

## CHAPTER 3

# Developing maximal strength for combat sports athletes

Braulio Henrique MAGNANI BRANCO<sup>1,2</sup>  & Emerson FRANCHINI<sup>\*3</sup> 

<sup>1</sup> *Research Group in Physical Education, Physiotherapy, Sports, Nutrition and Performance of the Cesumar University, Maringa, Brazil, Health Promotion Program, Cesumar University, Maringa, Parana (Brazil)*

<sup>2</sup> *Cesumar Institute of Science, Technology, and Innovation (Brazil)*

<sup>3</sup> *Martial Arts and Combat Sports Research Group, School of Physical Education and Sport, University of São Paulo, São Paulo (Brazil)*

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### Abstract

This chapter deals with historical aspects of strength training, contextualizing the relevance of strength training for combat sports to maximize the performance of grapplers, strikers, and mixed martial artists. Scientific articles were listed that presented data related to maximum strength in the leading research databases. Scientific evidence presented in official and simulated matches, and official competitions are presented. Likewise, longitudinal studies on the development of maximal strength in combat sports athletes, maximal strength tests for combat sports athletes (dynamic, isometric, and isokinetic tests), and reference for maximal strength (dynamic and isometric exercises) values in several exercises, as well as normative tables are presented. Another point approached was training prescription for muscle hypertrophy and maximal strength development (dynamic and isometric) for combat sports athletes.

**Keywords:** Martial arts; combat sports; training; performance; specific tests; muscle strength; strength training; weightlifting.

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### 1. Introduction

From ancient Greece, records have described strength training for athletes' physical preparation [1]. The story suggests that the legendary Milo of Croton, a one-time boys' champion and five-time adult champion of the ancient Olympic Games, carried a calf on his back during his physical preparation. As the animal grew, he continued to carry it by the stadium's distance in Olympia (approximately 212 m) [1,2]. Considering this information and eliminating the exaggerations of this story, one can presume that this is one of the earliest descriptions of the principle of progressive overload or training with increasing loads. Thus, one of the most pursued goals is to reach peak physical fitness in the main competitions. In this context, strength training has been used to maximize athletes' performance in various sports modalities [3]. Table 1 presents data from combat sports athletes who assigned part of their physical preparation to strength training.

Maximal strength is described in the literature as the highest tension that an athlete can perform during a maximal contraction and may be expressed in absolute or relative values [10]. The absolute maximal strength does not consider the body mass of the individual. In contrast, the relative strength is significant in combat sports because athletes are divided into categories according to their body masses [11].

During a match, the power requirement, e.g., entry of a throwing technique by a judo athlete [12] or a kick by a taekwondo/karate athlete [13], and muscular endurance (grip dispute in jiu-jitsu [14] and judo [15] and stepping [16] are common. Nevertheless, the manifestations of maximal strength appear to a lesser extent in the matches, e.g., jiu-jitsu or judo athlete being immobilized pushes the opponent to escape from a position or during the match when an athlete is lying down on

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\* E-mail: [emersonfranchini@hotmail.com](mailto:emersonfranchini@hotmail.com)

the groundwork combat, and the opponent needs to project him/her backward on the ground to receive the score [17].

**Table 1:** Report of athletes who used strength training during their respective physical preparations for competitions.

Athlete	Modality	Titles	Reference
Masahiko Kimura	Judo, jiu-jitsu, and MMA	Various titles	Kimura [4]
Marco Antônio Barbosa	Judo and Brazilian jiu-jitsu	4x Brazilian judo champion, world jiu-jitsu master champion by CBJJ (weight and absolute)	Barbosa [5]
Tiago Camilo	Judo	World judo champion, bronze at the Beijing Olympics Games, and silver in Sydney Olympic games	BJC [6]
Leandro Guilherme	Judo	2 <sup>nd</sup> place in the world judo championship and bronze in the Athens and Beijing Olympic Games	BJC [6]
Tarsis Humphreys	Brazilian jiu-jitsu	Champion of the 1 <sup>st</sup> world professional Brazilian jiu-jitsu	Dantas and Coutinho [7]
André Galvão	Brazilian jiu-jitsu, grappling, and MMA	World jiu-jitsu champion, champion in grappling tournaments, and athlete of high-level of MMA	Dantas and Coutinho [7]
Diogo Silva	Taekwondo	Pan-American champion in 2007 and the University games in 2009, 4 <sup>th</sup> place in the 2004 and 2012 Olympic Games	Silva [8]
Douglas Brose	Karate	2x world champion	Loturco et al. [9]

Nevertheless, maximal strength training is a determinant for the other phases of sports training periodization, such as power development and muscular endurance [18]. Strength training produces neural and structural changes in the neuromuscular system [3], and improve maximal strength may occur through increased neural activation. In turn, the muscular hypertrophy will result in an increased cross-sectional area of a muscle [19,20]. In this sense, Tricoli [21] shows a direct and linear relationship between muscle mass size and strength performance, e.g., a larger cross-sectional area results in a greater ability to produce strength. Therefore, we consider that the magnitude of strength is a result of three factors [10], including a) intermuscular coordination, b) intramuscular coordination, and c) the frequency of motor unit firing.

In combat sports, athletes' strength training and hypertrophy should emphasize the muscles related to the movements and techniques performed during the match [11,22]. In this view, Steward [23] reported that American Olympic wrestlers had developed muscles that are unnecessary for match demands, which may have a negative impact on performance because an increase in an athlete's body mass may result in a change in the weight category. A study conducted by Moss et al. [24] showed that 9-week training with loads of 90% of one repetition-maximum (1RM) increased participants' strength by up to 15% without increasing the circumference of the exercised muscle. This training systematization is a considerable tool for the physical trainer who works in combat sports, as an athlete who is at the upper limit of his category can maximize the strength gain without increasing muscle mass [22]. A feature of the grappling combat sports is the maximal handgrip strength. There is a substantial demand for maximal isometric handgrip strength in these modalities, and the maintenance of the grip is an essential factor for success in the immobilizations and submissions [11,25].

Therefore, Kraemer et al. [26] indicate that the maximal isometric handgrip strength tends to decrease during an Olympic wrestling competition. The authors suggest that this training method plays a significant role in the routine of elite wrestlers. Also, the maximal isometric strength is observed in different combat stages, for example, in the initial phase of the immobilizations (judo or



jiu-jitsu) and the defense of groundwork combat. The exercises that work the maximal isometric strength do not involve actions that alter the muscle's length. Therefore, there is no joint movement, which is considered static [27]. The maximal isometric strength may be worked with a load greater than the maximal concentric strength of an individual and may be combined with dynamic actions during the training. It is worth noting, as a limitation, that the adaptations generated by isometric training are angle-dependent [27].

During training, questions are often raised regarding which method may be most effective in determining victory or defeat in high-level athletes. In this sense, it is assumed that the physical aspects are decisive for success in addition to the technical-tactical question. However, there is no consensus about which training method is the most effective to maximize high-level athletes' performance in combat sports. Also, information regarding athletes' training referential in their respective modalities is not often described in the scientific literature [28]. Considering these aspects, Franchini and Takito [29] investigated the exercise routine of Olympic level judo athletes, and the results suggested that most athletes performed strength training in their respective physical preparations, which reinforces that strength training has been prescribed by physical trainers and performed by high-level athletes. Besides, the retrospective study conducted by Ball et al. [30], with Australian Olympic taekwondo athletes, stresses that strength training is crucial for the development of power (execution of kicks and punches in striking modalities and throwing techniques in grappling combat sports).

In the opposite sense, in some team sports, such as soccer, physical trainers, including Paco Seirulo of Barcelona and Marcelo Martins (ex - Bayer of Munich), have reported that the preparation and physical evaluation of the players have been conducted qualitatively both in real game situations. The professionals emphasized that the training emphasis is given to movement because it reinforces the principle of specificity in this context [31,32]. Researchers have questioned the transfer of strength gains in generic exercises to specific gestures of sports modalities [33]. Nonetheless, there are different physical capacities in combat sports, such as maximal strength, strength-endurance, muscular power, and complementary work with weights at the gym that may aid athletes' physical preparation. From this perspective, research has indicated that the development of these capacities can distinguish elite and non-elite athletes [12,15]. Although there is a belief that strong athletes are slow, no scientific evidence is associated with this empirical theory disseminated in various media [1]. The theory quoted was spread by the lay public who believed that the muscular horses had great strength to pull things; however, they were considered slow and without agility.

