Maximal isometric handgrip strength and endurance differences between elite and non-elite young judo athletes

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ABSTRACT

Background & Study Aim: Judo is a combat sport in which the maintenance of handgrip strength is essential because the judokas repeat this action continuously during the struggle for grip. While descriptions of maximal isometric handgrip strength in judokas are relatively common, few data exist concerning the ability to resist successive isometric contractions in the hands and its relation to performance. The aim of this study was the differences and similarities between elite and non-elite young judokas in terms of maximal isometric handgrip strength and their endurance to this strength.

Material & Methods: Seventy-three adolescents participants from three national (elite) and one regional team (non-elite) were tested. The maximal isometric handgrip strength was recorded during a maximum test of 6 s with an electronic Digimax dynamometer. The endurance to the isometric handgrip strength was measured by a test consisting of 8 contractions of 10 s each alternating with 10 s of passive rest, and was also recorded with the same machine.

Results: The endurance test decreases the relative and mean isometric handgrip strength of male and female judokas ($p \leq 0.01$), irrespective of their competitive level. However, male and female elite judokas developed higher levels of relative isometric handgrip strength in the maximum test and during all contractions of the endurance test than non-elite judokas ($p \leq 0.01$ for both sexes). In all cases, the non-elite group took longer to reach the maximal isometric handgrip strength ($p \leq 0.05$).

Conclusions: Maximal isometric handgrip strength and the endurance to this strength were able to distinguish between elite and non-elite young judokas. Coaches should include conditioning programs for both maximal isometric handgrip strength and the ability to resist successive isometric contractions to maximize performance.

Keywords: Handgrip force • Muscular Endurance • Fatigue • Judo Performance • Combat Sports.

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Handgrip strength: "A general term used in clinical and occupational settings and by strength athletes. It refers to the muscular strength and force that can be generated by the hands. The strength of a handgrip is the result of the maximum force that the subject is able to exert under normal biokinetic conditions through the voluntary flexion of all finger joints, thumbs, and wrists" [31].

Muscular endurance: "The ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time" [32].

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" [33].

Sports Performance: "Carrying out of specific physical routines or procedures by one who is trained or skilled in physical activity. Performance is¡ influenced by a combination of [physical], physiological, psychological, [emotional], and socio-cultural factors" [34].

Combat sports: "Competitive contact sports where two combatants fight against each other using certain rules of engagement" [35].

Introduction

handgrip strength is commonly evaluated in different clinical settings as an indicator of general health status and upper limb strength [1,2]. Evaluation of this parameter is also considered to be very important when assessing performance in some sporting activities [3-5].

The initial contact between two judokas occurs by way of different gripping techniques of the opponents uniform (judogi), known as *kumi-kata*. Grip control is considered to be a key factor affecting the outcome of the bout as it allows attack techniques to be executed and hinders the opponent's ability to act [6,7]. As a result, it is important to increase the handgrip and push/pull strength of the upper body in order to increase the chances of success [8].

Various authors have investigated the maximal isometric handgrip strength (MIHS) of judokas [7,9,10]. Numerous factors, including age [11], sex [12], weight [13], and forearm circumference [1] are known to affect the MIHS. These factors agree with the conclusions of Franchini et al. [14] in their review of the physiological profile of judokas, which highlights the different behaviour of MIHS between weight categories, competitive levels and sex, especially when expressed relative to body weight [4,9,15].

