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Original article

Investigating the Impact of Physiological and Neuromuscular Performance in Highly Trained Judo Athletes of Different Weight Categories

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Abstract

Background and Study Aim This study aimed to investigate the physiological and neuromuscular aspects influencing the performance of highly trained judo athletes across different weight categories.

Material and Methods: A total of twenty-one male judokas with an average age of 20.6 ± 1.8 years participated in the study. The participants had an average body mass (MC) of 77.3 ± 13.4 kg and an average height (SH) of 176.5 ± 8.4 cm. The study employed various assessments to evaluate muscle power, judogi strength endurance, special judo fitness, fight simulation, and incremental treadmill tests. Statistical analyses, such as the Shapiro-Wilk test, Pearson's linear correlation, "t" test for dependent samples, and one-way ANOVA, were used.

Results: there was significant correlations between the number of throws in the Special Judo Fitness Test (SJFT) and factors such as ANV, PV, and CMJ. However, no significant correlations were observed between Fmax and TMF_{max} on the dominant and non-dominant sides, as well as LAC_{max}. $\%FC_{max}$ did not show a significant correlation with ANV and DLS. A significant inverse correlation was found between LAC_{max} and VLA_n, while no correlation was observed between DLS and VLA_n. LAC_{max} values were significantly higher in the medium/medium-heavy category compared to the light/medium-heavy category, and the CMJ was significantly lower in the medium/medium-heavy category compared to the other categories.

Conclusion: conclusion, this study determined that muscle power, capacity, and aerobic power were the primary factors influencing the number of throws in the SJFT among highly trained judo athletes. Maximum strength, strength resistance, and glycolytic capacity did not significantly contribute to the number of throws. Athletes with greater aerobic capacity exhibited lower glycolytic demand during fights. these factors can contribute to the development of effective training programs and strategies to optimize performance in judo athletes of various weight categories.

Keywords: Physiological, Neuromuscular, judo, performance.

Анотація

Дослідження впливу фізіологічних та нервово-м'язових показників у дзюдоїстів високої кваліфікації різних вагових категорій

Передумови та мета дослідження. Це дослідження мало на меті дослідити фізіологічні та нервово-м'язові аспекти, що впливають на результати спортивної діяльності дзюдоїстів високої кваліфікації у різних вагових категоріях.

Матеріали та методи. У дослідженні брали участь 21 дзюдоїст чоловічої статі, середній вік яких становив 20,6±1,8 роки. Учасники мали середню масу тіла (МТ) 77,3 ± 13,4 кг та середній зріст (СЗ) 176,5 ± 8,4 см. У дослідженні використовувалися різні тести для оцінки м'язової сили, силової витривалості, спеціальної фізичної підготовленості дзюдоїстів, імітації бою та додаткові тести на біговій доріжці. У процесі дослідженні нами використовувалися статистичні методи аналізу, такі як: критерій Шапіро-Вілка, лінійна кореляція Пірсона, t-критерій для залежних вибірок та однофакторний аналіз ANOVA.

Результати: виявлено значну кореляцію між кількістю кидків у Спеціальному фітнес-тесті з дзюдо (SJFT) та такими факторами, як анаеробний поріг (ANV), максимальна швидкість та стрибок у протидії (CMJ). Однак достовірних значень кореляцій між максимальним значенням (Fмакс) та максимальною швидкістю збереження сили (TMF_{max}) на домінантній та недомінантній сторонах, а також концентратом лактату (LAC_{max}) не спостерігалося. % FCmax не показав значної кореляції з ANV та зі зниженням рівня лактату в крові (DLS). Між LAC_{max} та швидкістю на анаеробному порозі (VLA_n) було виявлено значну зворотну кореляцію, тоді як між DLS та VLAn кореляції не спостерігалося. Значення LAC_{max} були значно вищими у категорії «середній/середньо-важкий» порівняно з категорією «легкий/середньо-важкий», а CMJ був значно нижчим у категорії «середній/середньо-важкий» у порівнянні з іншими категоріями.

Висновки: у процесі дослідження було визначено, що м'язова сила, працездатність та аеробна потужність є основними факторами, які впливають на кількість кидків у SJFT серед висококваліфікованих спортсменів-дзюдоїстів. Максимальна сила, силовий опір і гліколітична здатність істотно не впливали на кількість кидків. Спортсмени з вищими аеробними здібностями демонстрували нижчу потребу в гліколізі під час поєдинку. Ці фактори можуть сприяти розробці ефективних тренувальних програм та стратегій для оптимізації результатів дзюдоїстів різних вагових категорій.

Ключові слова: фізіологічний, нервово-м'язовий, дзюдо, результативність.

