



Relationship between physical fitness and match-derived performance in judo athletes according to weight category

Rafael Lima Kons¹ · Daniele Detanico¹ · Jonathan Ache-Dias² · Juliano Dal Pupo¹

Received: 2 October 2018 / Accepted: 29 December 2018 / Published online: 23 January 2019
© Springer-Verlag Italia S.r.l., part of Springer Nature 2019

Abstract

Purpose This study aimed to verify the relationship between physical tests and match-derived performance in official judo matches, considering the weight category.

Methods Forty-one judo athletes participated in the study (19 women and 22 men), were divided into two groups according to weight category (lightweight and heavyweight) and were evaluated in two time points—(1) physical tests: countermovement jump (CMJ), handgrip strength (HGS), special judo fitness test (SJFT) and judogi grip strength test dynamic (JGST_{DIN}) and isometric (JGST_{ISO}), and (2) match-derived performance during official matches. The *t* test and Pearson's or Spearman's coefficients were used with a significance level set at 5%.

Results Heavyweight athletes (male and female) showed better performances in power output in the CMJ (CMJ_{PP0}), HGS, and number of throws in SJFT (female only) compared with lightweights, while lightweights (male and female) performed better in the JGST_{DIN} and JGST_{ISO}, respectively ($p < 0.05$). Additionally, a positive correlation was found between effective combat time (ECT) and CMJ_{PP0} for male lightweight athletes ($r = 0.65$). In the female lightweight group, the ECT was correlated with CMJ height ($r = 0.75$) and HGS ($r = 0.65$); the number of attacks was correlated with HGS ($r = 0.64$) and CMJ_{PP0} ($r = 0.75$). Considering the heavyweight female group, we verified a significant correlation between JGST_{ISO} and efficiency ($r = 0.67$), as well as between effectiveness and HGS ($r = 0.68$).

Conclusion Time motion performance in lightweight athletes depends more on HGS and muscle power of the lower limbs, whereas effectiveness and efficiency depend on HGS and resistance strength of the upper limbs in heavyweight athletes.

Keywords Combat sports · Muscle power · Strength · Body mass · Anaerobic capacity · Effectiveness

Introduction

Performance in combat sports has a multifactorial dependence in which technical–tactical and physical components play a major role [1, 2]. The structuring of training programs in these sports is a complex task, making it necessary to identify the characteristics of the sport and the main factors associated with performance. Judo is a combat sport in which athletes are engaged in several high-intensity efforts of an intermittent nature [3], requiring a combination of different physical capacities related to the neuromuscular [4] and metabolic systems [5]. In this sense, neuromuscular [4], aerobic [6] and aerobic/anaerobic [7] tests have been used to assess the metabolic and strength capacities of judo athletes.

During judo combat, in particular, strength parameters have been related to technical–tactical performance, e.g. Kons et al. [8] reported that match-derived performance (attack attempts, effective combat time, and effectiveness)

✉ Rafael Lima Kons
rafakons0310@gmail.com

Daniele Detanico
danieledetanico@gmail.com

Jonathan Ache-Dias
jonathanache@gmail.com

Juliano Dal Pupo
dalpupo@gmail.com

¹ Biomechanics Laboratory, Center of Sports, Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil

² Catarinense Federal Institute, Araquari Campus, Araquari, Santa Catarina, Brazil

were positively correlated with countermovement jump (CMJ) performance and maximal handgrip strength during official judo matches in female athletes, whereas in male athletes technical–tactical aspects were correlated with judo-specific tasks [9]. However, judo is a weight-classified sport, in which athletes on both male and female teams are divided into seven weight categories [10]. In this sense, whether the relationship between physical and technical–tactical performance differs according to weight category is unknown.

It has been pointed out athletes of different weight categories show different anthropometric, physical, and physiological profiles [4, 11–13]. According to previous studies, judo athletes in heavyweight categories seem to perform better strength exercises when absolute values are used (e.g. handgrip strength, bench-press 1RM, squat 1RM, and row 1RM) [12, 13], but inferior performance in explosive strength exercises [12] or in absolute values of muscle power in the lower limbs (e.g. vertical jump height) [11] compared to lightweight athletes. These data suggest that lightweight athletes perform better in terms of muscle power and velocity, whereas heavyweight athletes present higher levels of absolute strength and power. In addition, there was an inverse correlation between body mass (indicator of weight categories) and aerobic power markers in elite judo competitors [14]. Moreover, Franchini and Sterkowicz [15] reported that athletes in heavyweight categories showed a higher frequency of penalties (*shido*) and a lower frequency of arm throwing techniques (*Te-waza*) than lightweight athletes. Thus, judo athletes seem to show different technical–tactical profiles regarding weight categories. In this sense, the physical training demand should also be considered during the planning of the season.