The complexity of technical actions and combat tactics means that establishing a direct relationship between improved upper limb strength and competitive success is difficult [16]. Furthermore, the procedure by which MIHS is traditionally measured involves a single maximal isometric contraction test lasting between 5 and 15 s. However, this type of muscle work does not resemble that undertaken during a judo combat, where each grip lasts for between 10 and 40 s and is repeated a minimum of 15 to 20 times [17] during the average time of almost 8 min of the bout [14], thus meaning that the upper body strength requirements for a judoka are extremely high and in constant demand [18,19]. MIHS is therefore one of the main factors on which success in this sport is based [14]. In contrast, the number of studies concerning the effect of combat [10] or a series of handgrips [20] on the MIHS in judokas is much lower. Thus, it was observed a MIHS loss of between 13% and 17% in 12 national level judokas during a simulated competition (4 bouts of 5 min in real time with 15 min of passive recovery) [10]. In a further study [20] it was found a 39% decrease in MIHS during an interval-type test involving senior elite judokas based on 10 repetitions of 10 s each alternating with 10 s of recovery. These studies highlighted the fatigability of forearm muscles during judo practice as well as repeated contractions, and thus the need for a better understanding of this process in order to develop better training regimens to improve combat performance. This study aimed to: (a) differences and similarities in the behaviour of elite and non-elite judokas of both sexes in the MIHS during an endurance test, and (b) relationship between the MIHS and the endurance to maximal handgrip strength (E-MIHS) in these judokas.

Material and methods

Experimental Approach to the Problem

A transversal descriptive design, with non-probabilistic sampling for convenience, was used to achieve the objectives of this study. Crossing of the dependent variable (MIHS) was performed following sample-stratification criteria by sex (male or female) and competitive level (elite and non-elite). On the test day, the subjects were initially submitted to an anthropometric study, followed by an evaluation of the MIHS and finally an endurance test of the MIHS in the dominant hand (E-MIHS). Data were collected during the International Training Camp in Fuengirola (Spain), which is organised by the Spanish Judo Federation and included in the official calendar of the European Judo Union. All subjects were evaluated during the competition period. Subjects in the elite group were in the classification period for the European U-17 Championship. The non-elite group were preparing for the Spanish National U-17 Championship.

Subjects

Data were collected on a total of 73 young judokas, members of the U-17 Portuguese, Swedish and Danish national teams (elite: medallists in the National U-17 Championships in each country) and the regional team from Andalusia, in Spain (non-elite: non-medallists in the National U-17 Championships in Spain). Descriptive characteristics of the subjects are provided in Table 1. All subjects had practiced judo for more than 5 years, trained for between 4 and 10 h a week. The study was approved by the Institutional Review Committee of the University of Granada. The procedures were fully explained to the participants and their guardians, and they all gave their written informed consent before testing. All procedures were performed in accordance with the Declaration of Helsinki.

Procedures

Anthropometric measurements

The body composition of all subjects was evaluated. Measurements were taken by a trained investigator

Table 1. Characteristics of elite and non-elite male and female judokas.

Gender	Group	Age (years)	Weight (kg)	Height (cm)	Lean body mass (kg)	% Fat	Dominant arm lean area (cm^2)
Male	Elite (*n*=26)	15.0 ± 0.7	61.7 ± 11.1*	169.9 ±7.8	32.1 ± 5.7	10.6 ± 1.8*	30.0 ± 5.7
	Non-elite (*n*=19)	14.8 ± 0.6	70.1 ± 14.7	171.9 ± 6.6	35.1 ± 5.0	13.0 ± 4.8	31.2 ± 4.7
Female	Elite (*n*=21)	14.8 ± 0.6	55.1 ± 7.1	161.0 ± 5.0*	29.3 ± 3.2	14.0 ± 2.2	23.8 ± 2.7
	Non-elite (*n*=7)	14.6 ± 0.5	54.5 ± 9.5	154.9 ± 6.5	28.7 ± 4.8	15.6 ± 2.1	22.9 ± 4.1

Values are mean±SD for age, weight, height, lean body mass, %fat and dominant arm lean area. Significant differences between elite and non-elite: * ($p \leq 0.05$). % Fat: [21]. Dominant arm lean area (cm2): [22].

following the standard techniques proposed by the International Society for the Advancement of Kineanthropometry (ISAK). The measurements taken included age, 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 90º, 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 [21], and the muscle area in the dominant arm using that proposed by Heymsfield et al [22].