Introduction

judo is a high-intensity martial art that combines several physical qualities, making it the subject of many systematic investigations, including analyses of physiological and neuromuscular variables related to performance during fights [1]. The temporal characteristics of judo fights range from a few seconds to four minutes and even longer (golden score) [2], which

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makes it challenging to describe a single physiological model that quantifies the effort [3]. Moreover, athletes typically fight several times in the same day of competition, further complicating the analysis of fight intensity. The intermittent, short-duration, and high-intensity nature of fights place a high demand on anaerobic metabolism, as demonstrated by the high lactate concentrations observed [4, 5].

The extended maintenance of the energy release rate is largely determined by the use of lactic and alactic anaerobic stocks [4]. High blood lactate values after high-effort activities indicate a high participation of the transformation of glucose to lactate anaerobic glycolysis [6–8], which is associated with an individual's anaerobic capacity. However, it is essential to note that blood lactate concentrations (BLC) only suggest how much glycolysis was requested, with no indication of the use of phosphates [9, 10]. Although the anaerobic system is the primary determinant of metabolism in high-intensity training exercises, such as judo rondori and shiai [11], it has been suggested that the aerobic system plays an important role in rapidly increasing the energy (ATP) demand of the exercise, performing an essential role in maximum short-term efforts [12–14].

Furthermore, the aerobic capacity is essential when fights continue for a long time and there is a sequence of the duration and number of fights on the same day of competition. Taking this into account, Chaabene et al.(2016) found that, in addition to the use of muscle glycogen as an energy source in combat, there was an increase in the use of triglycerides, free fat acids, and glycerol, indicating an increase in aerobic demand, especially at the end of the fight [16]. The aerobic fitness of judo athletes has also been linked to metabolic recovery processes (MRP) [17].

Previous studies have shown that aerobic capacity seems to be associated with a lower accumulation of blood lactate after fight simulations [18, 19] and higher blood lactate removal after the fight in judo athletes who use active recovery [20]. Additionally, judokas with higher aerobic power can take advantage in periods of combat with a maximum duration (4 min), as the absolute supra-maximum effort may represent less intensity when compared to athletes with less aerobic power [21, 22]. Such aspects can contribute for the judoka to maintain the intensity in the sequence of the fights, contributing in the control of the muscular fatigue process.

In addition to the physical qualities related to energy metabolism, neuromuscular factors can also be considered essential components for performance in judo, such as muscle power, which is related to a higher number of attacks and higher effectiveness in landing with opponents. Power is determined by an optimal combination of strength and speed generated by the muscles [21–23], and factors such as the capacity for neural recruitment [24, 25], the use of Impact Loading and the Stretch Shortening Cycle (SSC), and the rate of energy release through the anaerobic metabolic pathway may determine the power to be produced [26].

Another neuromuscular variable is present in the kumikata grip in judogui (clothing used in judo), considered an important process for success in a judo shiai, because a kumikata grip that imposes difficulties on the opponent will positively influence the execution of techniques [27]. It has been verified that grip strength depends on several factors, such as maximum isometric handgrip strength, strength resistance, and dynamic strength, since in addition to the isometric contraction of the forearm muscles, the arm and trunk regions perform dynamic actions during the kumikata grip of a fight [28–30].

Bearing in mind that judo is a sport in which confrontations are divided by sex and weight categories, factors associated with performance may differ significantly between sexes and weight categories*. Relatively little research has analyzed such aspects [31] compared to some physical characteristics between the light, middle, and heavy weight categories and found, in general, an inverse relationship between the weight category and aerobic power [32], in addition to a positive relationship between body fat and the weight category [33]. In females, in particular, it was verified that the judokas of heavy weight categories presented higher absolute maximum strength of upper limbs when compared to those of light and middle categories. These results indicate that the physiological profiles of judokas differ significantly between weight categories, suggesting that the factors responsible for success are very specific for each category [34–36].

Based on the assumptions highlighted about the importance of investigating parameters associated with the performance of judo athletes, so that they can be used to control and prescribe training loads, the following research questions were formulated: what are the relationships between different physiological and neuromuscular indexes with specific high-performance actions in judo? Are there differences in these indices between the three weight categories?

The aim of this research was to investigate the neuromuscular and physiological aspects that contribute to high performance in judo, specifically in different weight categories.

Materials and Methods

Participants

Twenty-one male judokas from two training from Algerian national judo and one from west judo region participated in this study. Among the athletes, four belonged to the light category, three half-light, five light, one middle, two medium and three middle-heavy. The characteristics of the judokas are presented in Table 1.

Overall, the study conducted anthropometric evaluations, incremental tests on a treadmill, the Special Judo Fitness Test (SJFT), and fight simulations (Randori) to assess physical fitness and performance in a sample of judokas. The sample was intentionally selected, consisting of judokas of legal age with at least two years of practice in the sport, without any type of injury, who participated in competitions at least at the state level, and with a body mass less than 100 kg.

Table 1. Descriptive values referring to the characteristics of the study athletes.