Although knowledge about the relationships between physical and match official-derived performance is essential to a better understanding of the capacities involved during competition, it is also necessary to consider the specificity of the weight categories. However, the effect of physical fitness on match-derived parameters in official judo competition, taking weight categories into account, has not yet been reported. This information would provide more accurate indications for coaches during the routine training of judo athletes and identify the possible influence of weight

categories on physical fitness and technical–tactical performance. Therefore, the aim of this study was to analyze the relationship between physical and match-derived performance in official judo matches, according to weight category. We hypothesized that match-derived variables would be related to muscle power and aerobic index in lightweight athletes and to muscle strength in heavyweight athletes.

Materials and methods

Participants

Forty-one Brazilian judo athletes participated in the study, 19 women and 22 men. Athletes were divided into two groups according to weight category and following previous studies [16, 17]. The male team was composed of 11 lightweight athletes (55–73 kg) and 11 heavyweight athletes (81–100 kg), while the female team was composed of 11 lightweight athletes (48–57 kg) and 8 heavyweight ones (63–78 kg). The athlete characteristics are described in Table 1. Male athletes differed significantly in body mass [effect size (ES) = 3.75, large], height (ES = 1.01, large), body fat (ES = 1.62, large), and time of practice in years (ES = 0.74, large); the values of all these measures were higher in the heavyweight group. The female team differed in body mass (ES = 3.20, large) and height (ES = 1.29, large), these being higher in the heavyweight group.

All athletes trained regularly (physical, technical, and tactical training) four to five times per week during the evaluation period. They had on average 10.14 ± 3.0 years of judo experience for male team and 11.0 ± 4.5 years for female, and competed at state and national levels. Participants were included according to the following criteria: no reported musculoskeletal disorder or injury that would influence their maximal physical performance, training regularly for the last 5 years, and in a competitive period phase (not in a rapid-weight loss period). All participants were older than 18 years and received a detailed verbal explanation of the purpose, methods, and potential risks/benefits of the study. They then signed a written informed consent form agreeing to participate in the study. This study was approved by

Table 1 Age and anthropometric characteristics of judo athletes according to the gender and weight category

	Male		<i>p</i>	Female		<i>p</i>
	Lightweight (<i>n</i> = 11)	Heavyweight (<i>n</i> = 11)		Lightweight (<i>n</i> = 11)	Heavyweight (<i>n</i> = 8)	
Age (years)	19.2 ± 1.6	20.6 ± 2.2	0.10	20.9 ± 3.5	20.8 ± 3.2	0.92
Body mass (kg)	61.1 ± 6.8	88.0 ± 7.5	<0.001	52.0 ± 3.4	71.1 ± 7.7	<0.001
Height (cm)	173.1 ± 10.1	181.7 ± 6.4	0.01	158.1 ± 5.9	165.1 ± 4.9	0.007
Body fat (%)	10.7 ± 3.3	17.1 ± 4.5	<0.001	16.3 ± 4.5	19.7 ± 3.8	0.06
Time of practice (years)	9.0 ± 2.6	11.1 ± 3.0	0.003	10.3 ± 4.2	12.0 ± 5.0	0.21

the Research Ethics Committee of the local university, in accordance with the Declaration of Helsinki.

Study design

Assessments were performed in two stages: (1) anthropometric evaluation and physical tests and (2) recording of matches during official competitions for technical–tactical analysis. In the first step, after the anthropometric assessment, participants were submitted to physical tests: the countermovement jump (CMJ) and maximum handgrip strength tests. Twenty minutes later, the Judogi Grip Strength Test (JGST) and special judo fitness test (SJFT) were performed. All assessments were performed over a maximum of 2 weeks before the official competition (competitive period).

Anthropometric assessment

The body density of male athletes was estimated from the equation proposed by Petroski and Pires Neto [18] considering the sum of four skinfold thickness (triceps, subscapular, suprailiac, and medial calf). For females, the equation proposed by Jackson et al. [19] was used considering the triceps, suprailiac, thigh, and mid-axillary skinfolds. Afterwards, body density was used to obtain body fat according to Siri's equation [20]. Body mass was measured using a digital scale (0.1-kg accuracy), and height was assessed using a stadiometer scale with 0.1-cm accuracy. All measurements were performed before physical tests by an experienced evaluator (level 1 of the International Society for Advancement in Kinanthropometry—ISAK).