MIHS test

A manual electronic Digimax dynamometer (Mechatronic GmbH, Darmstadt, Germany) connected to a computer running Windows was used to determine the MIHS for the dominant hand. The software used monitored strength as a function of time, expressing it as the maximum and mean of that applied during each repeat. As a warm-up and to familiarize themselves with the measuring instrument and protocol, the subjects made various attempts, noting the most comfortable distance to the handle when gripping the dynamometer, and this distance was maintained during all subsequent tests [23]. A modified version of the measurement position recommended by the American Society of Hand Therapists (ASHT) was used [24]. Thus, the subject was sitting on a chair, with the back supported, feet on the floor, the shoulder of the executing arm in neutral adduction and rotation, the elbow flexed to 90º, the forearm in a neutral position and the wrist extended by between 0 and 30º, with an ulnar deviation of between 0 and 15º. Due to its weight, the dynamometer was placed on a height-adjusted table, in which the arm never rested (Figure 1). Once this position had been achieved, three attempts of 6 s each were made with the dominant hand, with a passive rest period of 30 s between each attempt [25]. The highest of the three readings was taken as the MIHS. The MIHS was expressed in absolute values (N), relative to the muscle

Figure 1. Measurement position.

area in the executing arm (N/cm^2) and as the mean of the absolute strength applied during the repeat (N). The digital analysis system allowed the time (s) taken to reach maximum strength during each repeat to be determined.

E-MIHS test

Once 5 min had passed after performance of the MIHS test, the subjects performed a test to evaluate the E-MIHS in the dominant hand. This test consisted of eight maximal isometric contractions of 10 s each alternating with 10 s of passive rest [20]. The execution position and materials used were the same as described above. Subjects were informed that they should generate the highest possible contraction strength during each repeat. The MIHS for each contraction was determined in absolute (N) and relative terms (N/cm^2), and as the mean of the MIHS applied during the repetition (N).

Statistical Analysis

Data are expressed as mean and standard deviation (mean±SD). The frequency distribution was determined using the Shapiro-Wilk test. The male and female elite and non-elite populations were compared using a means-comparison test for independent samples. The Levene statistic was used to determine the homogeneity of the variances, with the Welch test being used to compare means in the event of significance. The Mann-Whitney U-test was used to compare independent groups of variables with a non-normal distribution. The E-MIHS was analyzed using a linear repeated-measures model adjusted to a factor with eight levels or number of measurements. The Greenhouse-Geisser correction was applied in the event of a significant Mauchly sphericity test. The Sidak test was used during pairwise analysis in the event of a significant ANOVA. The Friedman test was used during overall analysis of the condition for those variables that showed a non-normal distribution. In the event of significance, pairwise analysis was performed using the Wilcoxon test with an alpha value of 0.05/n. A confidence interval of 95% was established for the remaining analyses.

Results

The analysis of the values showed higher absolute and relative MIHS values for female elite than for non-elite judokas (305.6 ± 40.5 N *vs.* 231.0 ± 63.8 N; 12.9 ± 1.8 N/cm^2 *vs.* 10.2 ± 2.6 2 N/cm^2 for elite and non-elite respectively; p≤0.01) (Table 2). Male elite and non-elite judokas showed a similar MIHS in absolute terms (460.7 ± 92.3 N *vs.* 415.1 ± 70.9 N, respectively; p≥0.05). However, the MIHS exerted was higher for elite judokas when expressed with respect to muscle area in the arm (15.4 ± 1.5 N·cm^2 *vs.* 13.4 ± 1.6 N/cm^2; p≤0.001). Significant differences were found between the absolute (p≤0.01) and relative (p<0.01) MIHS values for men and women. In all cases studied, the non-elite group took longer to reach the MIHS (p≤0.05).

