BMR (kcal)	0.176	-0.172–0.485	0.031	0.32	0.325	-0.014–0.597	0.106	0.061
mean NN intervals (ms)	0.170	-0.178–0.480	0.029	0.34	0.187	-0.161–0.493	0.035	0.29
maximum HR (bpm)	-0.032	-0.366–0.309	0.001	0.86	0.071	-0.273–0.399	0.005	0.69
SDNN (ms)	0.117	-0.230–0.437	0.014	0.51	0.256	-0.090–0.546	0.065	0.14
rMSSD (ms)	0.131	-0.216–0.449	0.017	0.46	-0.240	-0.586–0.054	0.057	0.17
pNN50 (%)	-0.052	-0.383–0.291	0.003	0.77	-0.187	-0.535–0.119	0.035	0.29
TINN (ms)	0.296	-0.046–0.576	0.088	0.089	-0.198	-0.546–0.106	0.039	0.26
Total power (ms^2)	-0.013	-0.349–0.326	0.000	0.94	0.210	-0.137–0.511	0.044	0.23
LF (Hz)	**0.484**	**0.175–0.706**	**0.235**	**0.003**	**0.653**	**0.405–0.811**	**0.427**	**<0.001**
LF (nu)	0.180	-0.128–0.528	0.033	0.31	0.027	-0.361–0.314	0.001	0.88
HF (Hz)	-0.213	-0.514–0.134	0.045	0.23	-0.164	-0.475–0.184	0.027	0.35
HF (nu)	-0.179	-0.527–0.129	0.032	0.31	-0.032	-0.373–0.302	0.001	0.86
LF/HF	-0.189	-0.495–0.159	0.036	0.28	-0.032	-0.366–0.309	0.001	0.86
SD1 (ms)	0.131	-0.217–0.448	0.017	0.46	-0.240	-0.106–0.534	0.057	0.17
SD2 (ms)	0.063	-0.281–0.392	0.004	0.72	0.279	-0.065–0.563	0.078	0.11
SD2/SD1	-0.168	-0.478–0.180	0.028	0.34	-0.058	-0.388–0.285	0.003	0.74
ApEn	-0.300	-0.579–0.042	0.090	0.085	-0.115	-0.436–0.232	0.013	0.52
PNS index	0.102	-0.244–0.425	0.010	0.57	**-0.400**	**-0.728–-0.150**	**0.160**	**0.020**
SNS index	0.254	-0.037–0.600	0.065	0.15	**0.405**	**0.157–0.732**	**0.164**	**0.017**

Bold type indicates significant correlations. ApEn: approximate entropy; HF: high frequency range; LF: low frequency range; NN: normal-to-normal; pNN50: percentage of interval differences of consecutive normal-to-normal intervals greater than 50 ms; PNS: parasympathetic nervous system; rMSSD: the square root of the mean squared differences between consecutive normal-to-normal intervals; SD1: standard deviation of the instantaneous variability beat-to-beat; SD2: standard deviation of long-term continuous NN intervals; SDNN: standard deviation of all normal-to-normal intervals; SNS: sympathetic nervous system; TBW: total body water; TINN: triangular interpolation of normal-to-normal intervals histogram; TP: total power.