	Age (years)	*weight(kg)*	*high (cm)*	*BF (%)*	*Practice (years)*	*Weekly Training(w)*	*Training (min)*
mean	20,6	77,3	176,5	13,4	9,4	5,7	105
SD	1,8	13,4	8,4	3,3	4,7	2	0,3
Max	29	98,9	193,7	20,8	19	7	120
Min	17	53,6	153	8,8	4	3	90

Note: BF-Body fat

Anthropometric measurements

were taken using the Adel et al., (2019) protocol, which involved the measurement of four skinfolds (triceps, subscapular, suprailiac, and medial calf) and age to estimate body density (BD). From BD, the Body fat percentage (%) was determined using Siri's (1961) equation. In our study, body length was measured using a stadiometer with a precision of 1 mm. Body weight was measured using a Tanita digital scale with a precision of 100 g. For skinfold measurements, a Gima «Skinfold caliper» with 10 g/mm2 precision was used.

Procedure

For The VLA_n and PV protocol involved an incremental test on a treadmill with an initial speed of 8 km/h and 1% incline. The speed was then increased by 1 km/h every 3 minutes until voluntary exhaustion, with a 30-second interval between each stage for blood lactate measurement from the earlobe [37]. LA_n, which represents the lactate threshold, was determined by linear interpolation of lactate levels and exercise intensity, with a fixed concentration of 3.5 mmol.L-1 [38].

To determine the peak velocity, the maximum speed attained by the athlete during the last stage of the test was recorded, provided that the athlete sustained the activity for at least 2 minutes. PV, which stands for peak velocity, is an essential metric in assessing athletic performance and represents the highest attainable speed for the individual during exercise [34, 39].

The SJFT protocol The SJFT (Special Judo Fitness Test) is a fitness test designed by Sterkowicz and described by [40, 41]. It requires three judokas with similar body mass, where one participant (TORI) performs the throws while the other two (UKE) receive them. The test is comprised of three 10-second recovery periods, each consisting of 15 seconds (series A), 30 seconds (series B), and 30 seconds (series C), during which the athlete must complete as many throws as possible. The number of throws completed in each period is recorded, and the athlete's heart rate is measured immediately after the test and 1 minute after the test using Polar Team 2 (Polar, Finland). The test's reliability was reported to be 0.97, and Figure 1 illustrates the SJFT.

Fight simulations

(Randori) involved fights between athletes with a difference of corporal mass inferior to 15%, with each fight lasting five minutes. Blood lactate concentration was measured using a lactate analyzer from YSI Life Sciences (Yellow Springs, Ohio, USA), were collected at various time intervals after the fight to determine the peak concentration of blood lactate (LAC_{max}) and the percentage of decrease of blood lactate (DLS). were calculated using the equation proposed by Pelayo et al. (1996) and adapted by Franchini et al.(2001).(equation 1).

$$\%DLS = \frac{(LA_{peak} - LA[_{15min}])}{LA_{peak}} * 100$$

Where: %DLS: percentage of the decrease in blood lactate concentration

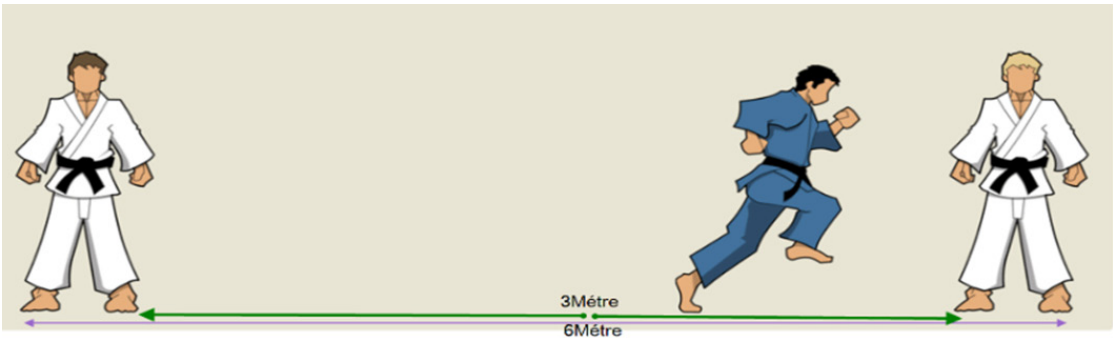

Figure 1. illustrates the Special Judo Fitness Test (SJFT)

SJFT Index equation.

$$SJFT\ index = \frac{(Final\ HR\ (bpm) - HR\ (bpm)\ 1\ min\ after\ test)}{\text{"Number of throws"}(N)}$$