There was a strong correlation between arm muscle area and forearm circumference (cm) (r=0.79, p≤0.001) and MIHS (r=0.810, p≤0.001). Likewise, it was found a strong correlation between forearm circumference (cm) and MIHS (r=0.80, p≤0.001) (Figure 2).

The intra-group analysis shows an overall effect of the eight successive series on the relative MIHS for each series for both sexes and levels (elite and non-elite; p≤0.001) (Table 3). The comparative analysis for the pairs established clearly shows a loss of relative MIHS throughout the test. Thus, the relative MIHS undergoes a decrease of 24.5 ± 9.1% and 18.8 ± 9.1% in male and 18.4 ± 9.3% and 16.8 ± 7.0% in female, elite and non-elite respectively, between the first and eighth repetition. Likewise, the relative MIHS decreases significantly during the first two repeats in male elite and non-elite judokas, but only after the first repeat in female elite judokas (p≤0.05).

Table 2. Comparison of MIHS, relative MIHS and time to MISH between male and female elite and non-elite judokas.

Gender	Group	MIHS (N)	MIHS (N/cm^2)	t-MIHS (s)
Male	Elite	460.7 ± 92.3	15.4 ± 1.5**	2.2 ± 2.1*
	Non-elite	415.1 ± 70.9	13.4 ± 1.6	2.9 ± 1.6
Female	Elite	305.6 ± 40.5**	12.9 ± 1.8**	1.5 ± 0.8*
	Non-elite	231.0 ± 63.8	10.2 ± 2.6	2.7 ± 1.6

Values are mean ± SD for MIHS. Significant differences between elite and non-elite: * (p≤0.05); ** (p≤0.01). MIHS (N): maximal isometric strength to in the dominant hand. MIHS (N/cm^2): relative maximal isometric strength to dominant arm lean area. t-MIHS (s): time to maximal isometric strength.