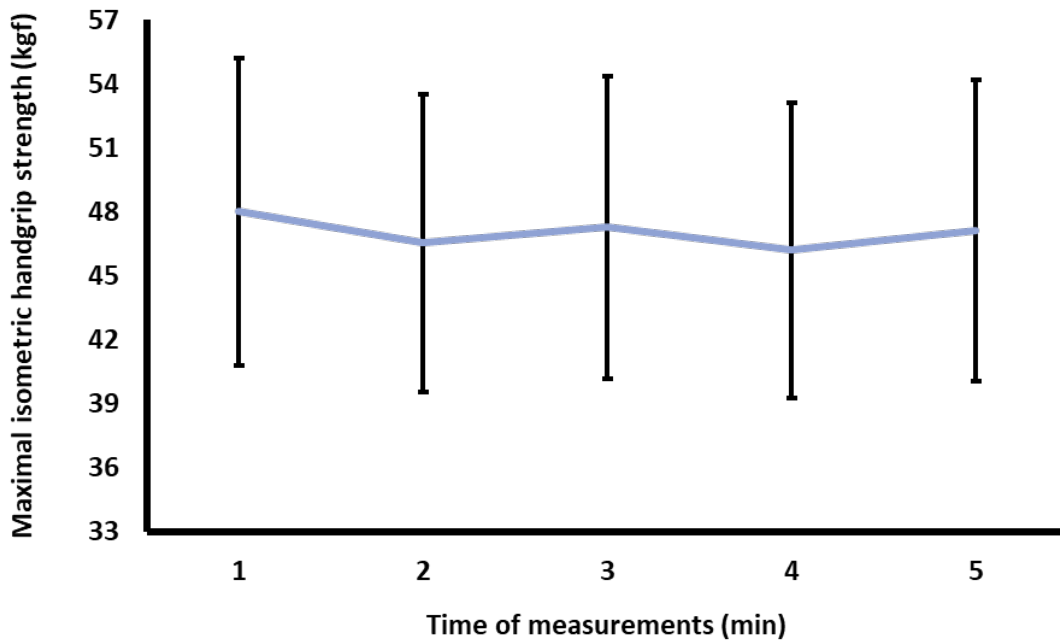
In contrast, Thoroughbred horses were considered famous for having great agility, speed, and muscle power. This thought had a substantial influence at the time (18<sup>th</sup> century), with diffusion until the present day [1]. However, it is evident that studies involving combat sports are incipient, and there is little information on this topic [34].

In this chapter, the responses of the maximal isometric and dynamic strength are assessed during official competitions, match simulations, and competitions, in response to specific training protocols, tests used to evaluate the maximal strength of combat sports athletes, means and methods for the development of maximal strength and the prescription of maximal strength training for combat sports athletes. In this aspect, the articles are indexed in international research bases, both for the grappling (judo, jiu-jitsu, and wrestling) and the striking modalities (boxing, Muay-Thai, karate, and taekwondo), were prioritized, as well as for mixed martial arts (MMA).

## **2. Maximal strength responses during grappling combat sports**

### *2.1. Measures conducted during match simulations*

To analyze the variation of the maximal isometric handgrip strength during a jiu-jitsu match simulation, Franchini et al. [35] submitted 22 regional level athletes to a 5-min match with breaks 30 s every 1 min. The maximal isometric handgrip strength was measured at the following time points: 1) at rest:  $54.2 \pm 6.7$  kgf for the right hand and  $51.4 \pm 6.1$  kgf for the left hand and 2) during the pauses: 1, 2, 3, 4, and 5 min. Figure 1 presents the maximal isometric handgrip strength values for the different measurement moments (1, 2, 3, 4, and 5 min).



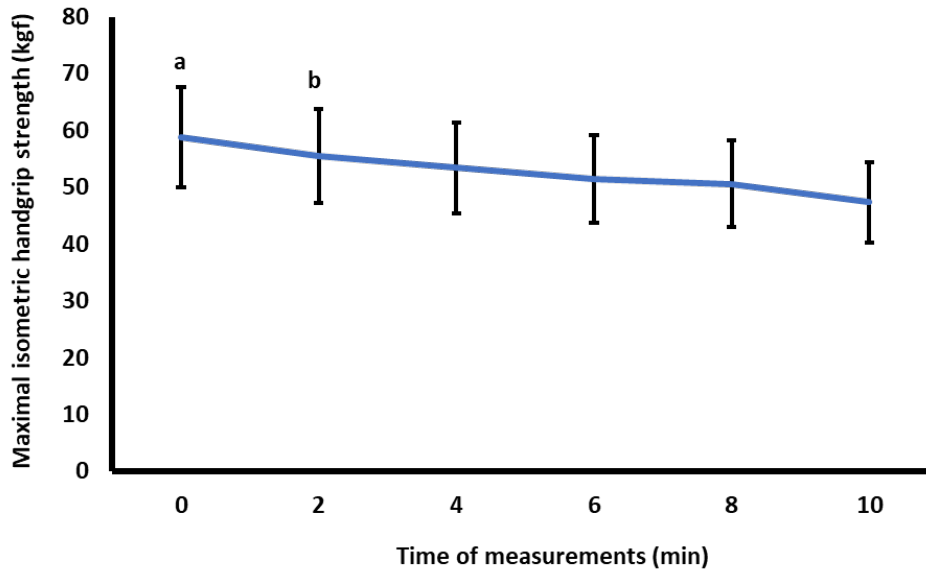
Note: the data represent the mean and standard deviation.

**Figure 1:** Maximal isometric handgrip strength measured at minutes 1, 2, 3, 4, and 5 (adapted from Franchini et al. [35]).

Regarding figure 1, no differences were found in the measurements made during the match simulations' pauses at different moments of measurement. However, the results showed a decrease of more than 12% of the maximal isometric handgrip strength from the first min of the match against the resting value. Despite this finding, the athletes maintained these values throughout the match, indicating physiological adaptations and/or technical-tactical control. It is valuable to highlight that the authors suggested that the forearm's muscular hypertrophy could maximize the maximal isometric handgrip strength, considering that the forearm circumference positively correlates with the mean maximal isometric strength the match ( $r = 0.72$ ). Additionally, this study provides the option of predicting the 15 consecutive manual holds (handgrip strength) in a resting situation to monitor muscular endurance during the matches. Also, the mean maximal isometric handgrip strength may be predicted by the mean value of the 15 consecutive contractions since there was a very high correlation ( $r = 0.93$ ) between these variables and the absence of a difference between the values during the match and the 15 contractions.

Similarly, the authors emphasized that the evaluated jiu-jitsu athletes did not have very high maximal isometric handgrip strength values. However, they were able to maintain this capacity during the whole match. Thus, we note that the pauses of 30 s substantially limit this study's results to perform the measurements every min; that is, the athletes would perform for 1 min, and they would rest for 30 s. Therefore, these pauses may be considered a bias in the recovery of handgrip strength during the match simulation. Nevertheless, the findings of Franchini et al. [35] provide significant answers regarding the isometric handgrip strength because maintaining the handgrip performance is essential for grappling combat sports; the test described (the use of the 15 consecutive contractions) can be a tool easily applied by professionals involved in the physical preparation of these athletes.

Furthermore, the research delineated by Franchini et al. [36] sought to understand the variation of the maximal isometric handgrip strength during jiu-jitsu matches, in which measurements were conducted in the resting condition and every two min with a 30 s pause to perform the measurements. Thus, eight black belt athletes were submitted to a 10 min match simulation (the measurements were performed in the resting condition with the dominant hand at 2, 4, 6, 8, and 10 min). Additionally, the athletes were divided according to their body mass and were instructed to perform the effort identical to that during competition. Figure 2 presents the maximal isometric handgrip strength values for the different measurement moments.

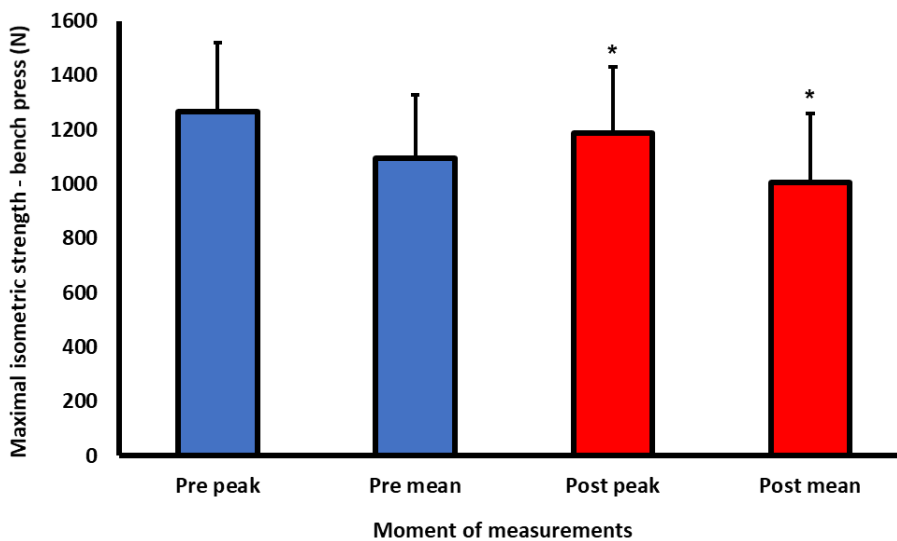


Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) from the values measured in the 4<sup>th</sup>, 6<sup>th</sup>, 8<sup>th</sup>, 10<sup>th</sup> minutes; b = different ( $p < 0.05$ ) from the value measured at the 10<sup>th</sup> minute.

**Figure 2:** Maximal isometric handgrip strength at rest and minutes 2, 4, 6, 8, and 10 (adapted from Franchini et al. [36]).

The results indicated that the maximal isometric handgrip strength presented decreases concerning the moment of rest with sharp declines between the fourth and tenth min. The authors also indicated that the maximal isometric handgrip strength reductions were 20%. The athletes who had less variation reported higher ratings of perceived exertion (RPE) during the match simulation. However, as one potential limitation of this study, one can consider the pauses of 30 s every 2 min since this interval could favor the partial recovery of the handgrip strength in the athletes, which was indicated by the research of Franchini et al. [35].