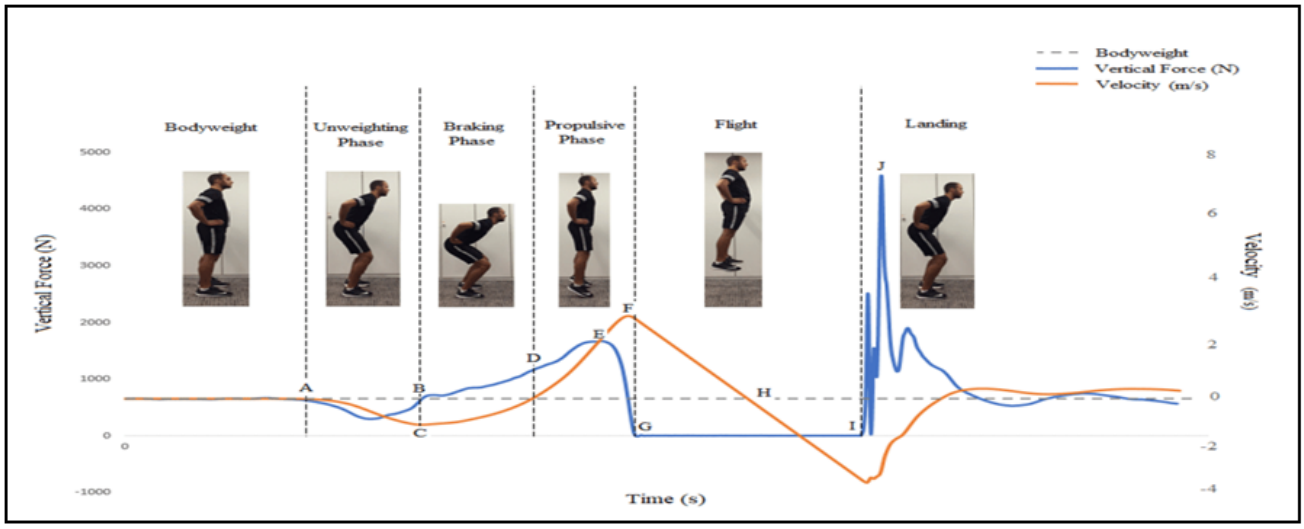

Figure 2. Illustrative of the performance of the CMJ [42].

LA_{peak}: peak lactate concentration in this interval
$LA_{[15min]}$: lactate concentration at the 15th minute
CMJ vertical jump protocol

To perform the CMJ, the athlete started from a standing position with his hands on his waist, arranged on the force platform. Subsequently, he executed a counter-movement, which consists in an acceleration downwards from the CG, flexing the knees to near 90º (Figure 2). During the jump, the trunk remained as vertical as possible[42].

The formula provided is the formula for calculating height (H) from the variation of velocity as a function of time. It uses the double integration method, which involves calculating the area under the curve twice. The instantaneous velocity is first calculated from the force, body mass, and known initial velocity, and then the variation of velocity as a function of time is obtained by integrating the acceleration. Finally, the height is obtained by integrating the variation of velocity as a function of time. The formula is:

$$H=(\mathrm{V}(t)\text{-}\mathrm{V}0)dt$$

Where: *H*: height, *V*: final velocity, Vo: initial velocity, *dt*: time derivative

This formula assumes that air resistance is negligible, and it is typically used to calculate jump height from force platform data.

Peak Force

The protocol to obtain the PF involved simulating a pull on the collar and sleeve of the judogi to create the phase of *kuzushi* (unbalance). The athletes were instructed to simulate the execution of the *kuzushi* as if they were in a real situation and to perform the pull-up after a verbal command, maintaining it for 10 seconds (see Figure 3). The judokas were instructed to exert maximum isometric force in the first instant of the pull-up and maintain it for 10 seconds. This time was chosen to estimate the isometric force strength during the pull-out phase, as demonstrated in a previous study [43].

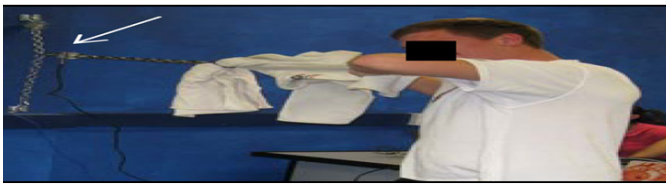

Figure 3. representation of the pull in judogi.

Two pull-ups were performed on the dominant and non-dominant sides, and the maximum value (Fmax) and maximum force maintenance rate (TMF_{max}) were considered for FP analysis. To calculate Fmax, the highest value obtained in the first second was used. To calculate the maintenance rate of Fmax, the force values (after the first second) were initially normalized by Fmax and then their average value was calculated (see Figure 4). TMF_{max} was calculated after the first second to maintain the same maintenance time for all subjects. For group analysis, Fmax values were normalized by the body mass of the subjects.

Statistical analysis

For the presentation of the results, descriptive statistics such as mean, standard deviation, minimum, and maximum were used. The Shapiro-Wilk test was used to verify the normality of the data. The Pearson's linear correlation was used to verify the correlation between the indexes and specific judo situations. The student's "t" test for dependent data was used to compare the PF between the dominant and non-dominant sides. Analysis of variance (ANOVA one way) was used to compare the physiological and neuromuscular indexes between weight categories, followed by the Tukey test. In all tests, a confidence interval of 95% was used.

