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Acute effect of successive judo bouts on peak arm power

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Abstract

Background and Study Aim: The high metabolic stress observed during judo bouts seems to affect the handgrip and arm pushing isometric strength and the shoulder rotation torque performance, while the are no data concerning explosive actions of the upper limbs during one or more bouts. The aim of this study was the knowledge about effect of a simulated judo competition on the arm force-velocity relationship.

Material and Methods: Twelve national-level male judokas participated in four 5-minute judo bouts, separated by 15 minutes of passive rest. Before and after each bout, participants performed three repetitions of concentric bench press at maximal intended velocity with the load linked to the maximal power achieved during a preliminary incremental loading test. Peak power (PP), force (PF) and velocity (PV) were measured at each repetition with a lineal position transducer. Finger capillary blood samples were taken 1, 3 and 14 minutes after each bout to determine the maximum lactate level and its removal.

Results: There was a time of measurement effect on absolute and relative PP ($p<0.01$), resulting in an improvement in the after-bout PP due to a rise in the after-bout PV ($p<0.001$). Changes between pre- and post-bout PP ranged from small to moderate (ES from 0.33 to 0.65; mean percentage of change of 17.7%). ANOVA showed no effect of the bout number on the absolute and relative PP, PV and PF ($p>0.05$). High lactate levels were found (mean 16.1 ±1.5 $mmol \cdot L^{-1}$), showing a reduction throughout the bouts ($p<0.001$).

Conclusions: Despite the high metabolic stress observed, judo bouts produced acute improvements in the arm pushing PP immediately after the bouts. Training strategies should focus primarily on achieving high levels of arm pushing power and maximum strength. Moreover, coaches should consider design warm-ups protocols to induce a potentiate state in the arms immediately before the combats.

Key words: peak power output • successive combats • fatigue • performance

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Judo – a grappling Olympic combat sport disputed in seven weight categories for both male and females, that requires complex skills and tactical excellence for success [56] as well as the development of several physical capacities, including aerobic and anaerobic power and capacity, maximal isometric and dynamic strength, muscle power and strength-endurance [18].

Maximal muscular power – describes the highest level of power (work/time) achieved in muscular contractions [57]. From an applied perspective, maximal power represents the greatest instantaneous power during a single movement performed with the goal of producing maximal velocity at take-off, release or impact [58, 59]. This includes generic movements such as sprinting, jumping, changing direction, throwing, kicking and striking and therefore applies to the vast majority of sports [60].

Fatigue – the decreased capacity or complete inability of an organism, an organ, or a part to function normally because of excessive stimulation or prolonged exertion [61].

Potentiation – a significantly increase in muscle performance as a result of its previous contractile history [62].

Performance – the level at which a player or athlete is carrying out their activity, either in relation to others or in relation to personal goals or standards [63].

Dan (dan'i) – a term used to denote one's technical level or grade [64].

INTRODUCTION

Judo is a high intensity intermittent sport, with work periods of ~30 seconds and passive rest periods of ~10 seconds, during the reglementary combat time [1]. Athletes try to gain an advantage by throwing an opponent to the ground on their back. High muscle power is required for the execution of throwing techniques involving both lower- and upper-body muscle groups [2, 3]. Judokas perform an average of 15 ±5 attacks per combat [4] and 5-7 combats in a single day if they reach medal positions [5]. Combats are generally separated by a minimum recovery period of 15 minutes [5, 6]. Thus, it is necessary to maintain this capacity throughout the entire and successive combats.

At the same time, during a judo bout the contribution of the glycolytic metabolism is very high. Blood lactate concentration usually reaches values between ~10 and ~ 20 mmol·L^{-1} after one or more bouts in real or simulated competition [2, 7-10]. Although lactate is not necessarily the major cause of fatigue, it is a reliable marker of the high exercise intensity [11]. During intense exercise, lactate increases brusquely and contributes significantly to a decrease in pH within the active muscles and, if a whole-body exercise is performed, in the blood [11]. Some authors consider that the increase in blood lactate concentration and the drop in intracellular pH (due to increasing hydrogen ions [H^+]) are not directly related to the inhibition of muscular function and reduction in power and strength [12-14]. A sum of different mechanisms has been proposed to explain why muscular strength and performance decrease. Thus, the accumulation of inorganic phosphate and potassium, the glycogen depletion and dehydration seem to be the main responsible for this impairment [15]. These adverse metabolic conditions may affect strength production during the bouts and over the tournament [2, 5], due to the interaction between neuromuscular and metabolic systems [16].