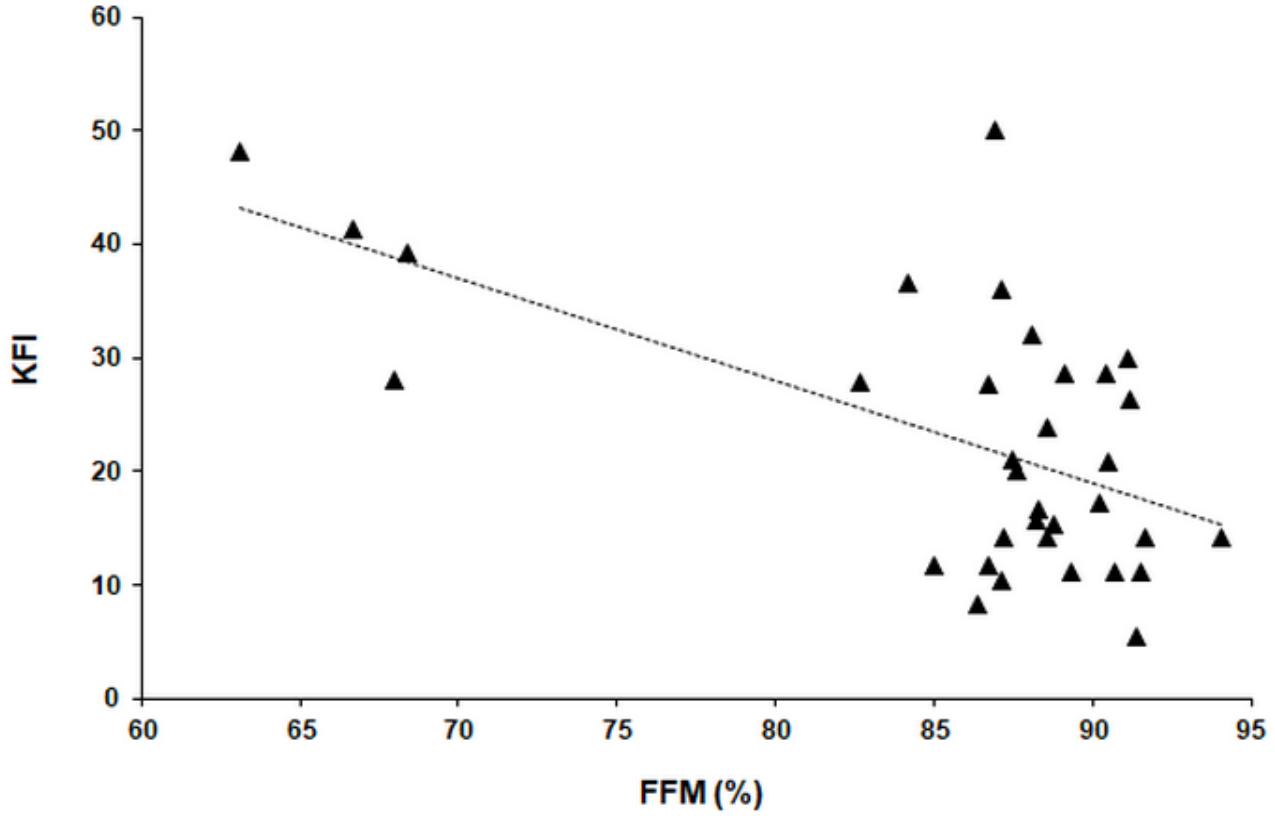

Figure 1. Relationship of kick fatigue index (KFI) with the fat-free mass (FFM, r_s = -0.419, 95% CI: -0.663--0.095, R^2 = 0.176, p = 0.013, moderate correlation).

Discussion

The ability to generate force in the lower limbs with the least amount of fatigue is critical to the success of many sporting events, including amateur Muay Thai fights. In this sense, we used the FSKT-10s technique and its multiple version, as they are among the most used techniques during an official competition.[14] Using HRV measurements coupled to the FSKT-10s, the main findings of the present study were that in amateur Muay Thai fighters, when comparing the periods before and during the FSKT, there is a vagal withdrawal (reduction of pNN50 and PNS index) and an increased sympathetic activity (elevation of SD2/SD1 and SNS index), with the ANS becoming less complex. In these athletes, the greater the number of kicks applied in the FSKT-10s, the greater the FFM and the greater the sympathetic activation assessed by LF. Furthermore, the greater the fatigue, the lower the FFM, the greater the sympathetic activation as assessed by both the LF index and the SNS index, and the greater the vagal withdrawal as assessed by the PNS index.

HRV measurement is a non-invasive and easily performed assessment tool that allows the identification of potential cardiovascular risks.[9] When moving from rest to the FSKT-10s technique, we observed an increase in parameters indicative of sympathetic activation and a

decrease in parameters indicative of vagal withdrawal. Consistent with our findings, Leite et al[30] studied the immediate effects of high-velocity low-amplitude thrust (HVLAT) in judo athletes and demonstrated that HVLAT was capable of altering HRV through sympathetic hyperactivity. However, these authors did not observe a decrease in PNS performance - as we observed in pNN50 and PNS index - suggesting that Muay Thai and Judo may have different effects on autonomic modulation. In fact, HRV indices and cortisol concentrations did not change during high-intensity intermittent activity using specific judo exercises, as demonstrated by Campos et al[31]. Consistent with our results, a recent meta-analysis showed that Tai Chi has a positive effect on key HRV parameters associated with ANS balance, including increased PNS activation, compared to non-active control conditions.[32] The possible mechanisms involved in the modification of HRV and especially parasympathetic modulation in the exercising participants are speculative, especially regarding the immediate effects. In the long term, exercise reduces levels of angiotensin II, a substance that inhibits vagal activity, and there is also an increase in nitric oxide, which may be related to greater activation of vagal modulation.[9]