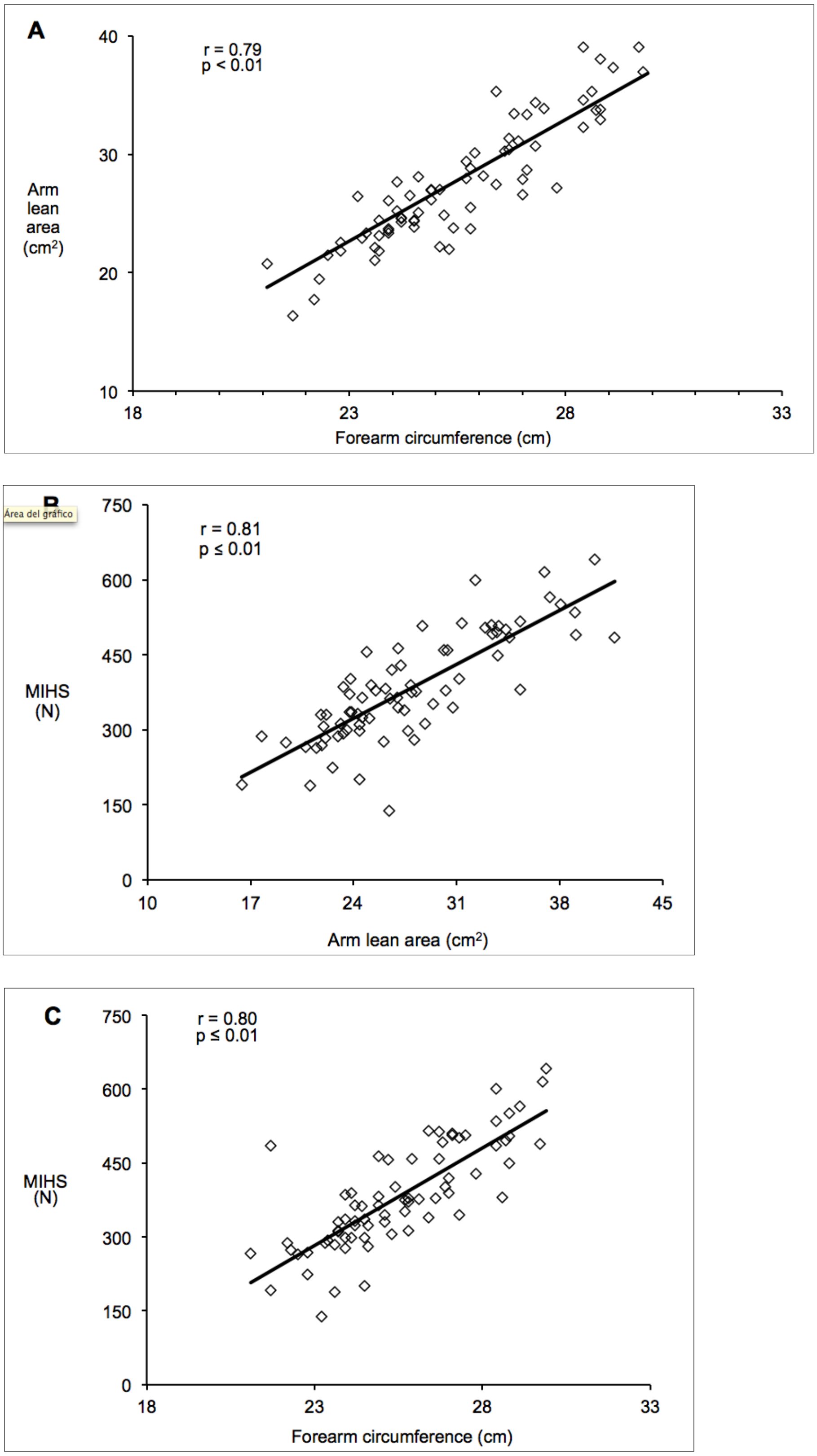

Figure 2. Correlations between arm lean area and forearm circumference (A), between arm lean area and MIHS (B), and between forearm circumference and MIHS (C), in all subjects.

Table 3. Study of the evolution of the relative MIHS during the resistance test in male and female elite and non-elite judokas.

Group	MIS	Gender	Mean ± SD	Global p
Elite	MIHS-1 (N/cm^2)	Male	14.9 ± 1.5*	0.000
		Female	12.4 ± 2.0*	
	MIHS-2 (N/cm^2)	Male	13.5 ± 1.6†	
		Female	10.9 ± 1.6†	
	MIHS-3 (N/cm^2)	Male	12.5 ± 1.6‡	
		Female	10.3 ± 1.3	
	MIHS-4 (N/cm^2)	Male	12.2 ± 1.8	
		Female	10.0 ± 1.4	
	MIHS-5 (N/cm^2)	Male	11.6 ± 1.7	
		Female	10.0 ± 1.6	
	MIHS-6 (N/cm^2)	Male	11.3 ± 1.8	
		Female	9.6 ± 1.4	
	MIHS-7 (N/cm^2)	Male	11.1 ± 1.7	
		Female	9.6 ± 1.6	
	MIHS-8 (N/cm^2)	Male	11.3 ± 1.7	
		Female	10.2 ± 1.6	
Non-elite	MIHS-1 (N/cm^2)	Male	12.8 ± 1.7*	0.000
		Female	9.4 ± 1.9	
	MIHS-2 (N/cm^2)	Male	11.5 ± 1.2†	
		Female	8.8 ± 1.7	
	MIHS-3 (N/cm^2)	Male	10.7 ± 1.3‡	
		Female	8.2 ± 1.4	
	MIHS-4 (N/cm^2)	Male	10.4 ± 1.3	
		Female	8.7 ± 1.8	
	MIHS-5 (N/cm^2)	Male	9.9 ± 1.3	
		Female	8.8 ± 2.2	
	MIHS-6 (N/cm^2)	Male	10.0 ± 1.3	
		Female	8.1 ± 1.5	
	MIHS-7 (N/cm^2)	Male	9.4 ± 1.4§	
		Female	8.0 ± 1.5	
	MIHS-8 (N/cm^2)	Male	9.5 ± 1.2	
		Female	7.8 ± 1.5	