In judo, most of the bout time is applied in grip fighting [17], while different levels of strength, power and endurance in a variety of movements are required [18]. Consequently, there is a high physiological demand on the upper-limbs [3, 9]. As it is shown in the literature, fatigue seems to affect the upper-limbs during the bouts. For example, a 15% decrease in maximal isometric handgrip strength was observed after four bouts [10]. Also, a decrease of 5% and 15% after the first and second bout, respectively [19], and of 12% in the right hand and 7.8% in the left hand after three bouts [20] were found. Moreover, losses were revealed in the external and internal shoulder rotation torque after three bouts [10]. Only one study investigated the pulling and pushing actions of the upper-body muscles during a judo bout [21]. The results showed a significant decrease in the mean and peak isometric strength in bench press with elbows at 90° after one single bout. However, more specific tests using dynamic movements would be more suitable, because after establishing the grip, judokas perform explosive pushing and/or pulling actions to unbalance and throw the opponent [10].

Therefore, the main objective of this study was the knowledge about effect of a simulated judo competition on the arm force-velocity relationship.

This information could clarify the performance of the upper-limbs during judo bouts and its succession, and provide coaches with valuable and more accurate information about training designs and pre-competitive warm-ups. It was hypothesised that successive judo bouts would reduce pushing power capacity, and therefore the possibility of effectively applying explosive arm extension actions during judo bouts.

MATERIAL AND METHODS

Study design

An intragroup repeated measures design was used to assess the effect of a simulated judo competition on arm pushing power. The participants undertook an anthropometric study, followed by a maximal incremental test to determine the force-velocity relationship in concentric bench press (CBP). Forty-eight hours later, each subject fought four bouts of 5 minutes each in a simulated competition, with 15 minutes of passive rest between them. Scoring an *ippon* (full point) did not cause the end of the bouts, contrary to the International Judo Federation (IJF) Referee Rules. The peak power (PP), peak force (PF) and peak velocity (PV) in the CBP were measured before and after each bout. Blood samples were taken during the recovery period to determine the lactate concentration and its removal between the bouts.

Participants

Twelve male judokas participated in this study (age: 22.0 ±3.2 years; body mass: 76.3 ±12.7 kg; height: 176.4 ±6.5 cm; fat percentage: 15.3 ±4.7%). They were medallists in national championships in Spain and France and participated in several international tournaments. Participants were selected based on the following criteria: currently participating in competitive judo, no previous history of upper-limb surgeries and experience in resistance training including bench press exercise for at least two years. All participants were evaluated during a competition period in which they had judo sessions (5–6 per week, 2 hours per session) and power-oriented resistance training (1–3 sessions per week). Their technical levels ranged from first to second dan black belt.

The study was approved by the local Ethics Committee in accordance with the Declaration of Helsinki. All participants gave written informed consent understanding the risks and benefits of the study.

Anthropometric measurements

Participants body composition was evaluated by a trained investigator following the standard techniques proposed by the International Society for the Advancement of Kineanthropometry (ISAK). The measurements taken included weight (scales, Seca Corporation 707, Colombia MD. Accuracy: 0.1 kg), height (stadiometer, GPM, Seritex, Inc., Carlstadt, New Jersey, USA. Accuracy: 0.1 cm), eight skinfolds (biceps, triceps, subscapular, suprailiac, supraspinal, abdominal, thigh and leg; skinfold caliper, Holtain Ltd, Crymych, UK. Accuracy: 0.2 mm), five circumferences (relaxed arm, arm contracted at 90°, forearm, thigh and leg; flexible, non-elastic metallic anthropometric tape measure, Holtain Ltd, Crymych, UK. Accuracy: 0.1 cm), and three diameters (humerus bicondylar, femur bicondylar and bistyloid; bicondylar caliper, Holtain Ltd, Crymych, UK. Accuracy: 0.1 cm). Three different measurements were taken for each skinfold and the average calculated. The fat percentage was estimated using the formula proposed by Faulkner [22] and the muscle area of the arms using that proposed by Heymsfield et al. [23].