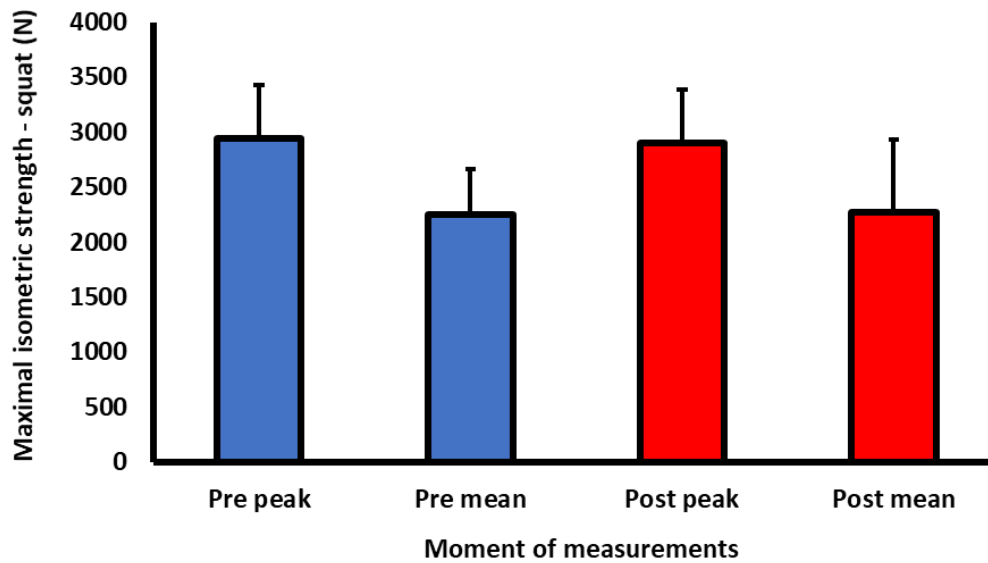
Moreover, the research delineated by Fernandez et al. [37] analyzed the variations of the maximal isometric handgrip strength and maximal isometric strength in the exercises: bench press, squat, and row, before and after a 5 min of match simulation. For this, 8 high-level Spanish athletes were submitted to 10 s of maximal isometric tests on a handgrip dynamometer for both hands and exercises: bench press, squat, and row. For the analysis, a load cell coupled to a bar was used. Figure 3 shows the values of the maximal isometric strength for the bench press before and after the match simulation.



Note: the data represent the mean and standard deviation.

**Figure 3:** Maximal isometric strength in the bench press: before and after judo match (adapted from Fernandez et al. [37]).

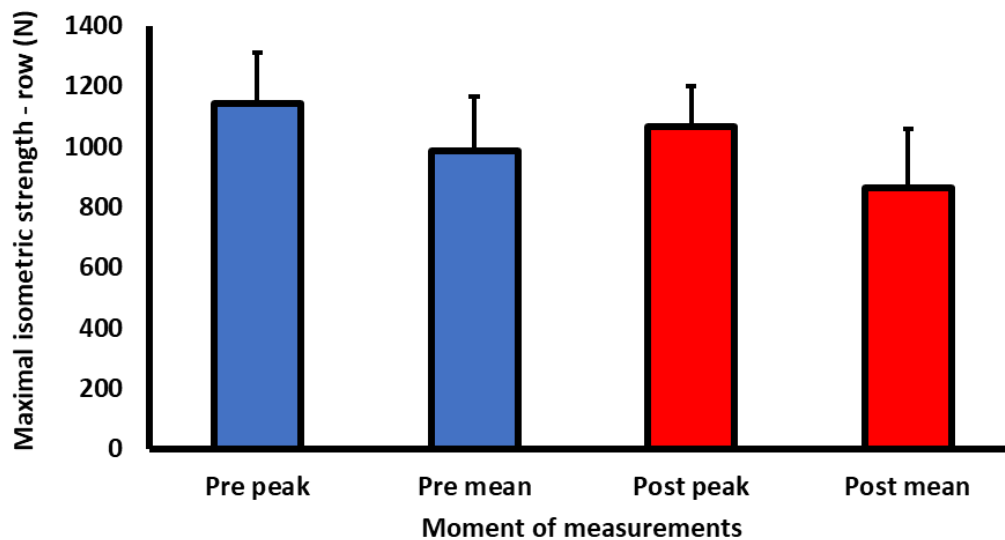
The findings indicated decreases in the maximal peak and mean isometric strength for the bench press with considerably lower values after the match simulation. Figure 4 shows the maximal isometric strength values for the squat exercise before and after the match simulation.



Note: the data represent the mean and standard deviation.

**Figure 4:** Maximal isometric strength in the squat: before and after judo match (adapted from Fernandez et al. [37]).

For the maximal squat isometric peak and mean strength, no differences were identified for the two measurement moments (pre- and post-match). Figure 5 presents the maximal isometric strength values for the row exercise before and after the match simulation.

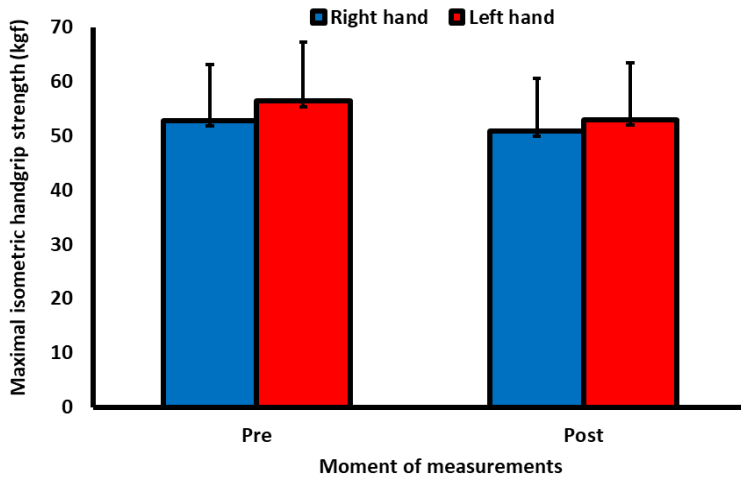


Note: the data represent the mean and standard deviation.

**Figure 5:** Maximal isometric strength in the row: before and after judo match (adapted from Fernandez et al. [37]).

Similarly, no differences in the maximal isometric strength in the row (peak and mean) were identified in the measurements performed before and after the match simulation. Figure 6 presents the maximal isometric handgrip strength values for both hands before and after the match simulation. In the same line, no changes in the maximal isometric handgrip strength were identified for both hands in the measurements made before and after the match simulation. From the results, it may be concluded that the decreases in the peak and mean in the maximal isometric strength in the bench press after the match simulation may be associated with the push actions, which are

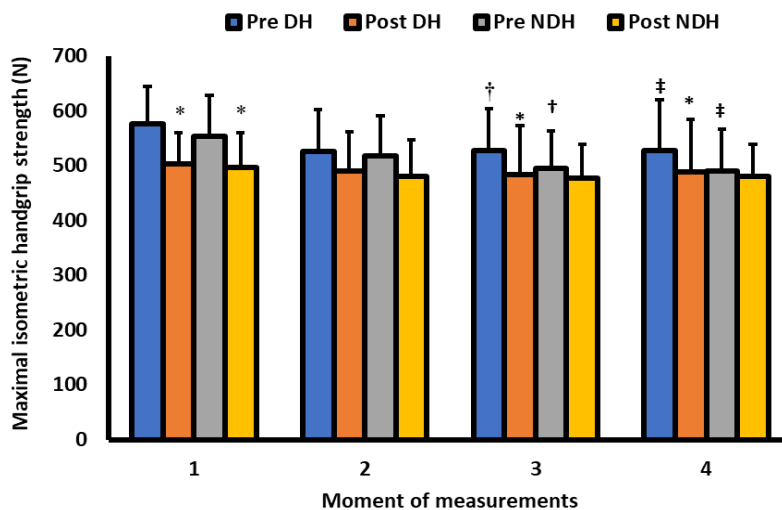
intended to maintain a safe distance from the opponent. However, the match simulations were not filmed; thus, it is only possible to infer that the significant decreases in the bench press's maximal isometric strength occurred due to these actions. Therefore, research that examines these aspects is necessary. Small improvements were identified for the lower limbs in the countermovement jump after the match simulation, which will be addressed in the muscle power chapter. Nevertheless, this study has submitted the athletes to only a one-match simulation, a situation that does not reflect the demand for an official competition, in which athlete medalists perform between 5 and 7 matches [38,39]. Thus, we indicate that the upper-body muscles' solicitation is very high in judo matches.



**Figure 6:** Maximal isometric handgrip strength before and after judo match (adapted from Fernandez et al. [37]).

Note: the data represent the mean and standard deviation.

The research outlined by Bonitch-Góngora et al. [40] investigated the variation of the maximal isometric handgrip strength during simulated judo matches. The objective of that study was to analyze the variations of maximal isometric handgrip strength during simulated judo matches, in which 12 European medalists (10 individuals were medalists in the French and Spanish national championships and two individuals obtained medals in regional competitions in Spain) performed four-match simulations with a duration of 5 min and an interval of 15 min between them. The matches followed the official rules of the competition. However, even with *ippon* (perfect technique), 2 *wazari* (almost perfect technique), joint locks, submission, immobilization techniques, or penalizations, the match was not interrupted because the study needed that the athletes would perform for the same duration. To measure the maximal isometric handgrip strength, the athletes stood with their elbows extended and were instructed to press the dynamometer with the greatest possible strength between 3 and 6 s. The results of the maximal isometric handgrip strength are shown in figure 7.