Values are mean ± SD for MIHS. Significant differences between 1 and 8 repetition: * ($p \leq 0.01$). Significant differences between 1 and 2 repetition: † ($p \leq 0.01$). Significant differences between 2 and 3 repetition: ‡ ($p \leq 0.01$). Significant differences between 6 and 7 repetition: § ($p \leq 0.05$). MIHS-n (N/cm^2): relative maximal isometric strength to dominant arm lean area in the repetition *n*.

The results of the inter-group analysis (elite vs. non-elite) for the relative MIHS during the endurance test are also shown in Figure 3. Thus, over eight repetitions, the relative MIHS exerted by male and female elite is significantly higher than that for non-elite ($p \leq 0.05$).

Discussion

The results of this study show differences, in both absolute and relative terms, between the ability of female elite and non-elite to exert high levels of MIHS in the dominant hand, although only in relative terms for males. Likewise, to the author's knowledge, this is the first study to report E-MIHS characteristics for judokas from different competitive levels. Thus, an effect of the successive contractions on the relative and mean MIHS can be seen for both sexes and levels, remaining higher for both groups of elite judokas throughout the test.

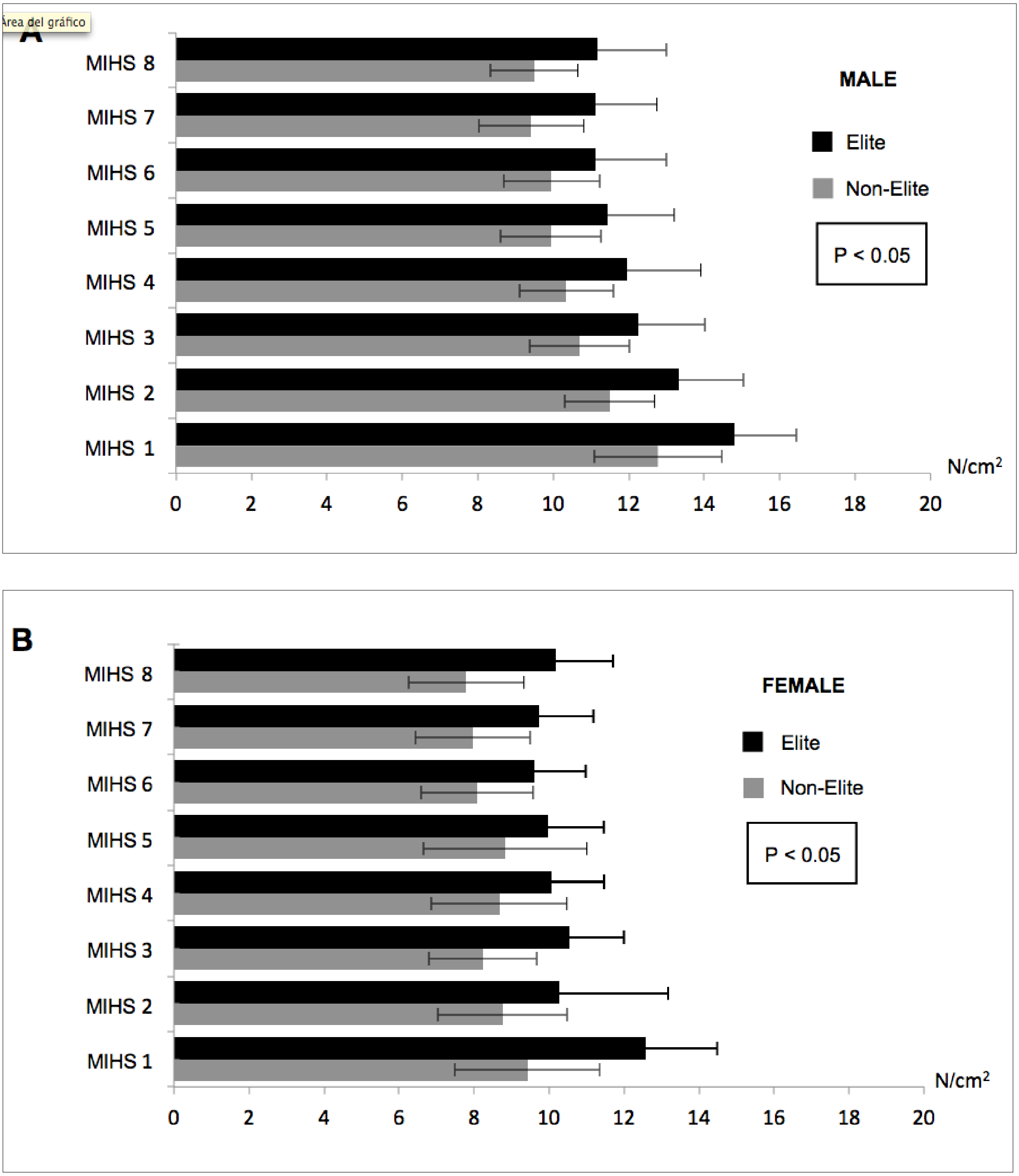

Figure 3. Comparison between the relative MIHS evolution in the endurance test of the male (A) and female (B) elite and non-elite judokas.

As judokas have to grip the opponent's uniform (judogi), previous studies have focused on MIHS. The MIHS values found in this study are higher in female elite than in non-elite judokas. However, these values for both these groups are lower than those obtained previously for senior elite female judokas [4]. No significant differences were observed between male elite and non-elite. Similarly, a previous study also found no differences in terms of MIHS between judokas of different competitive levels [9]. The MIHS values for male elite and non-elite were similar to those reported previously for Brazilian U-17 [26], U-20 and senior national non-elite [9], but higher than those for Canadian regional U-17 judokas [7].