Countermovement jump assessment

Before vertical jump assessment, the participants performed a familiarization/warm-up involving 30 s of hopping on a trampoline, three series of ten hops on the ground, and five submaximal countermovement vertical jumps. After a 3-min resting period, athletes performed a maximal CMJ on a piezoelectric force platform (model 9290AD; Kistler, Quattro Jump, Winterthur, Switzerland), which measures vertical ground reaction sampling at 500 Hz. To perform the CMJ protocol, the athletes started from a static standing position and were instructed to perform a countermovement (descent phase), followed by a rapid and vigorous extension of the lower limb joints (ascent phase). The athletes were then instructed to jump as high as possible. Participants were required to keep the trunk as vertical as possible, and the hands were placed on the hips. Participants were also asked to flex their knees at 90° in the transition between the eccentric and concentric phases. Verbal feedback was provided to the participants during the test to encourage them to maintain a knee angle of approximately 90° and maximum

performance until the end of the test. We presented the mean value (within three trials) of jump height and peak power output using absolute values (W) and normalized values for body mass ($W \text{ kg}^{-1}$). The reliability of vertical jump variables calculated by the three trials of the CMJ showed an Intraclass Correlation Coefficient (ICC) of 0.97 for jump height (CMJ_{JH}) and 0.99 for peak power output (CMJ_{PPO}).

Maximal isometric handgrip strength

The handgrip strength test followed the procedures adopted by the American Society of Hand Therapy (ASHT). Participants were seated with the spine erect, maintaining a knee flexion angle of 90°. The shoulder was positioned in adduction and neutral rotation, the elbow flexed at 90°, with the forearm in half-pronation and with a neutral grip. Athletes were instructed to hold the handgrip dynamometer (Carci®, SH 5001 model) and exert maximum effort for 3 s with the dominant hand, with a rest period of 30 s between each trial. We presented the absolute values of handgrip strength (N) and normalized values for body mass using a specific allometric exponent for each gender, because the absolute values are not linearly related with body mass. Thus, the ratio standard ($N \text{ kg}^{-1}$) is not adequate for normalizing these data. To extract the specific allometric exponent, log–linear regressions were established for each gender based on the natural logarithms of body mass (kg) and handgrip strength (N), following the procedures used by Kons et al. [21]. It was established an exponent of 0.67 ($N \text{ kg}^{-0.67}$) for male team and 0.86 ($N \text{ kg}^{-0.86}$) for female. The highest strength value was used for analyses. The reliability of the handgrip test was evaluated, showing an ICC of 0.97 for the dominant hand.

Special judo fitness test assessment

Before the SJFT, the athletes performed 5-min warm-ups, which consisted of jogging, judo falling techniques (*ukemi*), and repetitive throwing techniques without falling (*uchikomi*). Subsequently, three athletes of similar body mass and height performed the SJFT, according to the following protocol: two judokas were positioned at a distance of 6 m from each other, while the test executor was positioned 3 m from the judokas to be thrown. The procedure was divided into three periods: 15 s (A), 30 s (B), and 30 s (C), with 10-s intervals between periods [7]. In each period, the executor threw the opponents using the *ippon-seoi-nage* technique as many times as possible. Performance was determined based on the total throws completed during each of the three periods (A + B + C). Heart rate (HR) was measured immediately after the test and then 1 min later (Polar® M430-Kempele/Finland). The index was calculated through the sum of heart

rates (immediately after the test and 1 min later) divided by the total number of throws.

Judogi grip endurance strength test

The athletes were familiarized with the test by performing three submaximal repetitions on the *judogi* suspended on the bar. Male athletes performed the dynamic (JGST_{DIN}) and isometric (JGST_{ISO}) versions of the test, while women performed only the JGST_{ISO}. The JGST_{DIN} consists of holding the *judogi* rolled around the bar, with the elbow joint at maximal extension and flexing the elbow, moving the chin above the line of the handgrip. Athletes were asked to perform the maximal number of repetitions from a fully extended to a fully flexed elbow position as many times as possible. After a 15-min interval, the men performed the JGST_{ISO}, which consists of sustaining the position (elbow flexion) for the maximal possible time. The women performed only the last step. The chronometer was stopped when the athlete could no longer maintain the original position. The reliability of the JGST has been assessed in previous studies, presenting an ICC higher than 0.98 [4].