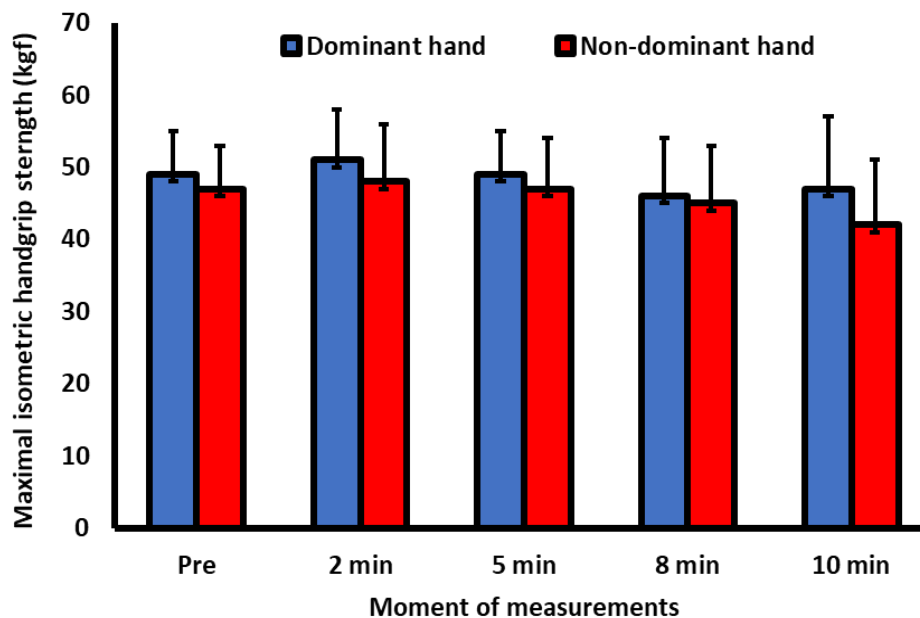


**Figure 7:** Maximal isometric handgrip strength before and after four judo matches (adapted from Bonitch-Góngora et al. [40]).

Note: the data represent the mean and standard deviation; \* = difference ( $p < 0.05$ ) between the measurements performed before and after the same match simulations; † = difference ( $p < 0.05$ ) between the measurements performed before the first match when compared to the third match for both hands; ‡ = difference ( $p < 0.05$ ) between the measurements performed before the first match when compared to the fourth match for both hands; pre = pre-match values; post = post-match values; DH = dominant hand; NDH = non-dominant hand.

As a result of the match simulations, there were decreases in the maximal isometric handgrip strength in the measurements performed before the third and fourth bouts compared to the first evaluation for both hands. However, no differences were found between the dominant and non-dominant hands after the matches. It should also be noted that the findings showed decreases between the measures conducted before and after the first match simulation for both hands. However, differences were identified only for the dominant hand in the measurements obtained before and after the third and fourth match simulations. Moreover, the maximal isometric handgrip strength decreases gradually with the matches' course.

In turn, the study delineated by Andreato et al. [41] aimed to identify the behavior of the handgrip strength of the dominant and non-dominant hands of brown and black-belts jiu-jitsu athletes ( $n = 10$ ) in match simulations (2, 5, 8, and 10 min). The matches' order with different durations was randomized, and there was approximately 60 min between the other duration matches. Two matches were performed on one day, and two were performed on the following day. The athletes were not informed of the match's total duration, which hypothetically would have a time of 10 min. Even if the end of the match via joint locks or submission occurred, it was not interrupted because the study's purpose was to submit the athletes to the same effort time. Figure 8 shows the values of the athletes' maximal isometric handgrip strength before and after the fragmented matches of 2, 5, 8, and 10 min are presented.



Note: the data represent the mean and standard deviation.

**Figure 8:** Maximal isometric handgrip strength before and after the jiu-jitsu fragmented match simulations (adapted from Andreato et al. [41]).

The maximal isometric handgrip strength did not vary because of the fragmented matches (2, 5, 8, and 10 min). These results differed from previous studies with 5-min (Franchini et al. [35]) and 10 min (Franchini et al. [36]) jiu-jitsu match simulations. However, the isometric kimono chin-up for the handgrip has decreased. It indicates a gradual reduction of muscular endurance (explored in the section of muscular endurance training).

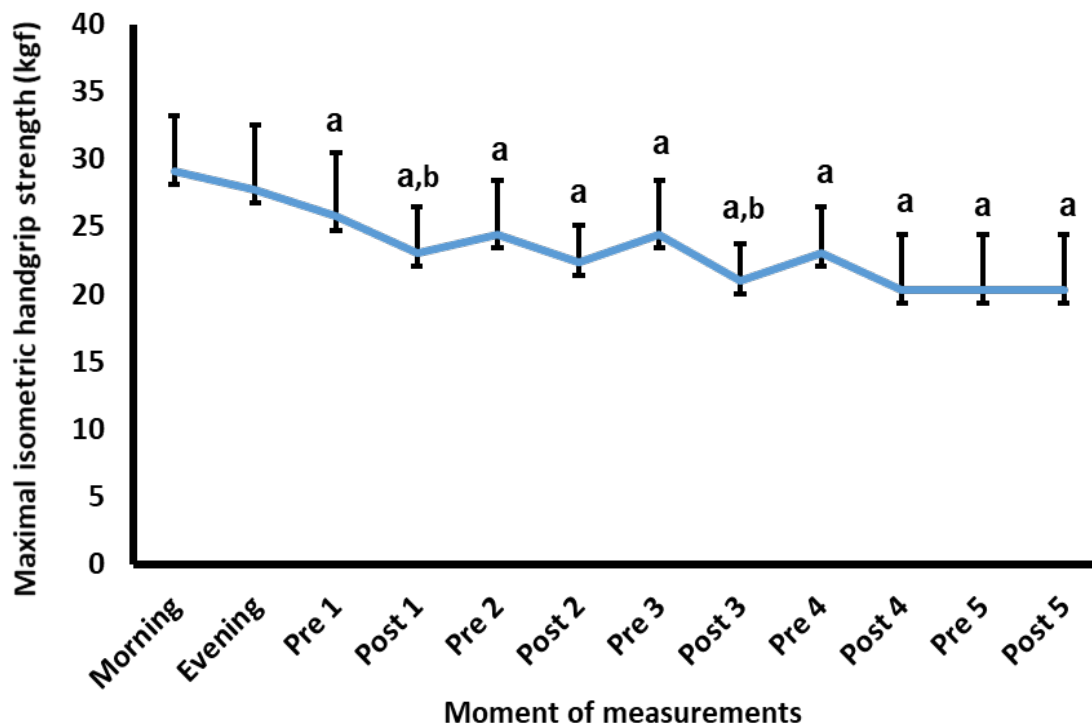
A similar investigation [42], but conducted with judo, compared the effects of match duration (1, 2, 3, 4, and 5 min) on dominant and non-dominant maximal isometric handgrip strength. They indicated no duration effect on dominant and non-dominant handgrip isometric strength. Still, there was a time point effect on non-dominant handgrip isometric strength, with lower values post-match compared to pre-match. This result can be attributed to the higher strength solicitation of the sleeve hand (non-dominant hand) due to wider movements during the grip dispute in the judo match compared to the lapel grip dispute (conducted with the dominant hand). Additionally, in this study, the tests were applied 6 min after the match, which may provide time to recover some of the maximal strength-related performance variables.



Through the research presented on this topic, it becomes evident that handgrip training should be directed towards maintaining the isometric strength in the forearm muscles, both for the flexor and extensor muscles. Based on the understanding of the muscular and physiological dynamics of *kumi-kata* (handgrip), training can be guided to maintain optimal levels of tension during training and competitions since the muscular demand of the forearm is predominant in grappling combat sports.