These findings should, however, be treated with care as the subjects in our study were not stratified by weight category. In this respect, various studies have found a positive correlation between MIHS and body weight [11,13]. In a recent review [14], it noted that, although the paper by Matsumoto et al. [27] does not contain a statistical comparison between the different weight groups, it seems that the MIHS increases with weight category. When the data are expressed relative to muscle area in the dominant arm, we observed differences between male and female elite and non-elite judokas. The differences in relative MIHS between elite and non-elite judokas have not been studied previously. Indeed, only two previous studies have provided relative MIHS values for judokas when comparing a sample in terms of age and sex. Thus, although Little [7] found differences between U-17 and U-20 and senior judokas in terms of MIHS, when an index of the isometric strength (including handgrip, back and arm) was expressed with respect to body weight, significant differences were only found between U-17 and senior judokas. Franchini et al. [14] proposed that the difference in MIHS is lower between elite male and female judokas than between those at a lower competitive level, probably due to the fact that high-intensity training reduces the differences in relative strength. In contrast, some authors [1,28] have suggested that the anthropometric measurements of the forearm are a better predictor of MIHS than body weight and height as they show a stronger correlation with MIHS. These findings are in agreement with our study, which shows a high degree of correlation between forearm circumference and MIHS. Furthermore, strong correlations are found between the muscle area in the dominant arm and the forearm circumference and MIHS. In light of the above findings, one of the key conclusions of our study is that presenting the values of MIHS relative to anthropometric measurements of the upper limb, such as muscle area in the arm, could allow us to more accurately distinguish between elite and non-elite judokas.

