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STRENGTH PARAMETERS IN JUDO ATHLETES: AN APPROACH USING HAND DOMINANCE AND WEIGHT CATEGORIES

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ABSTRACT
Purpose. This study aimed to relate strength parameters of the *judogi* pull test and countermovement jump (CMJ), and body fat with body mass and to compare strength parameters in the *judogi* pull test between the dominant and non-dominant hands. **Methods.** Eighteen male judokas took part in this study. The following parameters were analysed: maximal force (F_{max}), time to maximal force (TF_{max}), rate of force development (RFD) and rate of peak force decrement (RPFD) of the dominant and non-dominant hands during the pull test. Jump height (H_{max}), power, F_{max}, peak velocity (PV) and RFD in the CMJ were also measured. A *t*-test and Pearson's correlation were used. **Results.** F_{max} (absolute and relative) and RFD were greater for the dominant hand, whereas RFPD was greater for the non-dominant hand during the pull test. There was a significant correlation only between absolute F_{max} and body mass ($r = 0.51$) in the pull test. For the CMJ, relative power ($r = -0.57$), H_{max} ($r = -0.49$) and PV ($r = -0.53$) were negatively correlated with body mass, while absolute F_{max} ($r = 0.84$) and power ($r = 0.69$) were positively correlated with body mass. A significant correlation between body mass and body fat ($r = 0.88$) was found. **Conclusions.** There are differences in maximal and explosive force and the rate of peak force decrement between the dominant and non-dominant hand. Absolute values of power and maximal force increased according to body mass (and, therefore, a higher weight category); however jump performance decreased with an increase in body mass (weight category).

Key words: judo, strength, hand dominance, weight categories, training

Introduction

Judo is an intermittent sport with high-intensity actions, and judo athletes' (judoka) performance may be determined by several physical abilities, in which muscle strength in upper and lower limbs is of major importance [1]. However, there are different manifestations of muscle strength, such as muscle power, maximal strength and muscular endurance, that are each important parameters related to an athlete's performance in decisive actions during combat [2, 3].

During judo combat, strength and muscle power have been related to performance and judo-throw efficiency [1]. Previous research has shown that lower limb muscle power is a determinant of the numbers of throws performed in judo [4], and is related to the percentage of win during the male judo European World Cup competitions [5]. When a judoka executes a variety of judo throwing techniques (e.g. *seoi-nage*, *o-goshi*, *koshi-guruma*), power is optimised by muscle-elastic mechanisms, such as the stretch-shortening cycle (SSC), and results in an increase of movement efficiency [6].

Upper limb strength is another important aspect considered in judo performance, mainly during grip combat (*kumi-kata*) to attack, defend and maintain balance [7]. The constant dynamic changes of combat require athletes to use a combination of maximal strength and endurance during *kumi-kata*, mostly to control the distance between a judoka and his/her opponent [8, 9]. In addition, the ability to produce maximal strength or the rate of force development is another fundamental action during grip combat, as well as the ability to maintain strength for long periods of time, since the duration of any given match can be up to 5 min or more (golden score). Moreover, judo also features non-standing combat (*ne-waza*), which frequently takes places when a judoka wishes to apply a chokehold, an arm lock or other forms of immobilising an opponent; in these types of situations maximal strength and muscular endurance are incredibly important for successful judo performance [10].

Considering the importance of bilaterality in judo, these strength factors should be equally exhibited by both sides of the body. However, Bonitch-Góngora et al. [10] found that maximal grip strength was significantly larger in the dominant rather than the non-dominant hand of judo athletes. Another study also found that average healthy individuals feature larger values of peak grip strength in the dominant rather than the non-dominant hand, although it was pointed out that fatigue sets in quicker for the dominant hand [11]. Therefore, athletes with bilateral dominance and a high level of muscular strength and skills ought to have a tactical ad-

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vantage over their opponents and increase their chances of success [12]. However, one-sided training is common in judo practise sessions [12], where athletes perform exercises and techniques mostly using their dominant side. Unfortunately, no research on comparing these strength variables between hand dominance in judo athletes was found in the available literature.