## 2.2. Measures conducted during competition simulations

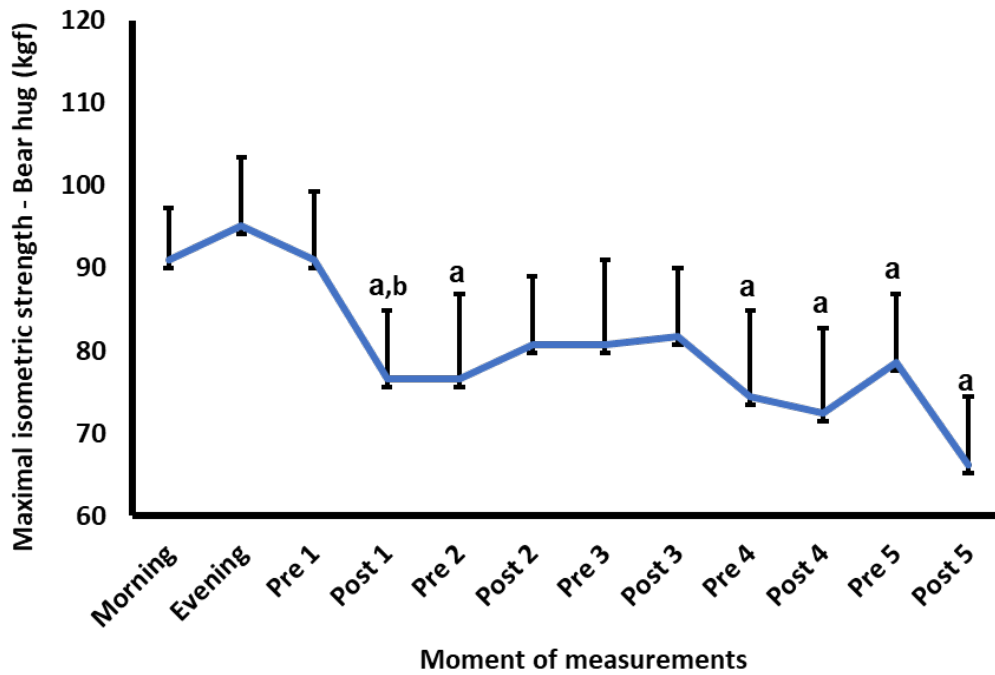
The research conducted by Kraemer et al. [26] aimed to investigate the physiological responses and performance of freestyle Olympic wrestlers ( $n = 12$ ) during a simulated two-day tournament. Participants were instructed to lose 6% of body mass one week before the competition, a common procedure in which athletes are classified according to their body mass. The weigh-in occurred 12 hours before the first match, and the athletes had to maintain their body mass throughout the competition, with a tolerance of up to 2%. The athletes performed wrestling matches with opponents of similar level and body mass. They performed three matches on the first day of competition and two matches on the second day, each match lasting 5 min. In the morning and afternoon rest periods and before and after each of the five matches, tests were performed for the maximal handgrip strength, bear hug, lumbar traction, and measurement of the isokinetic elbow extension and flexion peak torque. Figure 9 shows the values of the maximal isometric handgrip strength of the athletes in the different moments of measurement indicated.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) from the value measured in the morning and afternoon at rest conditions; b = different ( $p < 0.05$ ) from the value measured before the respective match; morning = measured at rest in the morning and afternoon = measured at rest in the afternoon.

**Figure 9:** Maximal isometric handgrip strength at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

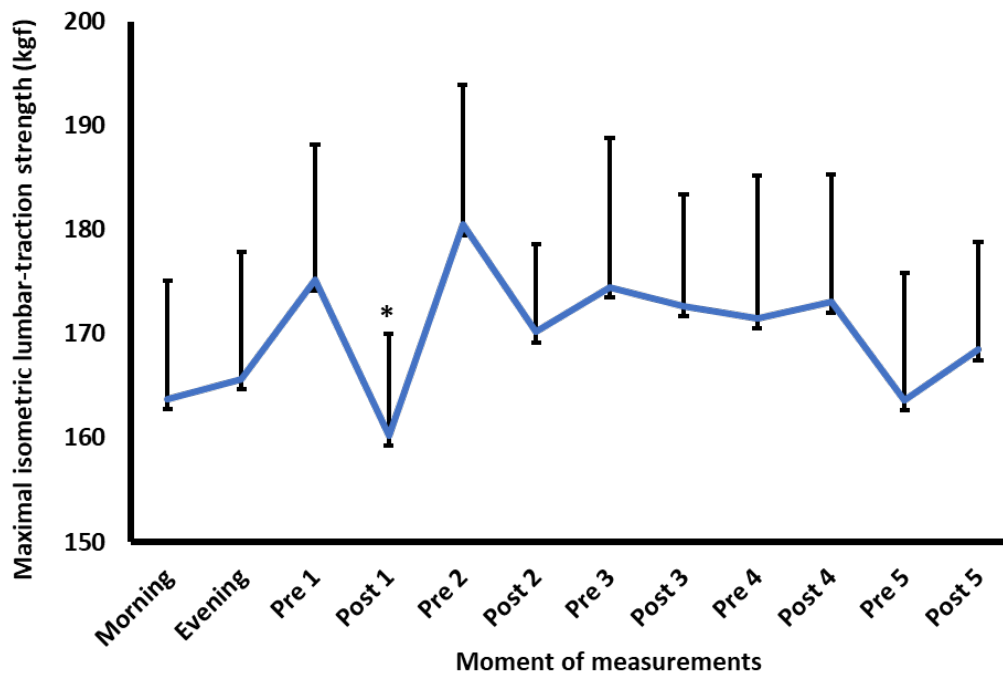
The results showed that the maximal isometric handgrip strength considerably decreased with the pre-match values of the 5 confrontations compared to the rest. Similarly, there were decreases in the maximal isometric handgrip strength when comparing the measurements obtained before and after matches 1 and 3, respectively. These authors indicate that handgrip strength is vital for the Olympic wrestlers and that weight loss may negatively influence athletes' physical performance. Figure 10 shows the values of the maximal isometric strength of the bear hug held by the athletes in the different moments of measurement.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) from the value measured in the morning and afternoon at rest conditions; b = different ( $p < 0.05$ ) from the value measured before the respective match; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 10:** Maximal isometric strength in the bear hug at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

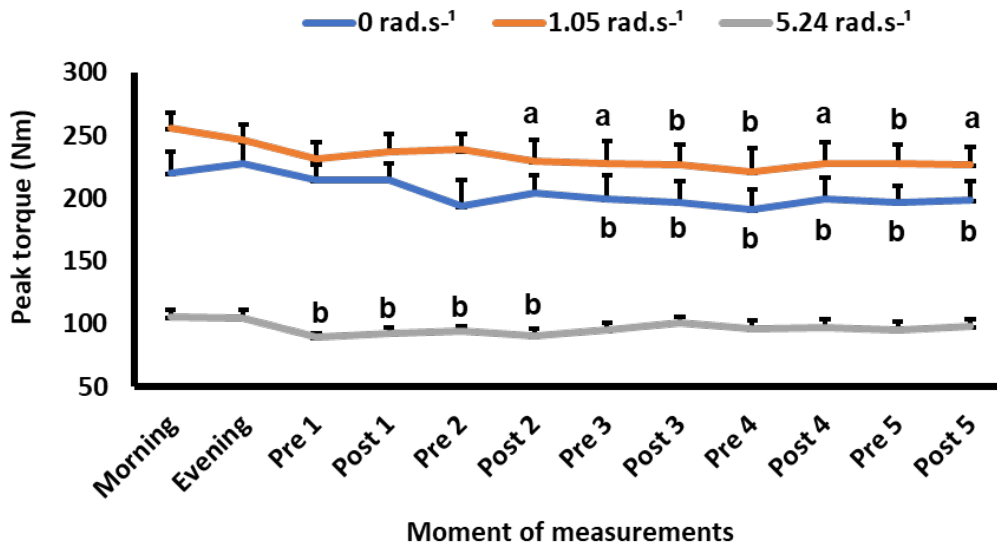
The results show decreases in the measurements performed after match 1 compared to the rest and before the respective match. Besides, there was a decrease in the measurements performed before match 2. Moreover, there were decreases in the measures performed before and after the fourth and fifth matches compared to the rest measurements. Figure 11 shows the athletes' maximal isometric lumbar traction strength at the different measurement moments indicated.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) from the value measured before the first match; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 11:** Maximal isometric strength lumbar traction at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

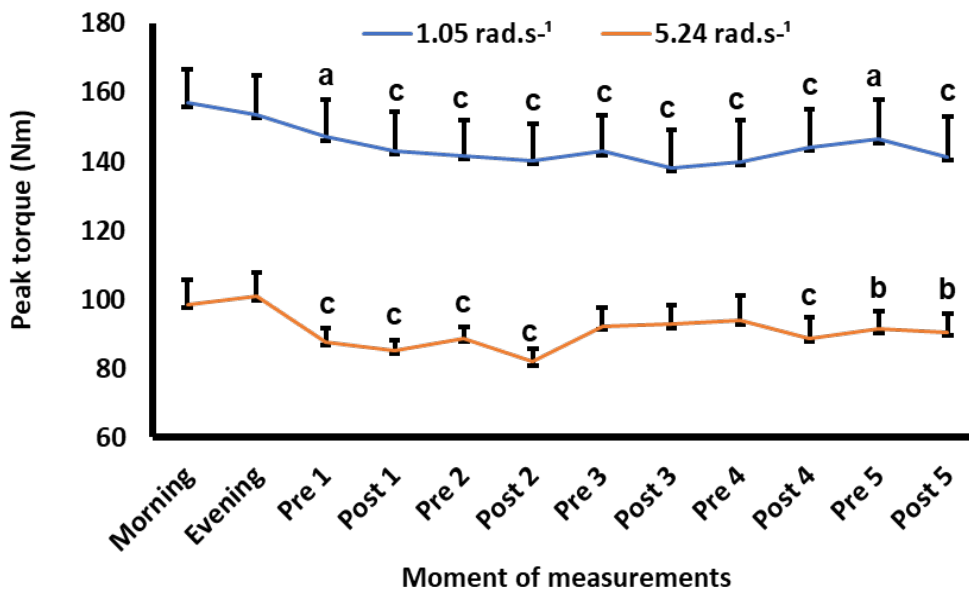
A low value was identified after match 1 concerning that obtained before the same match for the maximal isometric lumbar traction strength. For the other matches, no differences were detected. Figure 12 shows the knee extension peak torque values in the isokinetic test.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) from the value measured at rest condition in the afternoon; b = different ( $p < 0.05$ ) from the value measured at rest in the morning and afternoon periods; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 12:** Peak torque for knee extension in isokinetic apparatus with angular velocities of 0, 1.05, and 5.24 rad.s<sup>-1</sup>, at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