Force-velocity curve

A maximal incremental test to determine the force-velocity relationship in CBP was conducted 48 hours before a simulated judo competition. The test started after a standardized warm-up, that included joint mobility, dynamic stretching and two sets of five CBP repetitions of 20 and 30 kg each. The initial load was 10 kg, which was increased by 5, 10 or 20 kg per set based on mean velocity. Participants started the movement with their elbows fully extended and self-selected the barbell grip. Then, the barbell was lowered until it was positioned 1-2 cm above their intermammary line, and they were required to maintain this position for 1 second (velocity = 0 $m \cdot s^{-1}$). From that position, every participant was instructed to perform an explosive concentric action at maximum speed. The last acceptable extension with the highest load possible was defined as the maximum repetition (1RM). Two repetitions per set were performed until the bar displacement mean velocity dropped below 0.3 $m \cdot s^{-1}$, whereupon only one repetition was performed. The rest period between sets was 3 or 5 minutes for velocities above or below 1 $m \cdot s^{-1}$, respectively. The test was performed on a standard free-weight bench with an Olympic bar and calibrated disks according to previously described methods [24].

The PF, PV and PP were assessed by a linear position transducer (LPT) EV PRO Dynamic Isocontrol System (Quasar Control S.L. Madrid) attached to the barbell [2, 25], with a 1000 Hz sampling rate. The repetition with the highest PP was selected and used for subsequent analysis. In this exercise and testing conditions, barbell velocity testing showed moderate to high reliability [26]. PP-load was defined as the load that expressed the maximum PP in the individual load-PP curve.

Simulated judo competition

Each participant fought in four 5-minute judo bouts. Each bout was separated by 15 minutes of passive recovery [2, 9, 10]. The competition took place on an official judo mat and was controlled by official referees and timekeepers from the regional judo federation. The official regulation which specifies "*a contest will end when one contestant has achieved ippon or equivalent*" (Referee Rules of the IJF) was modified, restarting the bout until the end of the official combat time when an *ippon* occurred to ensure that all bouts lasted for the officially allotted time. To generate a demanding competitive environment, participants were grouped into pairs of the same weight (difference of less than 5%) and similar ranking [2, 9]. Each participant fought the four bouts with the same opponent.

The procedure reproduced real judo combat activity, as described in the literature for junior and senior male judokas, such as time motion structure [1, 27], blood lactate levels and removal [7, 28] and heart rate levels [29]. The entire experimental phase was recorded with a Sony DCR-TRV14OE digital camera. Judo bouts were analysed with LongoMatch open software by three judo experts with over ten years of experience in the sport. The mean preparation, grip, attack, groundwork and break phases, and the number of attacks were calculated for each bout [1, 27]. All contests took place between 9:00 am and 2:00 pm and the temperature of the room varied between 18° and 23°C.

Two CBP testing areas were set up at a distance of 4 meters from the judo mat. A standard free-weight bench with an Olympic bar and calibrated disks were used as in the previous incremental load test. In the 30 seconds before and after each bout, the judoka performed three repetitions of the CBP with the PP-load obtained in the preliminary test. The repetition with the highest PP was selected as the value of the PP-before and PP-after each bout. The PV and PF of the selected repetition were also determined.

The blood lactate concentration was determined using a photoenzymatic system (Dr. Lange, LP 20 plus). A 10 µl sample of capillary blood was taken from the fingertip 1, 3 and 14 minutes after each bout. The maximal blood lactate concentration (LACMAX) was determined for each bout. The difference between the LACMAX and the lactate concentration at minute 14 after the bout (LAC14) was considered as the percentage of lactate removal (%LACR).

Statistical analysis

All data are expressed as mean ± standard deviation (SD). Normal distributions of the data were confirmed using a Shapiro-Wilk test. The difference between the variables determined before and after each bout was obtained from a repeated-measures ANOVA with two intra-subject factors [factor 1: bout number (1st, 2nd, 3rd and 4th bout); factor 2: time of measurement (before and after the bout)]. The intra-subject effect was determined using the Greenhouse-Geisser test or the Huynh-Feldt correction for degrees of freedom if the result of the Mauchly sphericity test was significant. For subsequent multiple comparisons, Sidak's modified test was performed

Table 1. Effect of successive bouts on the power, force and velocity before and after each bout judo athletes (n = 12).