Results

Presentation of the analysed variables

The values of the physiological and neuromuscular indices analysed in judokas of all weight categories are described according to the tests performed.

Table 2. Descriptive values of the SJFT performance variables in judokas.

Variable	*Mean ± SD*
Number of throws A (15 s)	6.0 ± 0.6
Number of throws B (30 s)	11.0 ± 0.9
Number of throws C (30 s)	10.0 ± 1.1
Total Number of throws	27.0 ± 2.1
HR after test (bpm)	179 ± 10
HR 1 min after test (bpm)	155 ± 14.7
HRmax % 1 min after test	80 ± 6.2
SJFT index	12.5 ± 1.0

Note: bpm - beats per minute. SD - standard deviation.

Table 3. Descriptive values of the performance in the CMJ in the judokas analysed.

Variable	*Mean ± SD*
CMJ_H (cm)	45.36 ± 3.71
CMJ_{AP} (W.kg-1)	26.31 ± 2.72

Note: CMJ_H - height in counter movement jump cm - centimetres, W.kg-1 - watts per kilogram, CMJ_{AP} - average power in CMJ.

In addition, the data presented in the text indicates that

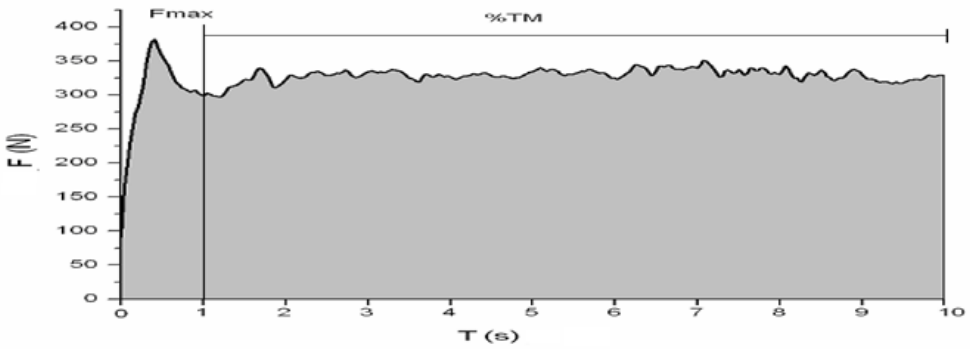

Figure 4. Representation of the variables Fmax and TMF_{max} in a force x time curve.

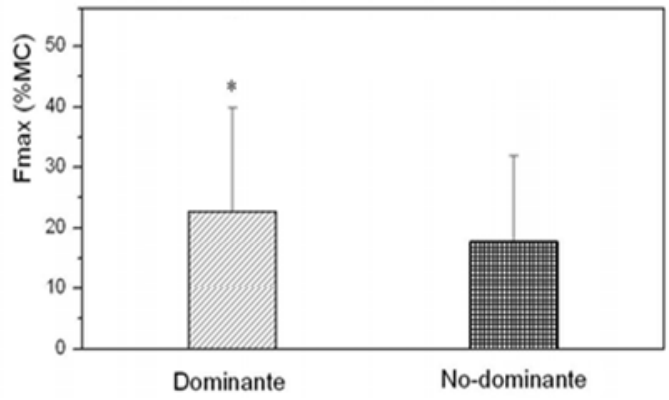

Figure 5. Maintenance rate of Fmax during the pull in judogi in dominant and non-dominant sides.

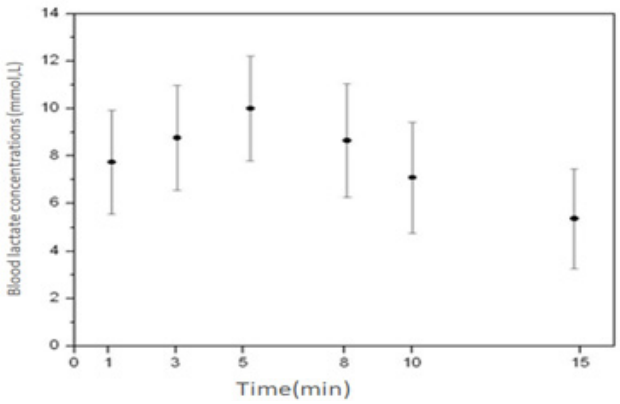

Figure 6. Blood lactate concentrations (mmol. L-1) after a judo fight.

there was a significant difference between the relative values of Fmax on the dominant and non-dominant sides (p= 0.02). The mean Fmax on the dominant side was 50.73 ± 27.62 %MC, while on the non-dominant side it was 45.66 ± 24.84 %MC. On the other hand, there was no significant difference in the maintenance rate of Fmax between the dominant and non-dominant sides (p= 0.06), with mean values of 70.68 ± 10.42 % and 75.62 ± 10.37 %, respectively.