Besides body laterality, another relationship of interest is the one between muscle strength and body mass (indicated by the use of weight categories in judo). In this regard, a positive correlation has been reported between these two variables [13], e.g. muscle strength increases according to heavier category. Analysis of judo combat reflects the different specific strength and power profiles among judokas from different categories [14]. However, some variables of strength and power, when normalised to body mass or other allometric scales, may change this relationship. This was verified by Thomas et al. [15], who found a positive relationship between body mass and handgrip strength only when these values were presented in absolute terms. Additionally, these relationships may sometimes be influenced by body fat, since increased body fat correlates with a rise in a judoka's weight category [2]. However, similarly in the case of hand dominance, there are no reports exploring this relationship with other strength parameters such as explosive force and muscular endurance in the upper and lower limbs.

Thus, the purpose of this study was: (1) to relate strength parameters, in this case a judo strength test (*judogi* pull test) and the countermovement jump (CMJ), with body fat and body mass; (2) to compare the strength parameters obtained from the *judogi* pull test between dominant and non-dominant hand strength.

Material and methods

Eighteen trained male judokas took part in this study (aged 20.6 ± 1.8 years). The participants were from different categories: four extra-light, two half-light, five light, two half-middle, two middle and three half-heavy. All athletes were in their pre-competitive phase of training. The inclusion criteria included: (1) participation in official judo competitions in the same year, (2) training at least three times per week, (3) possessing at minimum a purple belt (2° kyu), (4) aged 18 years or above, (5) without any kind of injuries and (6) competing in sub 100-kg weight categories.

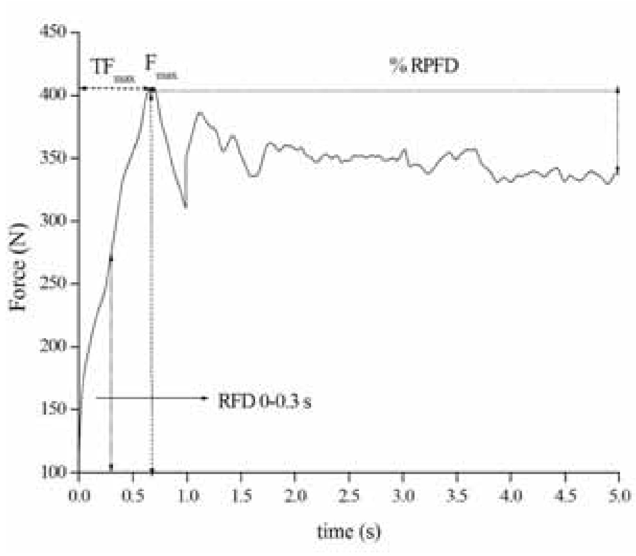
The tests were performed at the Federal University of Santa Catarina's Biomechanics Laboratory on the same day. All athletes were instructed to maintain a normal diet prior to the day of the test. The participants were informed about the purposes and methods of the study before signing a consent form. All procedures were approved by the ethics committee of the researchers' university (No. 168/2009) in accordance with the Declaration of Helsinki. The participants were informed that they would be free to withdraw from the study at any time.

First, body mass was assessed with the use of a digital scale (Mettler Toledo, Switzerland). Subsequently, four skinfold thickness measurements (triceps, subscapular, suprailiac and calf) were taken using a calliper accurate to 0.1 mm (Lange, USA). Body density was estimated by Petroski's equation [16], while relative body fat was determined by the Siri equation [17]. After the anthropometric measurements, the athletes performed stretching exercises and specific warm-ups for each of the tests. They then received technical instructions and were instructed on how to perform the *judogi* pull test and vertical jump in order to ensure that the procedure was standardised.