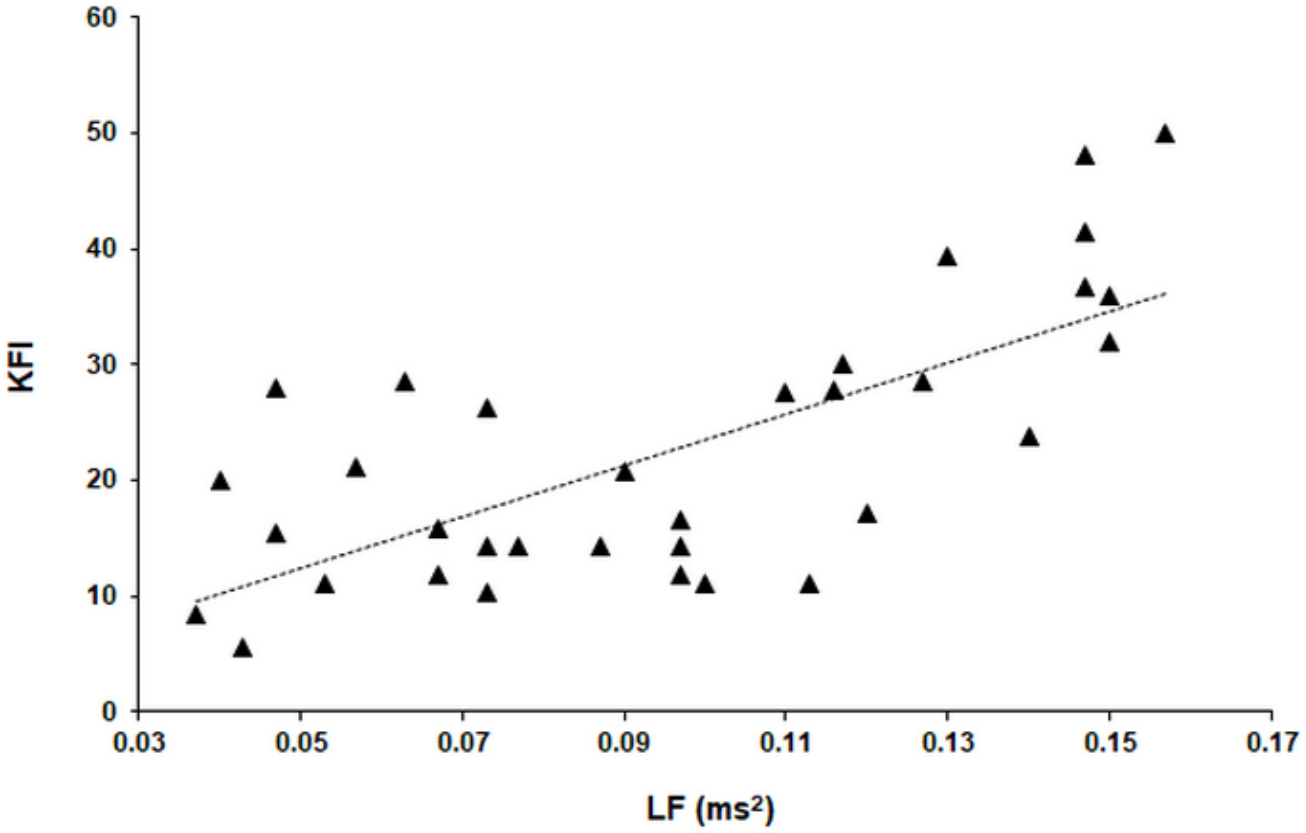

Figure 2. Relationships of kick fatigue index (KFI) with the low frequency range (LF, r_s = 0.653, 95% CI: 0.405–0.811, R^2 = 0.427, p <0.001, large correlation).

In high-performance martial arts, adaptations in HRV can be observed during each phase of training.[33] Interestingly, we observed a significant reduction in ApEn when the athlete left the resting position to strike in the FSKT. ApEn describes the predictability or randomness of

physical systems, where a high ApEn indicates high complexity and chaos of a given system, while a low ApEn indicates a more regular signal.[34] Although this parameter has not yet been evaluated in the literature in martial artists, the findings of Saraiva et al[12] and Bhattacharya et al[35] suggest that there is a greater time-dependent adaptability of the ANS in karate and judo fighters, which may contribute to resilience to stress and improve recovery time. In this sense, it is essential to carry out studies with larger cohorts and longitudinal evaluations to better define the benefits of Muay Thai on the ANS, since low ApEn is associated with better homeostatic behavior of the individual and reduced individual risk of cardiovascular disease.[36]