Match-derived variables in official competition

All combat bouts during state-level competitions were filmed using two cameras (Sony Action Cam AS200), positioned to capture the total combat area and the movements of the athletes without interfering in the event. One hundred thirty-two matches were analyzed—70 matches between males and 62 matches between females. Considering the male group, 32 matches were analyzed in the heavyweight category and 38 in the lightweight category, while in the female group, 28 matches were analyzed in the heavyweight category and 34 in the lightweight category. The videos were stored and separated into individual combat bouts for the athletes evaluated. Subsequently, the combat bouts were analyzed by a judo expert (black belt, 14 years of experience) using the software Kinovea (0.8.15, version 2) to obtain the following variables:

- (a) Efficiency index: quantification of the scores obtained during the competition considering the referees' evaluation divided by the total number of matches, according to the following estimation [22]:

$$\text{Efficiency} = \frac{(\text{number of ippon} \times 10) + (\text{number of wazari} \times 7) + (\text{number of yuko} \times 5)}{\text{Total number of matches}}$$

- (b) Effectiveness index: relative representation of the use of techniques performed in the competition, calculated

by dividing the scores obtained and the total number of techniques applied and multiplied by 100 [23].

- (c) Percentage of wins: number of wins obtained in each competition divided by the total number of matches multiplied by 100.
 (d) Effective combat time: actual working time of each combat bout.

The match-derived data were collected and analyzed according to the current rules in 2016, i.e. the *yuko* score was computed, and the official match time was 5 min for male and 4 min for female athletes.

Statistical analysis

Data are reported as means and standard deviations (SDs). The Kolmogorov–Smirnov test was used to verify data normality. Student's *t* test was used to compare the physical and match-derived variables between weight categories (heavyweight and lightweight). Considering the variables (absolute values) that presented significant differences, Pearson's linear correlation (normal data) or Spearman's correlation (non-normal data) was used to verify the relationship between physical (absolute values) and match-derived performance according to the weight categories. Analyses were performed in the Statistical Package for the Social Sciences (SPSS™) with the level of significance set at 5%. The effect size (ES) was calculated considering the comparison of means (two independent groups), and the classification of Cohen [24] was used: < 0.4 small, 0.41–0.7 moderate, > 0.7 large. Additionally, we adopted the Hopkins [25] criteria to classify the ES for the magnitude of the correlation: *r* = 0–0.1 (trivial), 0.11–0.3 (small), 0.31–0.5 (moderate), 0.51–0.7 (large), 0.71–0.9 (very large), and 0.91–1.0 (almost perfect).

Results

Table 2 shows the means and SDs of physical performance, as well as the match-derived performance for male and female judo athletes, according to weight category. On the male team, lightweight athletes performed better in the JGST_{DIN} (ES = 0.84, large) than heavyweights, while higher values of absolute CMJ_{PP0} (ES = 1.95, large) and HGS (ES = 0.76, large) were found in the heavyweight

group. In females, lightweight athletes performed better in the JGST_{ISO} (ES = 1.10, large) than heavyweights;

Table 2 Mean and standard deviation of physical tests and match-derived variables in male and female athletes according to weight categories

Physical tests	Male (n=22)		p	Female (n=19)		p
	Lightweight (n=11)	Heavyweight (n=11)		Lightweight (n=11)	Heavyweight (n=8)	
JGST _{DIN} (reps)	16 ± 3	12 ± 6	0.05	–	–	
JGST _{ISO} (s)	42.8 ± 8.8	37.0 ± 17.2	0.18	39.2 ± 12.7	25.6 ± 11.8	0.008
SJFT _{TT} (reps)	27 ± 1	28 ± 3	0.26	25 ± 1	27 ± 1	0.05
SJFT _{HR} (bpm)	139 ± 17	150 ± 12	0.05	141 ± 13	158 ± 14	0.07
CMJ _{JH} (cm)	44.1 ± 5.8	44.7 ± 4.8	0.40	34.3 ± 2.6	35.9 ± 3.4	0.19
CMJ _{PP0} (W)	2925.2 ± 532.4	4110.3 ± 671.9	<0.01	2037.7 ± 189.6	2734.2 ± 439.1	0.001
CMJ _{PP0} (W kg ⁻¹)	47.61 ± 4.66	46.60 ± 5.72	0.32	39.02 ± 2.09	39.46 ± 3.57	0.36
HGS (N)	445.2 ± 106.4	524.7 ± 101.0	0.04	301.7 ± 45.5	360.6 ± 36.6	<0.01
HGS (N kg ^a)	28.25 ± 5.89	26.01 ± 3.94	0.15	10.24 ± 1.20	10.19 ± 0.88	0.45
<i>Match-derived performance</i>						
Attacks (n)	3 ± 1	5 ± 0	0.18	3 ± 1	4 ± 2	0.73
Efficiency (a.u.)	8.6 ± 3.8	9.8 ± 4.6	0.46	6.2 ± 4.5	7.2 ± 4.0	0.33
Effectiveness (%)	27.2 ± 12.4	24.9 ± 15.4	0.60	24.9 ± 16.4	29.7 ± 16.2	0.74
ECT (s)	104.2 ± 63.3	101.8 ± 70.2	0.73	81.7 ± 49.7	107.1 ± 26.5	0.51
Wins (%)	81.6 ± 24.5	60.4 ± 30.9	0.09	60.8 ± 38.7	63.8 ± 34.3	0.85