Judogi pull test assessment

The *judogi* pull test consisted of a pulling movement used in judo on the *judogi* uniform by the lapel (*tsurite*) and sleeve (*hikite*), simulating the *kuzushi* (unbalancing an opponent). Athletes were instructed to perform the *kuzushi* by simulating a real-time situation for five-seconds using a combat grip for both the right and left hand. A shear beam load cell (model BTS, Primax, Brazil) measuring tension up 2000 N connected to a signal acquisition system (Miotool 200/400 USB, Miotec, Brazil) was used to obtain the athletes' isometric strength. The signal was filtered by a third-order low-pass 20 Hz Butterworth filter. The judoka performed two pulling movements, to the right and left. The reliability of the first and second pulling movements was reported by an intraclass correlation coefficient (ICC), equal to 0.97. The following variables were measured, as shown in Figure 1:

a) Maximal force (F_{max}): identified as the highest value obtained in the test expressed in absolute values (N) and normalised according to body mass
b) Time to maximal force (TF_{max}): time to reach F_{max}



F_{max} – maximal force, TF_{max} – time to maximal force, RFD – rate of force development, RPFD – rate of peak force decrement

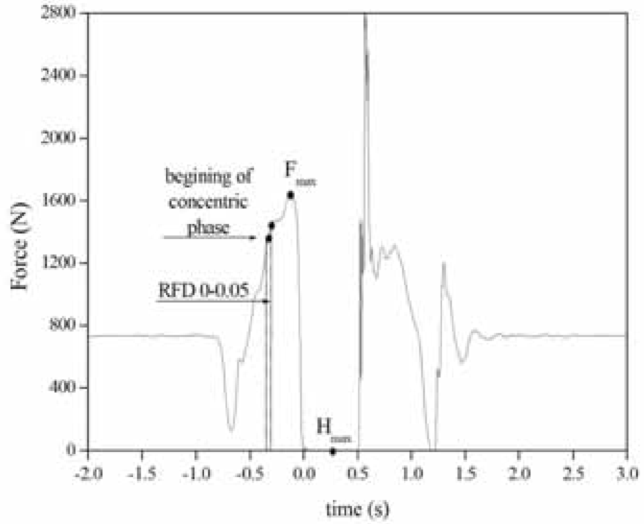
Figure 1. Representation of force-time parameters in the *judogi* pull test

c) Rate of force development (RFD): this was obtained as the average slope of the force-time curve (Δforce/Δ time) over the time interval from 0.0 to 0.3 s, at a value greater than 100 N; the RFD values were reported as $N \cdot s^{-1}$ and normalised by F_{max}
d) Rate of peak force decrement (RPFD): percentage of maintaining force after reaching F_{max} and until the last 5 s of the test

Countermovement jump (CMJ) assessment

The strength parameters of the lower limbs were obtained by CMJ assessment. During CMJ evaluation, the participants were instructed to start the jump from a vertical position with their hands on their hips and execute a vertical jump after a downward countermovement (where the knee must be flexed to 90 degrees at the end of the countermovement). The participants were trained prior to the test until they had obtained the motor skills necessary to perform this movement correctly. A piezoelectric force plate (model 9290AD, Quattro Jump, Switzerland) was used, which measured the vertical component of ground reaction force (GRF) at a frequency of 500 Hz. The signal was filtered by a third-order low-pass 20 Hz Butterworth filter. The following variables were measured (Fig. 2):

a) Jump height (H_{max}): calculated as a double integration of force. First, the acceleration curve was calculated by dividing the GRF values by body mass as measured on the platform. Then, a trapezoidal integration of the acceleration curve was used to obtain the velocity curve. The latter was integrated again in order to obtain the distance at each time point of the movement and the greatest vertical distance was entered as the jump height [18]
b) Power: calculated by multiplying GRF with velocity at the concentric phase of the jump. The beginning of the concentric phase was identified in the CMJ as the time when velocity became positive. The mean value of the curve was used for analysis and expressed in absolute values (W) and relative to body mass ($W \cdot kg^{-1}$)
c) Maximal force (F_{max}): identified as the highest value obtained in the concentric phase of the jump, expressed in absolute values (N) and normalised according to body mass