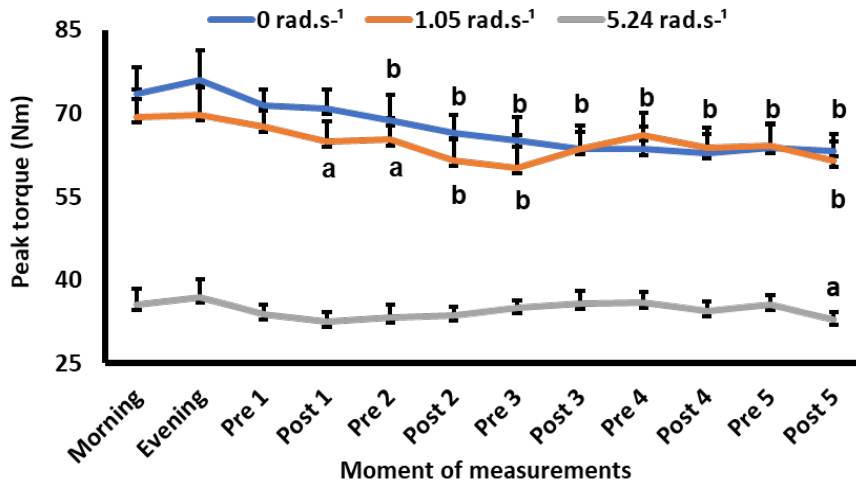
This figure identifies a sharp drop in the maximal peak torque for knee extension at 0 rad.s<sup>-1</sup> before match 3 and the other subsequent moments to the values measured at rest in the afternoon. Regarding the peak torque at 1.05 rad.s<sup>-1</sup>, decreases were identified from the pre-match 3 assessment and all subsequent measurements compared to the rest measured values in the two periods. Moreover, for the peak torque at 5.24 rad.s<sup>-1</sup>, decreases from the first match to the post-match 2 evaluation were identified when the measurements performed at rest in the two periods were compared. Figure 13 shows the peak torque values in the isokinetic test for knee flexion.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) at rest value measured in the morning; b = different, ( $p < 0.05$ ) at rest values measured in the afternoon; c = different ( $p < 0.05$ ) from morning and afternoon rest values; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 13:** Peak torque for knee flexion in isokinetic apparatus with angular velocities of 0, 1.05, and 5.24 rad.s<sup>-1</sup>, at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

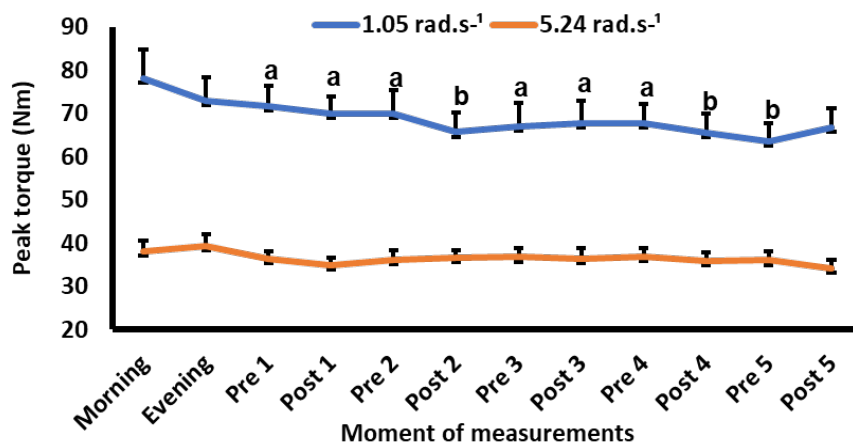
In this figure, there is a decrease in the peak torque for knee flexion at  $1.05 \text{ rad}\cdot\text{s}^{-1}$  before match 1 and before match 5 compared with the measurements performed at rest in the morning. Similarly, there were marked decreases in the peak torque for knee flexion at  $1.05 \text{ rad}\cdot\text{s}^{-1}$  after match 1 until after match 4 and after match 5 concerning the control condition measures in the morning and afternoon. For the peak torque for knee flexion at  $5.24 \text{ rad}\cdot\text{s}^{-1}$ , decreases were identified before match 1 through the post-match 2 assessment and post-match 4 compared to the measures performed in rest in both periods. Also, there were decreases in the measurements performed before match 5 and after match 5 with the values without previous fatigue (i.e., the control condition in the afternoon). In figure 14, we present the peak torque values in the isokinetic test for elbow flexion.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) at rest value measured in the morning; b = different, ( $p < 0.05$ ) at rest values measured in the afternoon; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 14:** Peak torque for elbow flexion in isokinetic apparatus with angular velocities of 0, 1.05, and 5.24  $\text{rad}\cdot\text{s}^{-1}$ , at rest, before and after 5 matches of Olympic wrestling (adapted from Kraemer et al. [26]).

This figure identifies decreases in the peak torque for elbow flexion at  $0 \text{ rad}\cdot\text{s}^{-1}$  after match 2 until the end of the competition's simulation. The values are measured at rest in the two periods. Moreover, decreases in the peak torque for elbow flexion at  $1.05 \text{ rad}\cdot\text{s}^{-1}$  after match 1 and before match 2 are identified compared with the control measures performed in the afternoon. Similarly, there were reductions after match 2, before match 3, and after match 5 compared to the measurements performed at rest in both periods. In turn, for the peak torque for elbow flexion at  $5.24 \text{ rad}\cdot\text{s}^{-1}$ , a decrease was identified only after match 5 about resting values in the afternoon. In figure 15, we present the maximal peak torque values in the isokinetic test for elbow extension.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) at rest value measured in the morning; b = different, ( $p < 0.05$ ) at rest values measured in the afternoon; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 15:** Peak torque for elbow extension in isokinetic apparatus with angular velocities of 0, 1.05, and 5.24  $\text{rad}\cdot\text{s}^{-1}$ , at rest, before and after 5 Olympic wrestling matches (adapted from Kraemer et al. [26]).

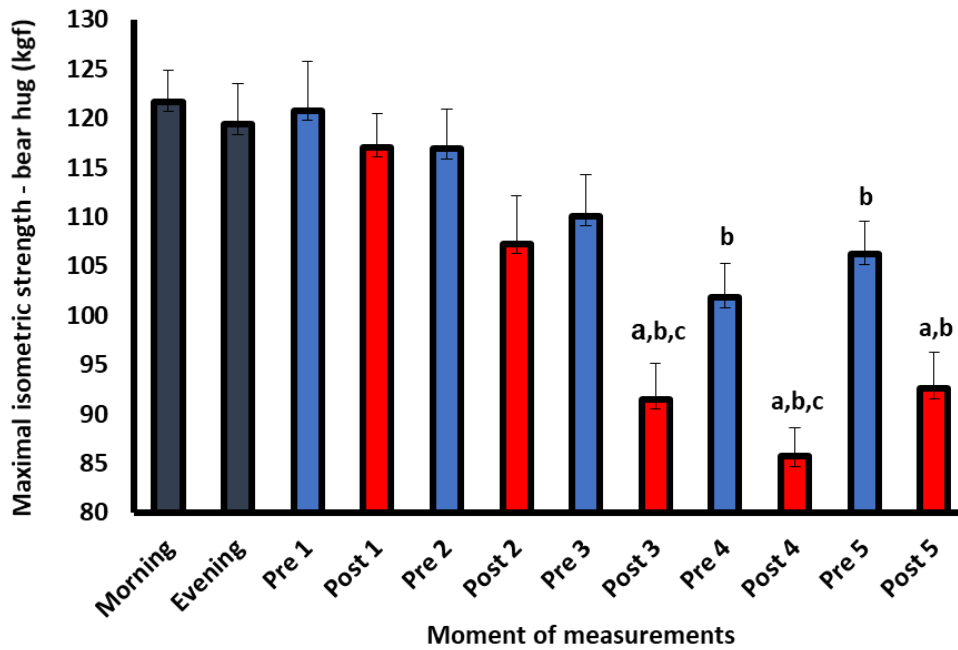
In this figure, it is possible to identify decreases in the peak torque for elbow extension at 1.05 rad.s<sup>-1</sup> in the measurements obtained before and after match 1, before match 2, before and after match 3, and before match 4 compared with the measurements performed in the rest situation in the morning. Similarly, there were differences in the measures performed after match 2 and 4 and before and after match 5 compared to the rest measures in the two periods. However, no differences were identified for the peak torque for elbow extension at 5.24 rad.s<sup>-1</sup>.

It is worth mentioning that the isokinetic test evaluates the peak torque of the joint in an isolated and unilateral manner with an isometric angular velocity for 0 rad.s<sup>-1</sup> and dynamic for 1.05 rad.s<sup>-1</sup> and 5.24 rad.s<sup>-1</sup>. In this sense, the athlete would have to expend extra strength to perform the test at a slower speed. Consequently, the tests' results at 1.05 rad.s<sup>-1</sup> showed marked decreases in the various moments of measurement for flexion and extension of knees and elbows. Isokinetic testing has been used to assess muscle imbalance between right and left sides and between antagonistic muscle groups in specific actions and is usually indicated after injuries or surgeries that keep athletes from training and competition. Although the authors evaluated the peak torque performance using these procedures, the degree of transference of the measurements obtained with certain muscle groups' isolation to more complex actions commonly required in applying techniques during the match is questionable [43-45].