In Figure 5 are arranged the average values of the blood lactate concentrations ([Lac]) after the fight simulation. The lactate peak (LAC_{max}) occurred, in average, in the fifth minute with concentration of 10.17 ± 3.13 mmol. L-1, and in the 15th min, the concentration was 6.52 ± 2.77 mmol. L-1, which corresponds to 37.32 ± 10.14 % of lactate removal during the recovery period.

Table 4 shows the values of the speed corresponding to the anaerobic threshold (ANL), referring to the fixed concentration of 3.5 mmol. L-1 and the peak speed (PV) reached in the incremental test on treadmill.

Table 4: Speed corresponding to the anaerobic threshold (ANLV) and peak speed (PV).

Variables	Mean	SD
LSLV (km.h-1)	11,7	1,3
BW (km.h-1)	15,6	0,9

Relations between physiological and neuromuscular aspects and specific judo situations In relation to the number of throws in SJFT, a significant correlation was found with VLA_n, PV and JMC (Figures 7, 8 and 9), but no significant correlation was reported with Fmax in dominant and non-dominant sides, with the maintenance rate of Fmax in dominant and non-dominant sides and with LAC_{max} (Figure 10). Thus, we reject the first and second null hypothesis, considering the existence of significant correlations among the variables number of throws in SJFT, VLA_n and PV. For the other hypotheses (H3 and H4) the null hypothesis is accepted, that is, the alternative hypotheses are rejected.

Overall, the results suggest that there are significant

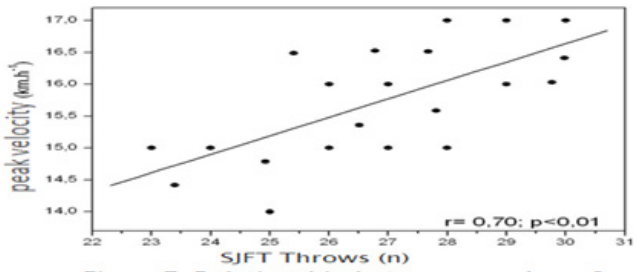

Figure7. Relationship between number of throws in SJFT and peak velocity (PV).

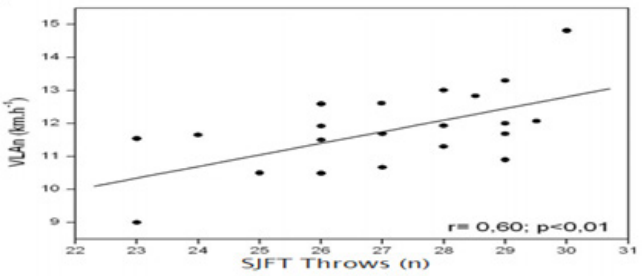

Figure 8. Relationship between number of throws in SJFT and speed at anaerobic threshold (VLAn).

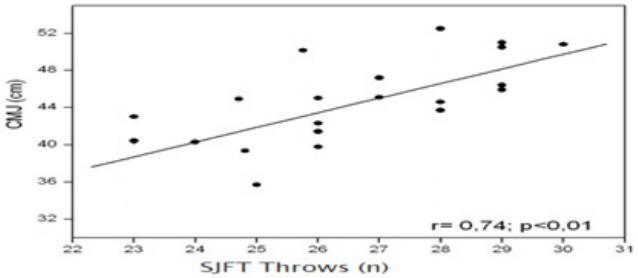

Figure 9. Relationship between number of throws in SJFT and performance in CMJ.

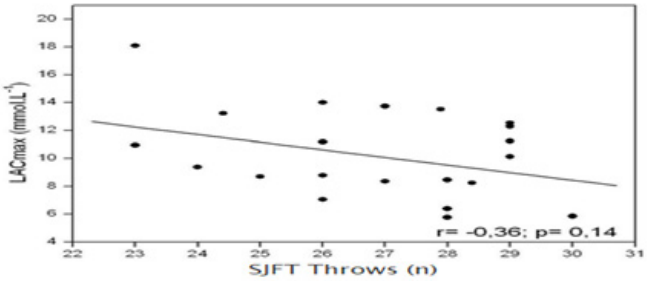

Figure 10. Relationship between number of throws in SJFT and peak blood lactate after the fight (LACmax).

Table 5. Comparison of physiological and neuromuscular indexes among judokas of the category's: light, middle and heavy weight.

variables	Light weight (n = 7)	Middele weight (n = 8)	Heavy weight (n = 6)
Number of throws SJFT (n)	28,3 ± 1,5	27,9 ± 1,3	26,1 ± 28
% FC_{max} 1 min SJFT	76,9 ± 7,5	83,9 ± 4,1	78,7 ± 3,3
LAC_{max} (mmol.L - ¹)	9,8 ± 2,0 *	8,5 ± 2,4	12,9 ± 3,2 *
DLS (%)	35,8 ± 4,7	39,8 ± 12,7	35,7 ± 10,1
VLA_n (km.h -¹)	11,9 ± 1,0	11,9 ± 1,5	10,8 ± 1,0
PV (km.h-¹)	16 ± 0,8	16 ± 0,8	15 ± 0,7
CMJ (cm)	45,4 ± 3,1	46,3 ± 3,9	41,9 ± 4,4 *