JGST_{DIN} judogi grip strength test dynamic, JGST_{ISO} judogi grip strength test isometric, SJFT_{TT} total number of throws of special judo fitness test-SJFT, SJFT_{HR} heart rate after the SJFT, CMJ_{JH} jump height of countermovement jump, CMJ_{PP0} peak power output in the CMJ, HGS hand-grip strength, ECT effective combat time

^aN kg^{-0.67} for male and N kg^{-0.86} for female

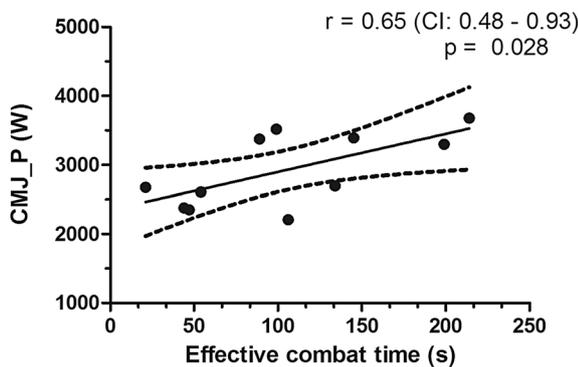


Fig. 1 Correlation between physical and match-derived performance in male lightweight athletes

however, the heavyweight group was superior in the SJFT_{TT} (ES = 2.04, large), absolute CMJ_{PP0} (ES = 2.05, large), and HGS (ES = 1.42, large). No significant differences were found in CMJ_{PP0} and HGS normalized for body mass, as well as in match-derived variables between the groups (ES = trivial – large).

We tested the correlation between these physical performance and match-derived variables, and found a significant correlation between CMJ_{PP0} and effective combat time (ES = 0.65, large correlation) for male lightweight athletes (Fig. 1). Analyzing the lightweight female group, a significant correlation was found in the number of attacks

with CMJ_{PP0} (ES = 0.75, very large correlation) and HGS (ES = 0.64, large correlation). In addition, effective combat time was correlated with absolute HGS (ES = 0.65, large correlation) and CMJ_{JH} (ES = 0.75, very large correlation) (Fig. 2a). Considering the heavyweight female group, we verified the significant correlation between JGST_{ISO} and efficiency (ES = 0.67, large correlation), as well as between effectiveness and absolute HGS (ES = 0.68, large correlation) (Fig. 2b).

Discussion

This study aimed to investigate the relationship between physical and match-derived performance in official judo matches, considering the weight categories. The main findings of this study were: (a) resistance strength of the upper limbs (JGST) was superior in lightweight male and female athletes, while muscle power in the lower limbs and hand-grip strength in absolute values were better in the heavyweight group in both gender; (b) muscle power of the lower limbs in absolute values was related to the effective combat time in male lightweight athletes and to the number of attacks in female lightweight athletes, whereas handgrip strength (absolute values) was related to the number of attacks and effective combat time in the female lightweight group; (c) resistance strength was related to efficiency, and