F_{max} – maximum force, RFD – rate of force development
H_{max} – maximum jump height

Figure 2. Representation of force-time parameters in the CMJ. Adapted from Dal Pupo et al. [19]

d) Rate of force development (RFD): mean slope of the force-time curve (Δ force/Δ time) over time interval from 0.0 to 0.05 s, corresponding to the beginning of the concentric phase beginning
e) Peak velocity (PV): highest value of velocity observed at take-off

Data are reported as means ($\bar{x}$) and standard deviations (SD). Data normality was verified by the Shapiro-Wilk test. We used a paired *t*-test to compare the pull test variables between the dominant and non-dominant hand and the effect size by using GPower 3.1 software. Additionally, Pearson's correlation was used to relate the pull test and CMJ variables with the athletes' body mass. The level of significance was set at $p \leq 0.05$.

Results

The anthropometric features of athletes were 77.3 ± 13.4 kg and 13.4% ± 3.3% body fat. A significant correlation was found between body mass and body fat ($r = 0.88$; $p = 0.0000$), i.e. the heavier judokas tended to feature greater body fat content than the lighter ones.

Table 1 shows the variables obtained in the pull test for dominant and non-dominant hands. F_{max} (absolute

Table 1. Mean and standard deviations ($\bar{x}$ ± SD) of the *judogi* pull test variables between dominant and non-dominant hands

	Dominant	Non-dominant	*p*-value	Effect size (η^2)
F_{max} (N)	478.85 ± 175.13	418.54 ± 126.46	0.0114	0.59
F_{max} ($N \cdot kg^{-1}$)	6.16 ± 1.96	5.41 ± 1.37	0.0166	0.54
RFD ($N \cdot s^{-1}$)	939.13 ± 407.73	827.87 ± 396.57	0.0185	0.54
RFD/F_{max} (s^{-1})	2.08 ± 0.88	2.07 ± 1.29	0.4903	0.01
TF_{max} (s)	0.37 ± 0.27	0.33 ± 0.15	0.0832	0.24
RPFD (%)	71.09 ± 8.72	76.12 ± 9.08	0.0353	0.47

F_{max} – maximal force, RFD – rate of force development, TF_{max} – time to maximal force, RPFD – rate of peak force decrement

Table 2. Mean and standard deviations and variation coefficients of the CMJ variables

	$\bar{x}$	SD	VC (%)
H_{max} (cm)	44.76	4.51	10.07
Power (W)	2109.48	307.70	14.59
Power ($W \cdot kg^{-1}$)	27.62	3.28	11.86
PV ($m \cdot s^{-1}$)	2.71	0.18	6.48
F_{max} (N)	1873.32	307.31	16.40
F_{max} ($N \cdot kg^{-1}$)	24.40	2.38	9.75
RFD ($N \cdot s^{-1}$)	3278.32	1425.32	43.48
RFD/F_{max} (s^{-1})	1.75	0.75	42.71

H_{max} – jump height, F_{max} – maximal force, RFD – rate of force development, PV – peak velocity