Note: SJFT – Special Judo Fitness Test; HRmax – maximum heart rate; LAC_{max} – peak blood lactate; DLS – decrease in blood lactate; VLA_n – velocity at anaerobic threshold; PV – Peak Velocity CMJ – Countermovement Jump *p≤ 0,05.

relationships between some physiological and neuromuscular variables and specific judo situations, as well as differences in some variables between weight categories. Specifically, the number of throws in SJFT was significantly correlated with VLA_n, PV, and JMC, indicating that these variables may play a role in the ability to execute throws in this test. However, no significant correlations were found between the number of throws and Fmax, maintenance rate of Fmax, or LAC_{max}. This suggests that these variables may not be as important for performance in the SJFT.

In terms of weight categories, it was found that LAC_{max} was significantly higher in the medium/medium-heavy category compared to the light/middle category, which may indicate differences in anaerobic capacity between these groups. Additionally, MJC was significantly lower in the medium/middle-heavy category compared to the other categories, suggesting differences in explosive power. However, most of the other variables did not show significant differences between weight categories.

It is important to note that the neuromuscular indexes related to pull force (Fmax and TMF_{max}) were not tested in relation to weight categories, as they were normalized by the participants' body mass. Overall, these findings provide insight into the physiological and neuromuscular factors that may influence performance in judo and highlight the importance of considering weight categories in the analysis of these variables.

Discussion

This study investigate the neuromuscular and physiological aspects that contribute to high performance in judo, specifically in different weight categories,also its indicate the particularly of the relationship between the number of throws in the Special Judo Fitness Test (SJFT) and indexes of aerobic capacity (VLAn) and aerobic power (PV). Despite Judo being categorized as a sport that primarily relies on anaerobic metabolism for decisive actions, this study highlights the importance of aerobic components in certain situational contexts within the realm of Judo [16, 44].

Franchini et al. (2007) also reported a significant correlation between the number of throws in the SJFT and aerobic power (VO2max) in judokas of the Brazilian National Team, indicating the importance of aerobic power in determining recovery between series of SJFT. Furthermore, it was observed that the resynthesis of phosphocreatine (PCr) was positively associated with aerobic power in trained judokas [46]. Elite judokas with higher aerobic potency may take advantage in periods of combat with a maximum duration of 5 minutes, as the absolute supramaximal effort may represent less intensity when compared with athletes with lower VO2max [9].

Previous studies have indicated that sports that are predominantly anaerobic can still have an aerobic component [47, 48]. Aerobic capacity, as indicated by the lactate threshold (LAn), and aerobic power, as indicated by the individual's maximum oxygen uptake (VO2max), were correlated with the time obtained in a repeated sprints test in professional judo athletes [48]. Similarly, a significant inverse correlation was found between VO2max and total time in repeated sprints when analysing elite football players [49]. High-intensity exercise, such as repeated sprints, was also found to have a significant contribution of aerobic metabolism [50, 51].

There is an inverse correlation between (VLAn) and LACmax, indicating that aerobic capacity may play a significant role in recovery after a fight [52, 53]. Similarly, Detanico, et al. (2012) found that VLAn was negatively correlated with peak lactate concentration after each fight. The ability to sustain predominantly aerobic metabolism during exercise can result in lower lactate accumulation, thus decreasing the demand for glycolysis and subsequently less energy required during recovery to remove lactate and H+ from the muscle [45, 53, 55]. Endurance training and high-intensity interval training can increase the rate of lactate removal during intense exercise by increasing the amount of lactate transporters and mitochondrial volume, thus decreasing lactate concentration in blood [9, 56, 57].

However, a study did not find any correlations between VLA_n and DLS with the %FCmax obtained one minute after the SJFT, suggesting that HR may not be a good indicator of aerobic capacity [46, 58, 59]. Although the absolute HR values obtained after the test were lower than those reported in other studies with elite judokas [44, 60, 61], This suggests that the athletes in this study may have greater or equal cardiovascular capacity to return to the pre-exercise state than those in the other studies, but in those investigations, HR was not related to indices of aerobic capacity.

In this study, the expected inverse relationship between lactate removal and recovery HR decrease after SJFT was not observed, possibly due to the non-linear behavior of HR kinetics in the initial instants of the recovery phase [40, 47, 62]. Fernandes et al. (2005) suggested that the fast phase of HR decrease is determined mainly by neural mechanisms related to motor cortex activity rather than aerobic fitness. On the other hand, the slow phase of HR decrease in recovery periods exceeding one minute is determined by the athlete's aerobic fitness [9, 63]. However, the accumulation of metabolites after exercise may stimulate muscular baroreceptors, maintaining myocardial sympathetic activity high and hindering the fall of HR during recovery [1, 64].