The performance oscillations between the tests performed before and after the match simulations (decrease in performance in the measurements) may be related to the athletes' technical-tactical actions. However, it is impossible to state this hypothesis because a technical-tactical analysis was not performed in this study. It is worth noting that the competition's simulation was carried out in 2 days, with three matches in one day and two matches on the following day. Similarly, elevations in muscle damage markers, such as creatine kinase (CK), were found, especially on the second day of competition, indicating the high damage caused by the three-match simulations on the first day [46,47]. Therefore, the physiological responses showed a limit for the strength generation. Also, there was no complete recovery between the match simulations, which corroborates the decrease in performance in the physical tests during the tests/matches. Besides, it is evident that despite the natural exhaustion of the matches and evaluations performed, the ideal physical preparation and the monitoring of the diet seem to be determinants for maintaining the competitive performance.

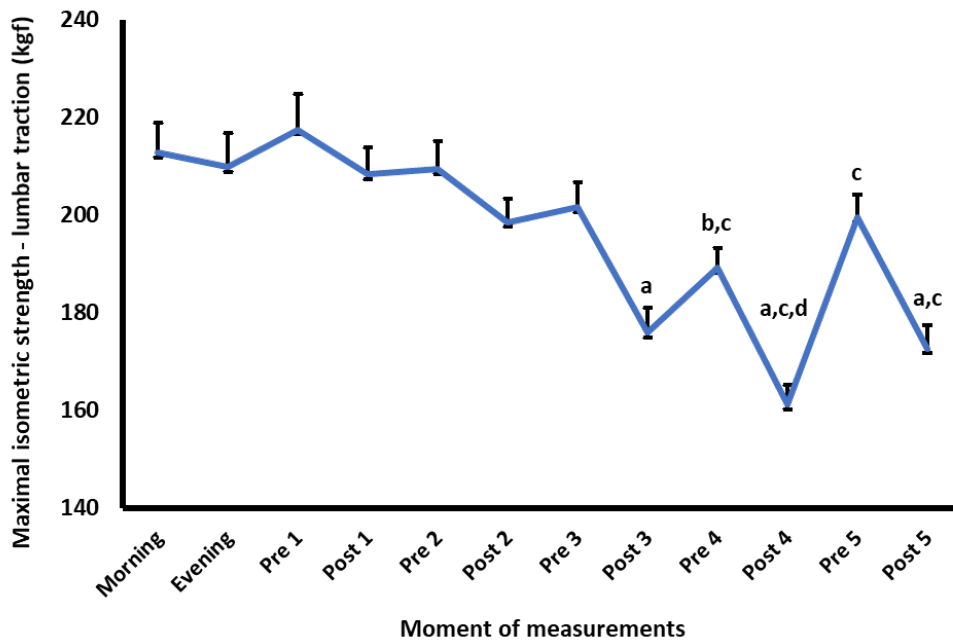
Furthermore, the research conducted by Barbas et al. [48] aimed to evaluate the physiological adaptations and performance of Greco-Roman style matches during a one-day competition simulation. To this end, 12 high-level athletes from the junior category were recruited. They were submitted to 5 three-round matches, 2 min for each round with 30-s intervals between the rounds. Baseline assessments were conducted in the morning and the afternoon one week before the simulated competition. The break from the first match to the second match was 80-90 min, from the second match to the third was 60-70 min, from the third to the fourth was 35-45 min and from the fourth to the fifth was 5-6 hours. The maximal strength tests performed included the bear hug, maximal isometric handgrip strength, and maximal isometric lumbar traction strength. All measurements were performed in the following moments and conditions: 1) rest in the morning and afternoon and 2) before and after the 5 match simulations. In figure 16, we present the variation of the bear hug's maximal isometric strength during the simulated tournament.

For the maximal isometric strength in the bear hug, lower values were found after match 3 compared with the measurements obtained before the respective match, the previous match, and the first match. In the evaluation performed before match 4, decreases were identified compared with the assessments conducted in the first match and the resting situation. About the measurements obtained after match 4, marked reductions were identified compared with the measurements obtained before the respective match and to the first match. Finally, decreases in the measurements performed before match 5 were identified compared to the measurements obtained during the first match and rest. Moreover, the evaluation performed after match 5 showed decreases in the measurements obtained before the respective match and in comparison to the measurements obtained in the first match. Figure 17 shows the athletes' maximal lumbar traction strength at different measurement moments.



Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) between pre and post-match values; b = different ( $p < 0.05$ ) from the value of the first match; c = different ( $p < 0.05$ ) from the previous match; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 16:** Maximal isometric strength in the bear hug at rest in the morning and afternoon and before and after the five simulated matches (adapted from Barbas et al. [48]).

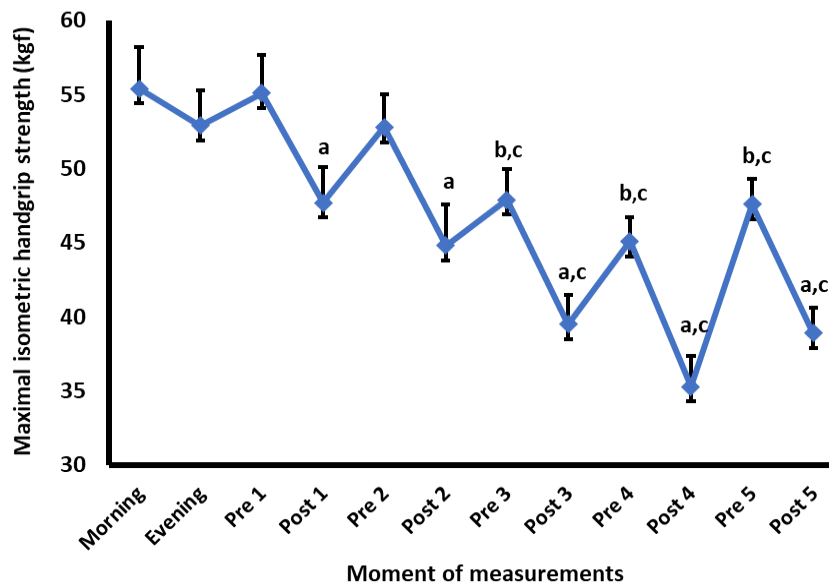


Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) between pre and post-match values; b = different ( $p < 0.05$ ) from the value of the first match; c = different ( $p < 0.05$ ) from the previous match; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 17:** Maximal isometric strength lumbar traction at rest in the morning and afternoon and before and after the five simulated matches (adapted from Barbas et al. [48]).

In this figure, we can identify decreases in the maximal isometric lumbar traction strength after match 3 compared with the measurements obtained before the respective match. Similarly, there were marked decreases in the measurements performed before match 4 compared to the measurements obtained in the first match and the rest situation. Consequently, reductions in the measurements obtained after match 4 were identified in comparison to the values obtained before

the respective match, the previous match, and the first match. Also, differences in the measurements obtained before match 5 were verified when compared to the first match measurements. Finally, decreases were identified after match 5 compared to the measurements obtained in the first match and before the respective match. Figure 18 shows the athletes' maximal isometric handgrip strength at different measurement moments.



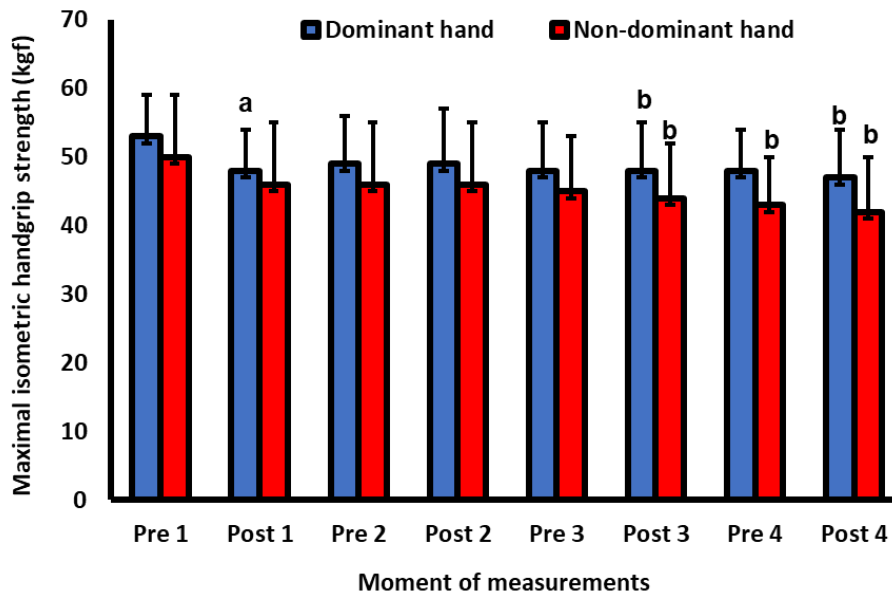
Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) between pre and post-match values; b = different ( $p < 0.05$ ) from the value of the first match; c = different ( $p < 0.05$ ) from the previous match; morning = measured at rest in the morning; afternoon = measured at rest in the afternoon.

**Figure 18:** Maximal isometric handgrip strength at rest in the morning and afternoon and before and after the five simulated matches (adapted from Barbas et al. [48]).