Bout	Moment	PP ($W\ kg^{-1}$)	PP ($W{\cdot}lean\ kg^{-1}$)	PP (W/cm^2)	PF (N)	PF ($N{\cdot}lean\ kg^{-1}$)	PV ($m{\cdot}s^{-1}$)
1	Before	778.08 ±306.79	12.07 ±4.19	9.84 ±3.11	565.00 ±130.43	9.13 ±1.77	1.41 ±0.49
	After	976.68 ± 414.72	14.99 ±5.03	12.30 ± 4.12	610.02 ±137.87	9.74 ± 1.55	1.60 ± 0.49
2	Before	907.08 ± 375.79	13.69 ±4.55	11.17 ±3.53	613.56 ±140.92	10.04 ±2.07	1.46 ±0.51
	After	1032.35 ±550.42	15.75 ±6.47	12.86 ±5.09	609.18 ±180.11	10.31 ±2.51	1.58 ±0.45
3	Before	853.76 ±419.99	13.25 ±5.73	10.78 ±4.57	595.93 ±141.93	9.64 ±1.68	1.43 ±0.57
	After	991.52 ±415.54	15.17 ±5.05	12.35 ±3.68	620.84 ±172.62	9.89 ±2.32	1.62 ±0.46
4	Before	823.51 ±473.19	12.70 ±5.83	10.37 ±4.74	540.45 ±127.25	9.25 ±1.94	1.40 ±0.49
	After	1092.90 ±438.29	16.85 ±5.10	13.77 ±3.87	609.62 ±137.56	10.30 ±2.17	1.70 ± .42
Moment main effect (before/after bout)		$p = 0.003$ $F = 14.878$ $\eta^2 = 0.575$	$p = 0.004$ $F = 14.029$ $\eta^2 = 0.584$	$p = 0.004$ $F = 14.308$ $\eta^2 = 0.589$	$p = 0.093$ $F = 3.381$ $\eta^2 = 0.235$	$p = 0.134$ $F = 2.653$ $\eta^2 = 0.210$	$p = 0.000$ $F = 36.802$ $\eta^2 = 0.770$
Bout main effect (bout number 1 to 4)		$p = 0.135$ $F = 1.991$ $\eta^2 = 0.153$	$p = 0.177$ $F = 1.775$ $\eta^2 = 0.149$	$p = 0.194$ $F = 1.672$ $\eta^2 = 0.143$	$p = 0.113$ $F = 2.146$ $\eta^2 = 0.163$	$p = 0.173$ $F = 1.774$ $\eta^2 = 0.151$	$p = 0.149$ $F = 1.897$ $\eta^2 = 0.147$
Interaction between moment and bout		$p = 0.248$ $F = 1.143$ $\eta^2 = 0.116$	$p = 0.253$ $F = 1.433$ $\eta^2 = 0.125$	$p = 0.280$ $F = 1.339$ $\eta^2 = 0.118$	$p = 0.459$ $F = 0.884$ $\eta^2 = 0.116$	$p = 0.394$ $F = 1.029$ $\eta^2 = 0.093$	$p = 0.11$ $F = 4.385$ $\eta^2 = 0.285$

Mean & **±** SD; **PP ($W{\cdot}kg^{-1}$)** relative peak power to body weight; **PP ($W{\cdot}lean\ kg^{-1}$)** relative peak power to lean body mass; **PP ($W{\cdot}cm^2$)** relative peak power to arms lean area; **PF (N)** peak force; **PF ($N{\cdot}lean\ kg^{-1}$)** peak force relative to lean body mass; **PV** ($m{\cdot}s^{-1}$) peak velocity; **p** statistical significance; **F** Snedecor's F; **η^2** partial eta square.

in the case of a significant ANOVA. Generalized eta-squared measures of effect size and thresholds (0.02 [small], 0.13 [medium] and 0.26 [large]) were calculated along with ANOVA effects [30]. The magnitude of differences was expressed as standardized mean differences (Cohen's effect size, ES). The criteria to interpret the magnitude of the ES was as follows: trivial (< 0.2), small (0.2-0.59), moderate (0.60-1.19), large (1.2-2.0) or very large (>2.0) [31]. All statistical tests were performed using the software package SPSS version 24.0 (SPSS, Inc., Chicago, USA). A 95% confidence interval was established.