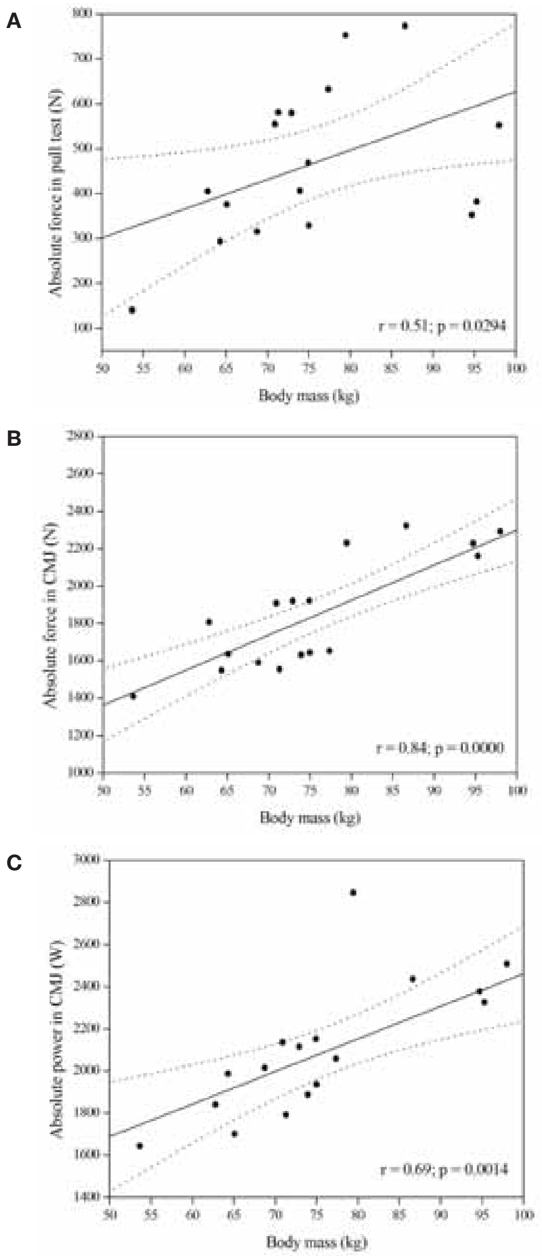


Figure 3. Relationship between body mass and absolute F_{max} in the pull test (A), and of absolute F_{max} (B) and power (C) with body mass in the CMJ

and relative) and RFD were greater for the dominant hand, whereas RPFD was greater for the non-dominant hand. Table 2 shows the descriptive values of the strength variables obtained in the CMJ.

Regarding the relationships between the *judogi* pull test variables and body mass, a significant correlation between absolute F_{max} and body mass (Fig. 3A) was found. No significant correlation between relative F_{max} ($r = 0.12$; $p = 0.6347$), RFD ($r = 0.24$; $p = 0.3392$), TF_{max} ($r = 0.29$; $p = 0.2494$) and RPFD ($r = 0.17$; $p = 0.5061$); and body mass was obtained.

In CMJ, absolute F_{max} and power were positively correlated with body mass (Fig. 3B and 3C, respectively),