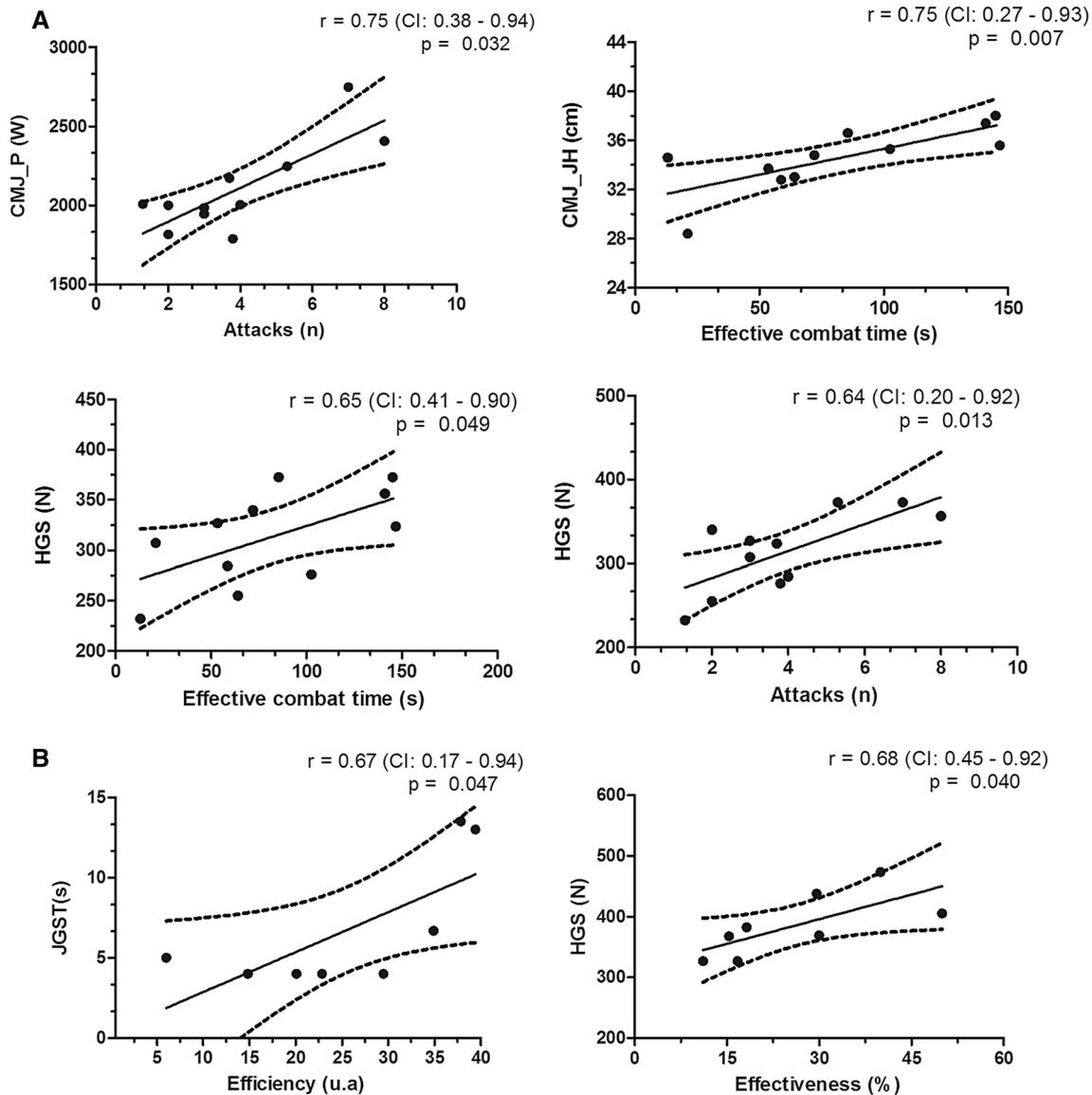


Fig. 2 Correlation between physical and match-derived performance in female team: **a** lightweight and **b** heavyweight group

effectiveness was related to handgrip strength in the heavyweight female group.

When comparing performance of judo-specific tests, such as the JGST and SJFT, between athletes of different weight categories, we can observe that test performance is directly influenced by body mass [26, 27], i.e. heavier judokas perform worse on both tests, mainly on the JGST, in which test performance depends on lifting one's own body mass [26]. The number of throws in the SJFT (anaerobic capacity indicator) was higher in female heavyweights compared with lightweights. Franchini et al. [13] verified a negative correlation between the number of throws in the SJFT and body mass in male judo athletes, but at the same time a positive correlation between body mass and body fat percentage was

observed, indicating a possible influence of body fat on the SJFT performance. In our study, no significant difference in body fat percentage was found between female heavyweight and lightweight athletes, which may justify the results. In addition, Casals et al. [28] verified that fat-free mass and muscle mass are predictors of the number of throws in the SJFT.

Another interesting outcome is that muscle power in the lower limbs (CMJ performance) and maximal handgrip strength in absolute values were higher in the heavyweight group in both genders. These results may be explained by the effect of body mass on performance when absolute values are considered; however, when the body mass effect was removed (normalization), there are no differences in these

variables between the groups. Torres-Luque et al. [12] found superior values of absolute handgrip strength in heavyweight judo athletes compared with lightweights, and Athayde et al. [11] verified higher absolute values of peak power and mean power output measured during the concentric phase of CMJ in heavyweight compared to lightweight athletes. Conversely, when the values were normalized to body mass, lightweight athletes showed higher CMJ peak/mean power output than heavyweights [11], suggesting that heavyweight individuals present lesser ability to generate higher power per kilogram of mass, but this finding was not confirmed in the current study.