RESULTS

The mean time registered during the bouts was 7.9 ±3.2 seconds for the break phase, 4.1 ±1.3 seconds for the preparation phase, 15.8 ±6.2 seconds for the grip phase, 0.9 ±1.3 seconds for the technique/attack phase and 17.4 ±9.0 seconds for the groundwork phase. The mean number of attacks recorded per bout was 13.6 ±4.2.

The CBP mechanical results obtained before and after each bout are shown in Table 1. ANOVA showed a large main effect of time of measurement on PP ($F = 14.878$, $p = 0.003$, $\eta^2 = 0.575$; $F = 14.029$; $p = 0.004$, $\eta^2 = 0.584$; $F = 14.308$; $p = 0.004$, $\eta^2 = 0.589$, for a PP expressed as absolute, relative to lean body mass and relative to lean arms area, respectively), resulting in an improvement in the after-bout PP due to a rise in the after-bout PV ($F = 36.802$; $p<0.001$; $\eta^2 = 0.770$). There was no main effect of the bout number on the absolute PP ($F = 1.991$; $p = 0.135$), PV ($F = 1.897$; $p = 0.149$) and PF ($F = 2.146$; $p = 0.113$), nor on the relative measurements ($p>0.05$).

The differences in pre- and post-bout PP for all participants. Post-bout PP was higher in all bouts ($p = 0.003$) (Figure 1). The magnitude of the differences ranged from small to moderate (ES from 0.33 to 0.65; mean percentage of change of 17.7%), with the greatest differences in the first and in the last bouts (Figure 2).

Differences between the four bouts were verified in the first ($p = 0.021$), third ($p = 0.001$) and fourteenth ($p = 0.001$) minute after bout, showing a progressive reduction in the lactate concentration throughout the bouts. A main effect of the bout number on the LACMAX ($p = 0.004$) was observed, displaying a reduction throughout the bouts (17.8 ±4.3, 16.6 ±3.5, 15.6 ±4.8, 14.2 ±3.7 $mmol \cdot L^{-1}$ in the four bouts, respectively; $p<0.001$). The %LACR reached after each bout was of 38.33, 36.44, 38.51 and 43.28% for the first, second, third and fourth bout, respectively ($p>0.05$) (Figure 3).

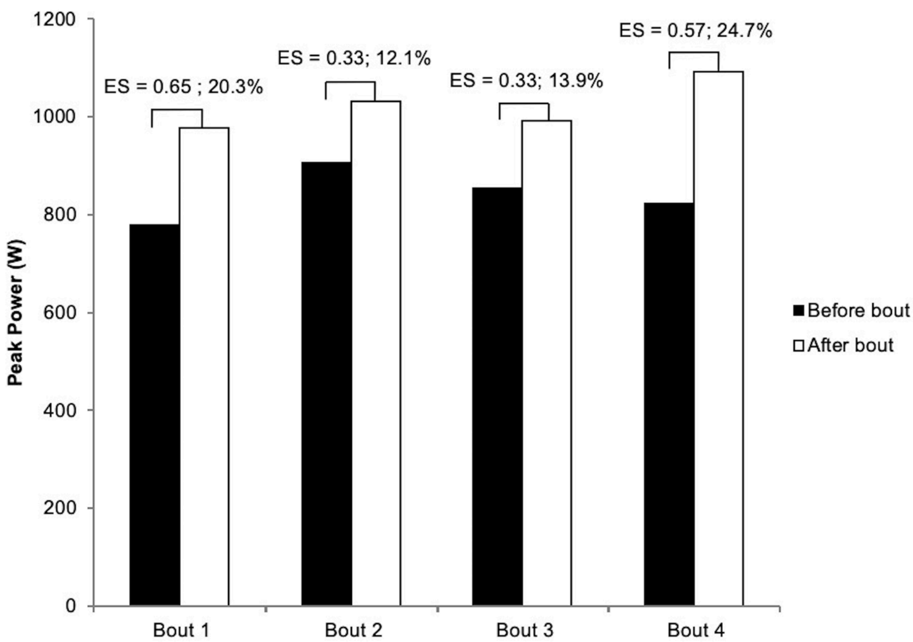

Figure 1. The differences in pre- and post-bout PP for 12 judo athletes.