An additional aim of this study was to analyse the E-MIHS and to determine the possible differences between young male and female judokas of different competitive levels. An increasing loss of relative and mean MIHS was observed with each repeat in the endurance test for both sexes and levels. These findings are in accordance with others, who concluded that the handgrip strength that can be maintained is lower than that which can be achieved initially [29], and those of Nicolay and Walker [1], who noted that the ability to exert MIHS decreases as the contraction time increases. The loss of MIHS with respect to muscle area in the dominant arm was 24.5 ± 9.1% in male elite, 18.8 ± 9.1% in male non-elite, 18.4 ± 9.3% in female elite and 16.8 ± 7.0% in female non-elite judokas. As can be seen, a greater loss occurs in those subjects that exert a higher initial relative MIHS (male and female elite judokas), which is in accordance with the findings of Yamaji et al., who suggested that the percentage loss of isometric handgrip strength could be related to the initial value [30]. This is probably due to the fact that the recovery time established between the successive contractions (10 s) is insufficient for elite judokas to recover their initial, much higher levels. In this line, following an almost identical protocol to ours (10 repetitions of 10-s of a maximal isometric contraction separated by 10 s of passive rest), Bonitch-Góngora et al. observed a 39% loss of MIHS in the dominant hand ($p < 0.01$) in senior international Austrian judokas [20]. The greater percentage loss exhibited by senior judokas, who exert higher levels of initial MIHS (539 ± 89 N) than the U-17 judokas in our study, supports this hypothesis. However, although the loss of isometric strength is higher in the elite groups than in their non-elite counterparts, the former always exert higher levels of relative MIHS in each of the repetitions performed. These findings show, for the first time, that higher competitive level judokas could be able to exert greater levels of MIHS throughout a bout than those at a lower competitive level, thereby dominating the *kumi-kata* and increasing their likelihood of success.

Only a previous study has investigated the effect of a succession of judo bouts on MIHS. Thus, the authors simulated a competition consisting of four bouts separated by 15 min of passive rest and found a loss of MIHS in the dominant hand of 12.7% after the first bout, and 15.0% after all four, in U-23 and senior national level judokas [10]. The fact that these losses are lower than those found in our study for the endurance test suggests that the quality of the grip applied during a bout is sub-maximal [10], whereas maximal values were applied during each repetition in the present study. This is in accordance with the findings of Yamaji et al., [30] who found that the loss of handgrip strength increases when the grip is performed at 100% of the MIHS.

In studies of this phenomenon interesting methodological approach present Franchini et al. [36]. They used Judogi Strength Test in isometric and dynamic version. In conclusion, this study claimed that isometric version of this test was not able to properly discriminate judo athletes from different competitive levels, the Dynamic Judogi Strength Test can be successfully used to do it. However Juan Cortell-Tormo et al [37] in conclusion of the recent studies declare that the handgrip strength is mostly dependent on the basic (body height) and hand-specific anthropometric parameters in judokas. In their opinion these results are very interesting because athletes with specific hand dimensions may have biomechanical advantages regarding handgrip strength and this information can be valuable for coaching and talent identification in judo.

Conclusions

In summary, this study revealed higher MIHS and E-MIHS levels in the young elite judokas than the non-elite group in both sexes. These findings suggest that the elite judokas are able to develop higher levels of handgrip strength and also have better strategies to resist successive contractions, which is more representative of the reality of judo competition.

The data presented on this study can be used by sport scientists and coaches to evaluate the MIHS and E-MIHS characteristics of male and female young judokas, and therefore, to design novel training routines to improve the performance of their pupils. Taking into account that maintaining a good grip during a judo bout is key to success [10], and that this may depend on both MIHS and E-MIHS, the novel findings of this study suggest that elite judokas may be better able to undertake the vital technical-tactical task of *kumi-kata*, thereby obtaining a clear advantage over their adversaries. In light of the importance of achieving *kumi-kata* in judo, training regimens that increase the MIHS and E-MIHS of forearm flexor muscles should be designed.

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