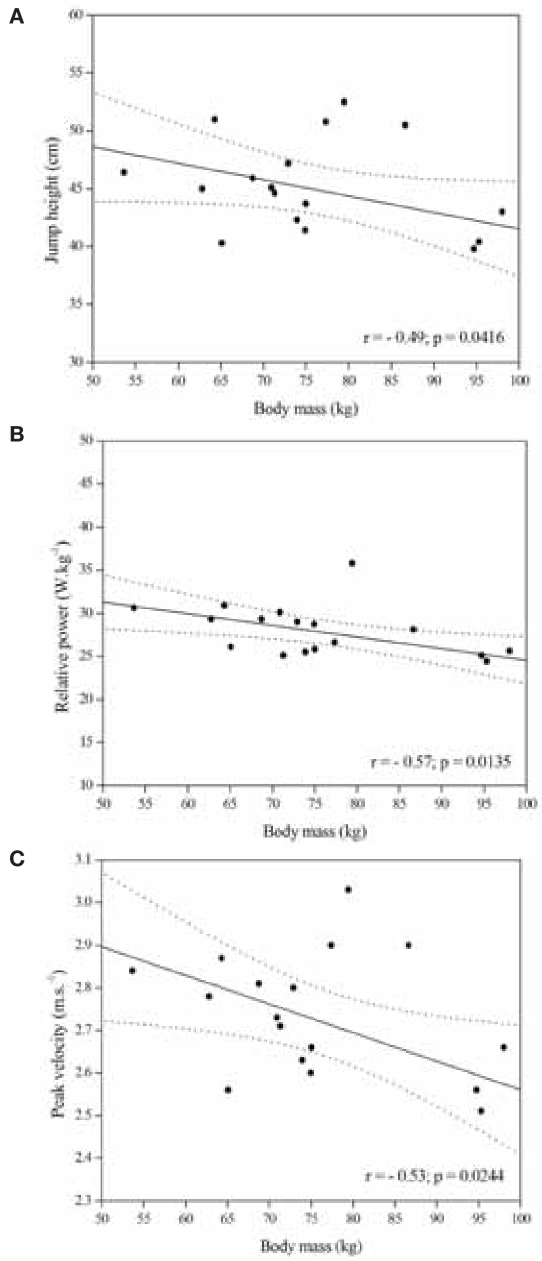


Figure 4. Relationships of body mass with jump height (A), relative power (B) and peak velocity (C) in the CMJ

while H_{max} and relative power were negatively correlated with body mass (Fig. 4A and 4B, respectively). In addition, a significant correlation between PV and body mass was reported (Fig. 4C) and no significant correlations of RFD absolute and relative to maximal force with body mass ($r = -0.06$; $p = 0.8207$; $r = -0.26$; $p = 0.2907$, respectively) were found.

Discussion

This study's main aims were to analyse two aspects: the possible differences of muscle strength parameters in the *judogi* pull test between hand dominance and a possible correlation between the strength variables of the pull test and CMJ, with body mass.

Analysing hand dominance in the *judogi* pull test, F_{max} (absolute and relative to body mass) and RFD were greater for the dominant hand, whereas RPFD was greater for the non-dominant one. Using a similar *judogi* pull test in judokas, Hassmann et al. [20] found smaller values of F_{max} ($4.56\ N \cdot kg^{-1}$) and TF_{max} (0.11 s) than those obtained in our study. These results show that the judokas in the present study seem to present greater maximal force while the athletes in Hassmann et al.'s study [20] presented greater explosive force. Both maximal and explosive force are important when performing *kumikata* [7, 9, 10, 21], but they are dependent on athletes' characteristics and training [22]. No studies were found that analysed RPFD and RFD by comparing the muscle strength parameters derived from a similar pull test between the dominant and non-dominant hand.

Handgrip strength is the most commonly tested aspect in studies on judokas, which aim at measuring maximal force. Bonitch-Góngora et al. [10] found maximal grip strength significantly greater for the dominant hand than the non-dominant one during combat simulations. Ache Dias et al. [21] and Franchini et al. [23] found no significant differences in maximal force between the dominant and non-dominant hand. As of now, it can be said that there is no consensus concerning .hand dominance strength.

In this study, F_{max}, RFD (indicator of explosive force) and RPFD showed differences in relation to hand dominance. These results may be explained by the characteristics of judo training, in which unilateral work is more common as athletes perform exercises and techniques mostly using their dominant side. According to Sterkowicz et al. [12], many coaches more frequently instruct their younger athletes to perform judo techniques on the dominant body side during training sessions at their clubs. Thus, when judokas perform, for example, throwing techniques that demand maximal and explosive force with the combat grip, these physical abilities tend to improve more on the dominant side. These strategies, besides reducing the chances of success in competitions [12], may lead to postural problems. Additionally, previous research [24] has found a positive association in Brazilian judokas between unilateral training and postural deviations.

The rate of peak force decrement during the *judogi* pull test presented results contrary to other variables, since the result for the non-dominant hand was greater than the dominant one. It has been documented that the dominant hand produces greater absolute force than the non-dominant one, but fatigues significantly quicker [11], i.e. the non-dominant hand is less strong, but is able to sustain force for a longer amount of time. This was similar to what was found with the judokas in this study during the pulling movement. According to Nicolay and Walker [12], absolute grip strength and endurance are unrelated. Instead, maximal strength depends on the ability to recruit motor units and the number of nerve impulses that reach the muscle, while endurance depends on metabolic factors such as the amount of available energy [25].