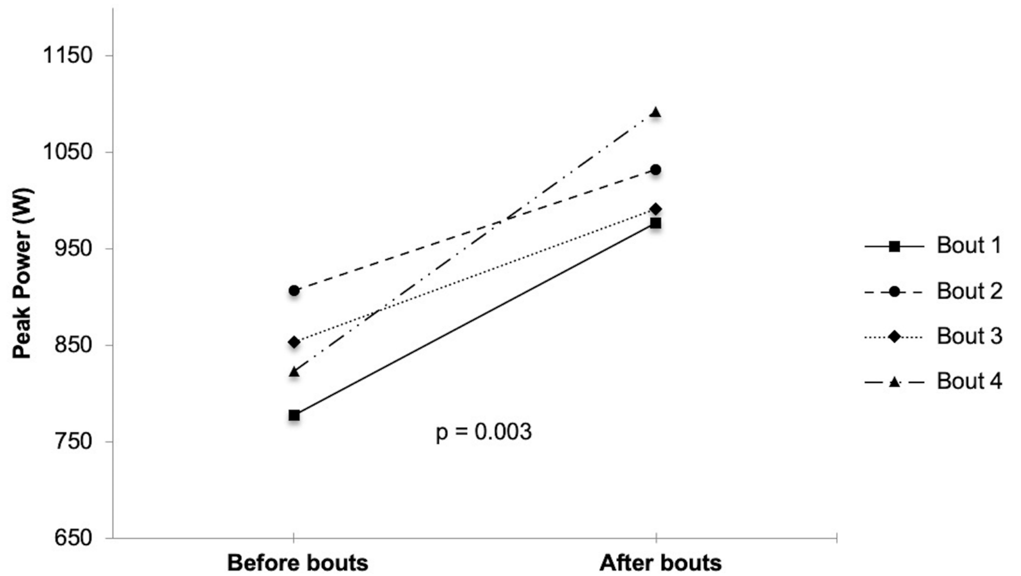

Figure 2. The differences before and after bout PP for 12 judo athletes, was expressed by the Cohen's effect size (ES).

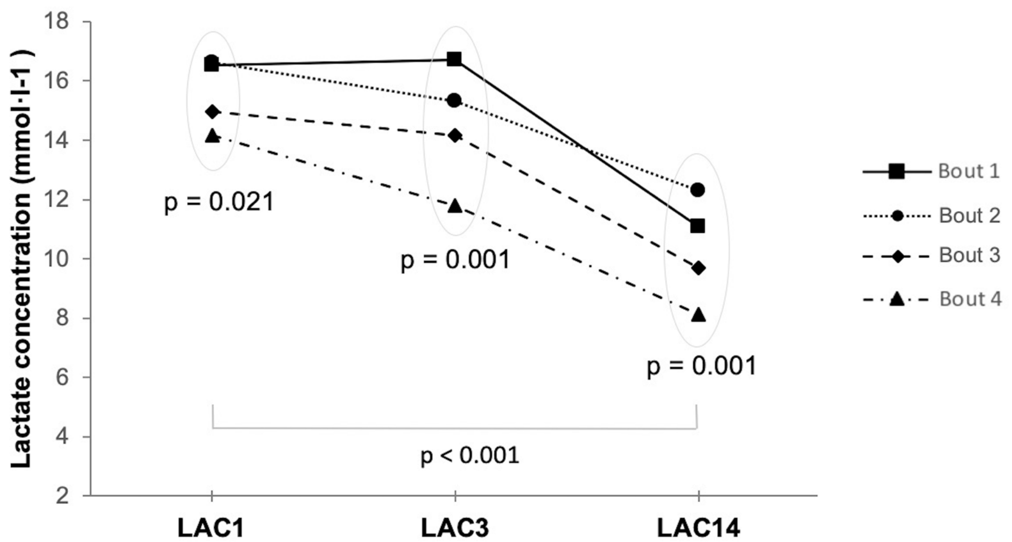

Figure 3. Blood lactate concentrations during the recovery of each bout 12 judo athletes during simulated judo competition.