The absolute values of CMJ peak power output and handgrip strength were correlated with the effective combat time and number of attacks in male and female lightweight groups. This indicates that lightweight athletes with high levels of muscle power in the lower limbs and handgrip strength were able to perform stronger attacks and maintain longer working times during combat (e.g. preparing to attack, grip dispute, attacks, counterattacks, time spent on groundwork, etc.). A judo match requires explosive and powerful efforts in the lower limbs and engagement in sudden directional changes for attack or defense [1]. Another relevant aspect is that the use of the stretch shortening cycle (SSC) during the execution of the throwing technique may be different between heavyweight and lightweight athletes, i.e. a higher body mass may induce less use of the SSC, which is considered the major factor in the ability to generate optimal levels of muscle power [29].

The efficiency and effectiveness indexes were correlated with strength parameters of the upper limbs (JGST_{ISO} and HGS, respectively) in heavyweight female athletes. These indexes have been used to represent performance in official judo competition [22, 30]. Our results indicate that heavyweight female athletes who presented higher isometric endurance strength in the upper limbs were more efficient (higher quality of scores per match), whereas athletes who showed higher isometric handgrip strength were more effectiveness (higher scores with fewer techniques applied) [22]. Thus, it seems that isometric strength in the upper limbs (maximal and endurance) contributes to better execution of judo throwing techniques, leading to a high quality of scores, particularly in heavyweight athletes. It is possible to suggest that athletes in the heavyweight category need greater control of the opponent (due to their higher body mass), which allows for better balance and represents an advantage in throwing technique performance during matches.

Conclusion

We conclude that heavyweight athletes showed higher performance in absolute handgrip strength and muscle power of the lower limbs (male and female team), whereas

lightweight athletes showed higher resistance strength of the upper limbs (male and female group) and anaerobic capacity (female group). In general, the time motion variables (attack attempts and effective combat time) in lightweight athletes is more dependent on handgrip strength and muscle power of the lower limbs, whereas effectiveness and efficiency are dependent on handgrip strength and resistance strength of the upper limbs in heavyweight athletes.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest relating to the publication of this manuscript.

Ethical approval All procedures were approved by institutional ethic review of the Federal University of Santa Catarina, Santa Catarina, Brazil

Informed consent All subjects provided written informed consent.

References

1. Franchini E, Artioli GG, Brito CJ (2013) Judo combat: time motion analysis and physiology. *Int J Perform Anal Sport* 13(3):624–641
2. Miarka B, Panissa V, Julio UF, Del Vecchio FB, Calmet M, Franchini E (2012) A comparison of time-motion performance between age groups in judo matches. *J Sports Sci* 30:899–905
3. Franchini E, Del Vecchio FB, Matsushigue KA, Artioli GG (2011) Physiological profiles of elite judo athletes. *Sports Med* 41(2):147–166. <https://doi.org/10.2165/11538580-00000000-00000>
4. Franchini E, Miarka B, Matheus L, Del Vecchio F (2011) Endurance in judogi grip strength tests: comparison between elite and non-elite judo players. *Arch Budo* 7:1–4
5. Bonato M, Rampichini S, Ferrara M, Benedini S, Sbriccoli P, Merati G, Franchini E, La Torre A (2015) Aerobic training program for the enhancements of HR and VO₂ off-kinetics in elite judo athletes. *J Sports Med Phys Fit* 55(11):1277–1284
6. Azevedo P, Oliveira JC, Zagatto A, Pereira PE, Perez SEA (2018) Aerobic and anaerobic threshold determined by specific test in judo is not correlated with general test. *Sport Sci Health* 14(3):531–535. <https://doi.org/10.1007/s11332-018-0454-1>
7. Sterkowicz S, Zuchowicz A, Kubica R (1999) Levels of anaerobic and aerobic capacity indices and results for the special judo fitness test in judo competitors. *J Hum Kinet* 2:115–135
8. Kons RL, Dal Pupo J, Ache-Dias J, Detanico D (2018) Female judo athletes' physical test performances are unrelated to technical-tactical competition skills. *Percept Mot Skills* 125(4):802–816. <https://doi.org/10.1177/0031512518777586>
9. Kons RL, Ache-Dias J, Detanico D (2017) Can physical tests predict the technical-tactical performance during official judo competitions? *Arch Budo Sci Martial Art Extreme Sports* 13:143–151
10. International Judo Federation (2018) Sports and organization rules of the international judo federation. http://99e89a50309ad79ff91d-082b8fd5551e97bc65e327988b444396.r14.cf3.rackcdn.com/up/2018/10/IJF_Sport_and_Organisation_Rul-1539980456.pdf. Accessed 27 Aug 2018