Neuromuscular aspects are crucial determinants of performance in judo, as highlighted in previous studies [10, 65]. In particular, the power of the lower limbs is a significant factor in the success of judo athletes, as demonstrated by the significant correlation between the number of throws in SJFT and performance in CMJ ([47, 66]. The Counter-Movement Jump (CMJ) is considered the best indicator of the muscular potency of lower limbs [67].

Higher lactate concentrations in the middle/middle-heavy weight category may indicate a greater demand for the glycolytic pathway during the fight, as reported in literature [9, 68] This suggests that heavier athletes may have a higher intensity of effort during the fight, thus requiring greater utilization of the anaerobic metabolism. Additionally, heavier athletes typically have a larger amount of muscular mass, which can potentially lead to greater energy transfer through anaerobic processes [69, 70].

No much studies were found in the literature comparing peak lactate levels after a fight across weight categories. The average lactate levels for the light/middleweight category were 8.5 mmol.L-1[3, 17, 45, 71], which is lower than levels reported in several studies with elite judokas and both elite and non-elite groups [28]. In contrast, the heaviest weight category had an average lactate level of 12.9 mmol. L-1, which is higher than levels reported in the aforementioned studies.

Another factor that could explain the difference in levels of muscular power between weight categories is the efficiency of certain muscle-elastic mechanisms present in the muscular actions performed, such as stiffness [72, 73] and speed in the transition between the eccentric and concentric phases [74, 75]. According to these authors, this transition should be done in a short space of time to avoid the dissipation of elastic energy accumulated in the muscle-tendon structures. This mechanism may not be as efficient in heavier athletes due to the higher overload (body mass) during the eccentric phase compared to lighter athletes, making the elastic energy storage process for power production more difficult.

No studies comparing muscle power between weight categories were found in the researched literature. The values of performance in the countermovement jump (CMJ) for the athletes in the light/middle-light and light/middle-middle groups were close to 46 cm, while the medium/middle-heavy group was close to 42 cm. [76] found values averaging 37 cm in Portuguese judokas of various categories, and [43] reported values averaging 36 cm in Spanish judokas. These values were lower than those reported in the athletes of this study, regardless of weight category; however, Bosco et al., (1983) considers values of approximately 50 cm in the CMJ to be ideal for fighters.

The other variables analysed in this study did not present a significant difference among the weight categories. Regarding the aerobic indexes (VLAn and PV), while they showed slightly superior values in the athletes of lighter weight categories (light/middle-light and light/middle-middle) compared to heavier ones (medium/middle-heavy), these were not significant.

In this study, the authors found that heavier elite judokas did not present lower aerobic power, which differed from the results found by [31]. This discrepancy can be attributed to the possibility of heavier athletes having a larger amount of body fat, which can negatively affect their performance in judo due to difficulties in generating movement. Emerson Franchini et al., (2018) reported that judokas with higher body fat percentage had lower VO2max, and elite judokas with greater body mass achieved a lower number of throws in the SJFT. However, in the present study, the number of throws in the SJFT did not differ between weight categories, possibly due to similar aerobic indexes (VLAn and PV) among the categories. Muscle power, which was significantly lower in heavier athletes, could have affected the number of throws, but was not confirmed in this study. The DLS and %FCmax, which are dependent on aerobic capacity, did not differ between weight categories, possibly because the VLAn, a more precise indicator of aerobic capacity, also did not differ. However, the reduced sample size per category and the absence of consideration of biomechanical, tactical, and psychological factors could have affected the results.

Conclusions

Based on the results of this study and the limitations encountered, several important conclusions can be drawn. Firstly, there was a significant difference in maximum upper limb strength between the dominant and non-dominant sides in the pull-up simulation in judogi, but no changes in the maintenance rate of maximum strength were observed based on hand dominance. Secondly, the study found that higher levels of muscular power and aerobic capacity were positively correlated with better performance in the SJFT, indicating the importance of these factors in judo-specific situations. Thirdly, the study showed that maximum force and force resistance did not play a significant role in the number of throws made by athletes, and glycolytic capacity was not related to the SJFT performance. Fourthly, the recovery heart rate was not a good predictor of aerobic capacity, and the removal of blood lactate was not related to the percentage of HR_{max}. Fifthly, the study found an inverse relationship between LAC_{max} and VLA_{n}, suggesting that higher aerobic capacity reduces the glycolytic demand of athletes during the fight simulation. Lastly, the study revealed that muscular power was essential in this type of effort, and heavier judokas may require more lactic anaerobic metabolism during fights, which may affect their lactate production.

Overall, the findings suggest that aerobic fitness and muscular power are essential in judo training, and a focus on these factors may improve athlete performance. Furthermore, training strategies may need to be adjusted based on weight categories, with heavier athletes requiring more emphasis on muscular power training. Future studies should consider investigating physiological and neuromuscular characteristics in larger groups of judokas by category to gain a more comprehensive understanding of their relationships during judo actions.

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