DISCUSSION

The present study was designed to analyse the effect of successive judo bouts on upper-body muscle power capacity and its relationship with the metabolic changes that happened throughout four combats. Contrary to what was hypothesized, the high metabolic stress registered during the bouts, as shown by the high blood lactate concentration, did not impair the arm pushing capacity. Moreover, it was observed a potentiating effect resulting in a 17.7% mean improvement during the post-bout CBP, due to a PV increase reached after the bouts (Figure 2; Table 1). The incomplete metabolic recovery between bouts (15 minutes of passive recovery) also had no effect on the mechanical ability of the arm to achieve an optimal force-velocity ratio during the pushing action. On the other hand, the absence of a main effect of the bout number on the absolute PP indicates that the PP remained stable throughout the competition.

Several authors reported that arm strength and power are essential for judo performance [8, 32-34] and also allow to discriminate between judokas of a different competitive levels [35-37]. With a ~50% of the combat time spent in grip fight [1, 38], the grip dominance is essential to increase the opportunities to apply throwing techniques [39], involving many movements such as carrying and pulling or pushing the opponent [34]. However, surprisingly only one study analysed the arm pushing action during judo bouts [21]. The results reported a significant decrease in the mean and peak isometric strength after one single 5-minute bout in bench press with elbows at 90°. The discrepancy with the results of the present study may be due to differences in the way that dynamic and isometric contractions respond to fatigue and recovery, it being more difficult to eliminate metabolites and to supply oxygen to allow the creatine phosphate resynthesise in isometric contractions [40, 41]. In this line, various studies with a similar design to the one used in the present study reported losses in isometric contractions performed with the forearm muscles during the bouts. For example, a significant decrease of 15% in maximal isometric handgrip strength after four 5-minute bouts was observed, which correlated positively with maximal blood lactate concentration [9]. Iglesias et al. [19] and Kons et al. [20] also showed an impairment in the forearm capacity to generate force after two or four 5-minute bouts, respectively. In addition, losses were also revealed in external and internal shoulder rotation torque after three 5-minute bouts [10], establishing a significant correlation with other fatigue and muscle damage markers, such as creatine kinase and lactate dehydrogenase. Nevertheless, the capacity to generate lower-limb strength at high velocity seems to be not affected after one to four 5-minute bouts [2], highlighting, as in our study, that it is independent of blood lactate concentration [2, 19, 21]. These results together confirm that judo bouts and their succession may affect differently the performance of different muscle groups. As judo activity implies a variety of technical movements depending on the opponent responses, each action has a different energy demand [7, 42]. Judo grip is an example of an action that requires the almost constant isometric contraction of the forearm muscles, while the shoulder muscles work dynamically to continuously hinder the opponent's grip. Consequently, both muscular groups are affected by fatigue as displayed in the studies discussed above. On the other hand, explosive actions activate the upper- and lower-limb muscles occasionally when the judoka performs an attack [2]. In the present study it was registered a mean of 13.6 ±4.2 attacks per combat with a mean duration of ~1 second each, which represents a ratio of ~3 attacks per minute or ~1 attack each 20 seconds. These results are in accordance with other studies with a similar ratio of attacks [4, 38], suggesting that there is enough rest time between explosive actions through the combat to activate fast recovery mechanisms (e.g.: adenosine triphosphate rephosphorylation) [43].