11. Athayde MS, Detanico D, Kons RL (2018) Influence of body fat on countermovement jump performance in judo athletes from different weight categories. *Braz J Phys Educ Sports* (in Portuguese) 31(2):345–353. <https://doi.org/10.11606/1807-5509201700020345>
12. Torres-Luque G, Hernandez-Garcia R, Garatachea N, Nikolaidis PT (2015) Anthropometric characteristics and neuromuscular function in young judo athletes by sex, age and weight category. *Sport Sci Health* 11(1):117–124. <https://doi.org/10.1007/s11332-015-0218-0>
13. Franchini E, Nunes AV, Moraes JM, Del Vecchio FB (2007) Physical fitness and anthropometrical profile of the Brazilian male judo team. *J Physiol Anthropol* 26(2):59–67
14. Callister R, Callister RJ, Staron RS, Fleck SJ, Tesch P, Dudley GA (1991) Physiological characteristics of elite judo athletes. *Int J Sports Med* 12(2):196–203
15. Franchini E, Sterkowicz S (2003) Tactics and techniques in high level judo competition (1995–2001): considerations about weight category and gender (in Portuguese). *Rev Mack Edu Fís Esp* 2(2):125–138
16. Sterkowicz S, Franchini E (2000) Techniques used by judoists during the World and Olympic tournaments 1995–1999. *Hum Mov* 2(1):24–33
17. Kuvačić G, Krstulović S, Caput PD (2017) Factors determining success in youth judokas. *J Hum Kinet* 56:207–217. <https://doi.org/10.1515/hukin-2017-0038>
18. Petroski EL, Pires Neto C (1996) Validation of anthropometric equations for the estimation of body density in men. *Braz J Phys Act Health* 1:5–14
19. Jackson AS, Pollock ML, Ward A (1980) Generalized equations for predicting body density of women. *Med Sci Sports Exerc* 12:176–182. <https://doi.org/10.1249/00005768-198023000-00009>
20. Siri WE (1961) Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Henschel A (eds) *Techniques for measuring body composition*. National Academy of Science and Natural Resource Council, Washington, pp 223–244
21. Kons RL, Ache-Dias J, Detanico D, Barth J, Dal Pupo J (2018) Is vertical jump height an indicator of athletes' power output in different sport modalities? *J Strength Cond Res* 32(3):708–715. <https://doi.org/10.1519/JSC.0000000000001817>
22. Adam M, Smaruj M, Tyszkowski S (2011) The diagnosis of the technical-tactical preparation of judo competitors during the World Championships (2009 and 2010) in the light of the new judo sport rules. *Arch Budo* 7:5–9
23. Sterkowicz S, Maślej P (1999) An evaluation of the technical and tactical aspects of judo matches at the seniors level. *Sport Wyczyn* 10:45–53
24. Cohen J (1988) *Statistical power analysis for the behavioral sciences*, 2nd edn. Hillsdale, Erlbaum
25. Hopkins WG (2004) How to interpret changes in an athletic performance test? *Sportscience* 8:1–7
26. Branco BHM, Diniz E, Santos JFSS, Shiroma SA, Franchini E (2017) Normative tables for the dynamic and isometric judogi chin-up tests for judo athletes. *Sport Sci Health* 13(1):47–53. <https://doi.org/10.1007/s11332-016-0331-8>
27. Franchini E, Takito MY, Bertuzzi RCM (2005) Morphological, physiological and technical variables in high-level college judoists. *Arch Budo* 1:1–7
28. Casals C, Huertas JR, Franchini E, Sterkowicz-Przybycień K, Sterkowicz S, Gutiérrez-García C, Escobar-Molina R (2017) Special judo fitness test level and anthropometric profile of elite Spanish judo athletes. *J Strength Cond Res* 31(5):1229–1235. <https://doi.org/10.1519/JSC.0000000000001261>
29. Zaggelidis G, Lazaridis SN, Malkogiorgos A, Mavrovouniotis F (2012) Differences in vertical jumping performance between untrained males and advanced Greek judokas. *Arch Budo* 8:87–90
30. Adam M, Mirosław S, Radosław LA (2014) Technical and tactical profile of the double Olympic judo champion: a case study. *Int J Sports Sci Coach* 9:123–138. <https://doi.org/10.1260/1747-9541.9.1.123>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.