In the present study, the greater the number of kicks applied in the FSKT-10, the greater the sympathetic activation assessed by the LF. Consistent with our study, Lu and Kuo[9] compared the autonomic profile of two martial arts groups (tai chi chuan and wai tan kung) with a control group; these authors reported that both martial arts groups had higher LF values compared with controls. Importantly, we observed that higher KFI was associated with sympathetic activation and vagal withdrawal. Although it is believed that the availability of adenosine triphosphate and phosphocreatine energy reserves and the ability to perform successive high-intensity actions are key elements in achieving good performance in martial arts, a balance between rest and effort is necessary to generate potential.[37] Analyzing the biomechanics of the kicking leg using 3D kinematic data from Muay Thai fighters, Gavagan and Sayers[38] observed that the effectiveness of the roundhouse kick is characterized by rapid rates of pelvic axial rotation and knee extension, and rapid movements of the center of mass toward the target, although all of these conditions can predispose to fatigue if overused and not properly trained. From an athletic standpoint, it is important to monitor HRV on a regular basis; athletes with greater vagal modulation at rest have higher HRV and faster post-exercise lactate clearance.[39]

Based on BMI, we observed that almost half of our sample consisted of eutrophic athletes. In agreement with our results, Machado and Medeiros[15] showed that 70% of Muay Thai practitioners have an adequate body composition and 53% also have a eutrophic nutritional status according to BMI, although 83% of them follow a hypocaloric diet. Still on body composition, we observed significant correlations between FFM and both performance on the FSKT (positive correlation) and KFI (negative correlation). Comparing the level of physical fitness between Muay Thai and Brazilian Jiu-Jitsu athletes, Wąsacz et al[3] recently observed that Jiu-Jitsu athletes performed better in strength tests, with high correlations between training load and level of physical fitness in flexibility and strength tests in Jiu-Jitsu athletes and in most strength tests in Muay Thai athletes. In contrast, Rapkiewicz et al[2] found no significant correlations between physical fitness indicators and basal body fat or BMI in Muay Thai athletes. However, since there is heterogeneity in age group and percentage of body fat and BMI, the adaptations provided by training may differ according to the characteristics of the athletes. In this scenario, FFM measurement may be a more reliable indicator of performance and fatigue. Therefore, from an athletic standpoint, it is important to coordinate resistance training with nutritional adequacy (e.g., increased protein intake and creatine supplementation); this will result in hypertrophy and an increase in FFM.[40]

The strength of this study is that it evaluated in detail the behavior of the ANS before and during an exercise test in amateur Muay Thai fighters and observed associations with body composition as measured by BIA. However, limitations must be noted. First, the evaluation of a control group not undergoing the FSKT could strengthen our results with regard to the strength of the correlations found with HRV and body composition. Second, we use BIA to assess FFM and body fat. In addition to limitations related to measurement differences between BIA devices, caution should be exercised in situations that alter water and electrolyte balance, such as intense physical activity, pretest fluid intake, and dehydration or fluid retention. Although we used equations for BIA that account for ethnicity and athletic performance, other more precise techniques, such as dual-energy X-ray absorptiometry (DXA) and computed tomography (CT), may more accurately evaluate changes in body composition.[41] Third, we did not directly measure cardiorespiratory fitness using cardiopulmonary exercise testing to obtain oxygen consumption. Third, the lack of a control group makes important interpretations of the magnitude of our results difficult. Despite these limitations, our study can serve as a starting point for randomized controlled longitudinal studies to evaluate the prognostic value of HRV in Muay Thai athletes. A gap to be addressed in future studies is the use of DEXA or CT to assess body composition and its relationship to HRV. In addition, long-term assessment of HRV following interventions that may alter performance and body composition may help to better understand these athletes.

In conclusion, in amateur Muay Thai fighters, there is an acute effect on the ANS with increased sympathetic activation, vagal withdrawal, and decreased system complexity when these athletes are subjected to the FSKT-10s. In these athletes, there is a relationship between FFM and both performance on the FSKT-10s and susceptibility to fatigue. Furthermore, there is a relationship between sympathetic activation and the number of kicks and the susceptibility to fatigue. Thus, the results of this study can be used by coaches as guidelines for developing strength and conditioning programs for their Muay Thai athletes in preparation for martial arts competitions. In particular, coaches can use our findings to optimize athlete performance and injury prevention based on body composition and HRV parameters obtained before and during the FSKT-10.

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