Results showed high blood lactate concentrations that reflect a great contribution of the glycolytic metabolism during the bouts (above 14 mmol·L^{-1} in all cases). These values are in accordance with the standards registered after one or more bouts at real [7, 28] or simulated competition [2, 4, 8-10]. Although the contribution to fatigue of lactate *per se* and concomitant reductions in pH is likely minimal [44], other associated peripheral mechanisms, such as 1) the irritation of muscle pain receptors, contributing to the sensation of discomfort and the accumulation of potassium in the muscle interstitium; 2) accumulation of inorganic phosphate because of the insufficient time for full resynthesise of aerobic adenosine triphosphate and creatine phosphate reserves; 3) limitation of calcium ion influx; 4) glycogen depletion; and 5) dehydration have been associated with reduced muscular strength and performance [15]. These mechanisms, together with the LACMAX progressive reduction reached after the bouts throughout the competition, the incomplete blood lactate removal and also the fact that %LACR followed a similar trend after each bout could be interpreted as the expected fatigue instauration and as a reduction in the combat effort intensity [2, 9]. Nevertheless, it did not seem to affect the mechanical ability of the upper-limbs to achieve an optimal force-velocity ratio during the arm extension. As stated in the literature [45-48], when intermittent high-intensity exercise is performed, aerobic metabolism is involved during both the work and recovery phases. Some studies suggested that power output during this type of exercise is supported by energy that was mainly derived from creatine phosphate degradation and an increased aerobic metabolism [46, 47, 49]. During judo bouts, the anaerobic system provides the short, quick, all-out bursts of maximal power actions, while the aerobic system contributes to the athlete's ability to sustain effort for the duration of the combat and to recover during the brief periods of rest or reduced effort [5]. The current results are in accordance with others studies in which explosive actions were not affected after the bouts [2, 19, 21]. In addition, the arm PP remained stable throughout the competition. In line with this, Franchini et al. [6] observed that the minimal recovery time reported in judo competitions (15 minutes) is long enough for the arms to recover sufficiently to maintain performance during a Wingate test.

Moreover, an improvement in the after-bout PP was showed, due to a rise in the after-bout PV. This potentiating effect has been related with some physiological mechanisms, such as the phosphorylation of myosin regulatory light chains, which increases calcium sensitivity of myofilaments, the increase in the recruitment of higher order motor units and a possible change in pennation angle [50]. It has been well documented that both fatigue and potentiation can occur and their relationship can be influenced by, among others, variables related to the characteristics of the previous activity (e.g.: intensity and number of muscular contractions, recovery interval between muscular contractions, dynamic or isometric contractions), subject characteristics and individual differences, suggesting that both effects are multifaceted [50, 51]. Since physical activity in judo is not directly measurable or reproducible [52] like the potentiation protocols referred in the sports field as post activation potentiation (PAP), the present study did not aim to standardize the judo bout as a protocol to induce potentiation. However, these results have an important application for the design of training and warm-up strategies.

The increase in the rate of force development and muscular power by means of an optimal warm-up immediately before a competitive event is of paramount importance [53]. Previous studies showed that a warm-up that induces potentiation before competition can be more helpful to athletes than a traditional one (running and stretching exercises), enhancing subsequent explosive activities, such as jumping, throwing and sprinting [50]. When designing a PAP protocol to potentiate an acute effect it should be noted that sports with a single action (such as long jump) will benefit more than sports whose repetitive actions can have a potentiating effect by themselves (such as combat sports), as has been stated in this study. Despite this, since a judo combat may end in the first seconds by scoring an *ippon*, judokas would benefit from starting the combat in a potentiated state.

Limitations of this study include a small sample size. This prevented the data analysis by weight category, which would be advisable since some studies found differences between male judokas of the same competitive level and different weight categories in terms of body composition [18], maximal strength [54] and techniques used [55]. It should also be noted that in this study judokas were not randomly selected for participation but were selected considering their ranking, to match them according to their level. This introduces potential selection bias because all participants were at a national level and may not truly reflect changes across all levels of competitive performance. Differences described between judokas of different competitive levels, mostly in terms of maximal dynamic strength, muscle power, muscular endurance and anaerobic profile [18] reinforce this idea. Therefore, future investigations should use wider samples and compare the behaviour of different muscle groups during successive judo bouts, in judokas of different weight categories and different competitive levels.

CONCLUSIONS

The results of this study show that the high metabolic stress registered during judo bouts did not negatively affect the arm explosive pushing actions. Contrary, judo bouts induced a potentiating effect on the arm pushing capacity immediately after the bouts. In addition, this potentiating effect dissipated from one combat to another, keeping the arm pushing PP stable throughout the successive combats.

HIGHLIGHTS

To date it has been assumed that judo bouts produce a generalized fatigue in the upper-body. According to the results available in the literature, forearms and shoulders are clearly affected by fatigue. Nevertheless, considering the results of this study in which it was displayed a rise in PP after the bouts and an absence of changes throughout the competition, we recommend that training strategies for arm pushing capacity should focus primarily on the development of high levels of maximal strength and muscle power. In addition, the potentiating effect of a bout in the subsequent PP production should be also considered during a competition warm-up.

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