We correlated the strength parameters with athletes' body mass (indicator of weight categories) in order to check whether it may determine different specific strength and power profiles. Regarding the *judogi* pull test variables, absolute F_{max} was the only variable that correlated with body mass, indicating that the upper limbs' absolute force increases with body mass. No previous study was found that investigated this variable during the pull test while considering body mass. Most of the studies refer only to handgrip strength, which is the most common parameter investigated among the upper limbs. Analysing maximal handgrip strength, Farmosi [26] did not identify differences between judoka from different weight categories. On the other hand, Claessens et al. [27] have found that greater left-handgrip strength was observed in the middle weight category when compared to the lighter weight. Using a correlation approach, previous research has found a positive relationship ($r = 0.76$) between body mass and absolute handgrip strength, but when these values were presented relative to body mass, the correlation disappeared [15]. Similar results were observed in the present study when analysing F_{max} during the pull test. This may be explained by the fact that an increase in body mass (therefore, a greater weight category) does not signify an increase in muscle mass. In this study, the percentage of body fat increased with weight category, and, consequently, it may have influenced the amount of strength produced by the muscles.

Concerning the other variables of the pull test (RFD, TF_{max} and RPFD), they were not significantly correlated with body mass, finding that explosive force (TF_{max} and RFD) and the capacity to sustain peak force (RPFD) seem not be influenced by body mass. A negative correlation could be expected between explosive force parameters and body mass because explosive actions are performed during training and competition more frequently by lightweight athletes compared to heavyweight athletes; however, no significant relationship was found in the present study. It is important to consider that different factors may influence explosive force such as the type of fibre contraction, muscle fibre distribution, muscle properties and neural factors [28, 29]. Therefore, these aspects should be considered during the training of athletes in different categories.

Regarding the relationship between the lower limb strength parameters measured in CMJ and body mass, a negative correlation of jump height and relative power with body mass was verified, demonstrating that the lightweight judokas presented greater performance in the CMJ than the heavyweights. Additionally, absolute power and F_{max} were positively correlated with body mass, i.e. heavyweight athletes presented greater force and absolute power in their lower limbs than lighter ones. Power is determined by an optimal combination of force and velocity ($P = F \times V$) [30]. Thus, the greater absolute power obtained by the heavyweight athletes is due to a greater amount of force applied to the ground than lighter athletes, even though the velocity at take-off (PV) was greater in lighter judokas. This was confirmed by a negative correlation between PV and body mass. As PV is the main determinant of jump height and relative power [19, 31], lighter athletes apply more velocity than heavier ones, resulting in better jump performance in this group of judokas.

Another factor that may explain the better jump performance of lightweight athletes is the efficiency of muscle-elastic mechanisms involved in the muscle actions of the CMJ, such as the fast transition between eccentric and concentric phases [32]. According to Komi and Gollhofer [32], this transition must be accomplished in a short period of time in order to prevent the dissipation of elastic energy accumulated in the musculotendinous structures. This mechanism may not be very effective in heavyweight athletes due to the larger overload (body mass) they feature. This hampers the fast transition between the eccentric-concentric phases during the jump and the subsequent use of elastic energy to power production.

The rate of force development, absolute and relative to maximal force, was also analysed during CMJ. As observed for the upper limbs' strength parameters, the explosive force in the lower limbs seems to also not be influenced by the effects of increased body mass. Other parameters, like power and force seem to be more dependent on body mass and, consequently, they behave differently among weight categories.

Conclusions

This study found that there are differences in strength parameters, such as maximal and explosive force and the rate of peak force decrement, during the *judogi* pull test between hand dominance, highlighting the unilateral training characteristics of judoka. The absolute values of maximal force measured during the pull test and CMJ, and the absolute power of CMJ, increased according to body mass (higher weight categories). On the other hand, jump height and relative power increased with decreasing body mass, probably due to the higher take-off velocity achieved by the lightweight judokas.

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