In this figure, it is possible to identify a decrease in the maximal isometric handgrip strength after matches 1 and 2 compared to the measurements performed before the respective matches. Significant reductions were placed in the evaluations conducted before match 3 compared to the first match measurements and the rest of the two periods. Similarly, differences in the measurements obtained after match 3 were identified compared to the measurements obtained before the same match. Therefore, decreases were found compared to the first match measurements. Regarding the evaluations performed before the 4<sup>th</sup> match, there were decreases compared to the assessments conducted during the first match and the rest situation in the two periods. After match 4, reductions were observed to the measurements obtained before the respective match compared to the first match measurements.

Similarly, reductions were found in the measurements obtained before match 5 compared to the first match and the two periods' resting condition. Besides, there were reductions in the measurements performed after match 5 compared to the first match and the evaluations conducted before the respective match. The largest decreases were identified after the fourth match, as the rest between the third and fourth matches (between 35 and 45 min) were insufficient for optimum recovery of the athletes. The authors indicated that the performance presented a progressive impairment during the one-day competition, mainly attributed to fatigue, stress, and muscular micro-damage. Finally, the adoption of recovery strategies can be developed to maintain elite wrestlers' performance in competitions.

Additionally, the research delineated by Andreato et al. [49] had among its objectives to identify the behavior of the handgrip strength of the dominant and non-dominant hands of experienced jiu-jitsu ( $n = 10$ ) athletes (brown and black belt) during a competition simulation, which included 4 simulated matches. The match time was the same as in an official competition for an adult black belt (10 min), with a 20-min interval between the simulations. The matches were not interrupted in finalization cases (submission or joint lock) because the research intended to submit the athletes at the same effort duration. Figure 19 presents the values of the maximal isometric handgrip strength of the study of Andreato et al. [49].



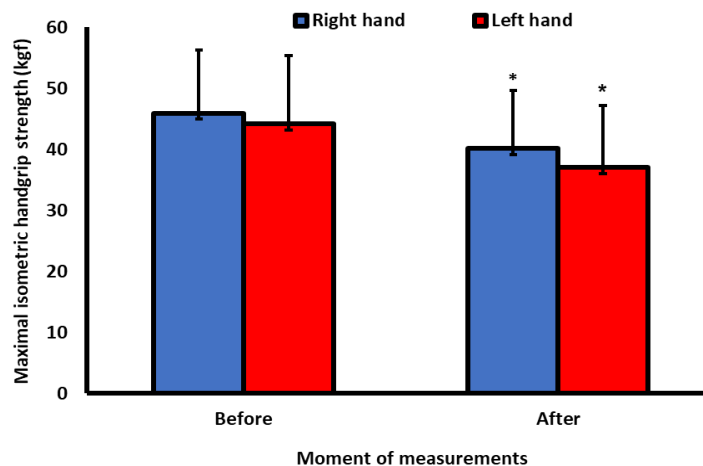
Note: the data represent the mean and standard deviation; a = different ( $p < 0.05$ ) from the measured value before the first match simulation for the dominant hand; b = different ( $p < 0.05$ ) from the measured value before the first match simulation for both sides.

**Figure 19:** Maximal isometric handgrip strength before and after jiu-jitsu match simulations (adapted from Andreato et al. [49]).

This figure's results indicate decreased values in the maximal isometric handgrip strength in the dominant hand after the first, third, and fourth match simulations. For the non-dominant hand, decreases in the maximal isometric handgrip strength were identified after the third and before and after the fourth match simulations. Nonetheless, there is a decrease in the maximal isometric handgrip strength during the matches. Previous studies have indicated that the forearm strength-endurance seems to be more essential to maintain the handgrip in a jiu-jitsu match [14,35] and judo [15] maximal isometric handgrip strength.

### 2.3 Measures conducted during official competitions

The research conducted by Andreato et al. [50] had the objective to evaluate the maximal isometric handgrip strength before and after matches in an official jiu-jitsu competition. Thirty-five white to brown-belt athletes from different competitive levels agreed to participate in the study. Figure 20 values the athletes' maximal isometric handgrip strength before and after the matches are presented.



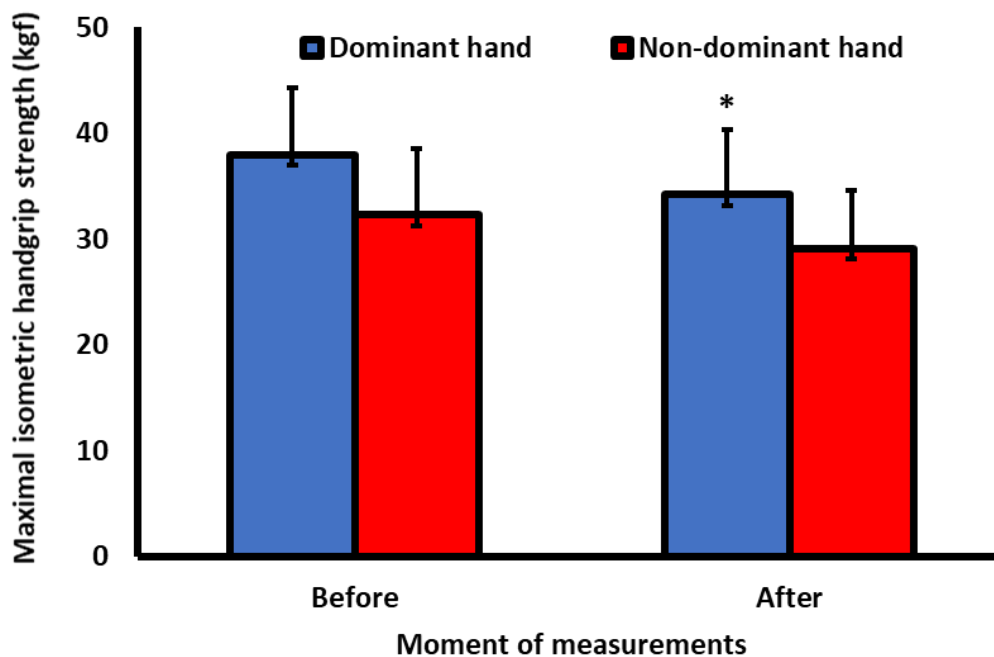
Note: the data represent the mean and standard deviation; \* = different ( $p < 0.001$ ) from the measured values before the match.

**Figure 20:** Maximal isometric handgrip strength before and after jiu-jitsu official match (adapted from Andreato et al. [50]).



There was a decrease in the maximal isometric handgrip strength after official jiu-jitsu matches. The authors emphasized that exercise to handgrip in training sessions, i.e., exercises such as dynamic and isometric chin-ups using the *gi*, may maintain the handgrip during the matches. In the chapter about strength-endurance, specific handgrip and forearm exercises will be performed because of this finding.

Likewise, the study by Andreato et al. [51] had as the objective to assess the maximal isometric handgrip strength of the dominant and non-dominant hands in 12 athletes (three athletes were medalists in national competitions and nine athletes received medals in regional competitions) of jiu-jitsu during an official competition. The athletes were blue-belt with  $2.8 \pm 1.2$  years of systematic training. As an inclusion criterion, athletes with a year and a half of uninterrupted practice of the modality were accepted in the study. For this purpose, measurements of the maximal isometric handgrip strength were performed before and after the official jiu-jitsu matches. In figure 21, the values of the maximal isometric handgrip strength of the athletes before and after the matches are presented.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) from the measured values before the match.

**Figure 21:** Maximal isometric handgrip strength before and after jiu-jitsu official match (adapted from Andreato et al. [51]).

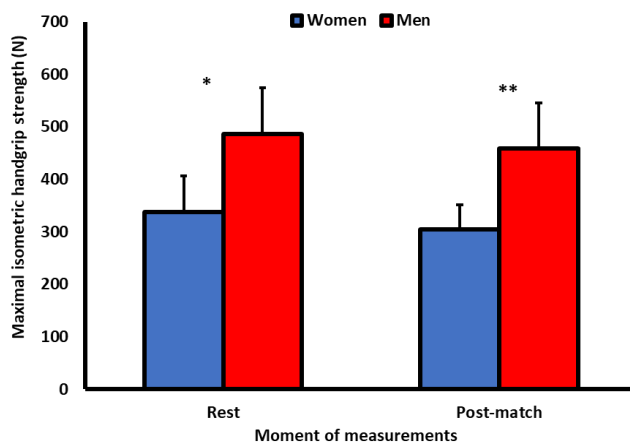
There were significant decreases in the maximal isometric handgrip strength in the dominant hand after the combat than the fight measurements. There was a downward trend for the non-dominant hand. However, no decreases were identified after the official fight. The findings may show that athletes performed more intense actions with the dominant hand; however, this variable was not measured in the study, as mentioned above. The study results indicate that the maximal isometric handgrip strength was maintained at 90% of the resting situation values since the high incidence of forearm fatigue was reflected in the decrease in the maximal isometric handgrip strength.

So far, only one investigation measuring maximal isometric handgrip strength in judo official matches was found [52]. A different number of athletes was assessed along an official competition (post-match 1 = 34 athletes; post-match 2 = 28; post-match 3 = 25; post-match 4 = 9), comparing medalists and non-medalists, and information is provided only for right and left hand, with no details concerning dominant and non-dominant hand or the interval duration between matches. They reported that no difference was found between medalists and non-medalists. In contrast, the maximal isometric right handgrip decreased post-matches 3 and 4 compared to pre-match, post-matches 1 and 2, whereas for the left hand, lower values were observed post-match 3 compared to pre-match, and lower values post-match 3 compared to post-match 2.

### 3. Maximal isometric strength responses during striking combat sports

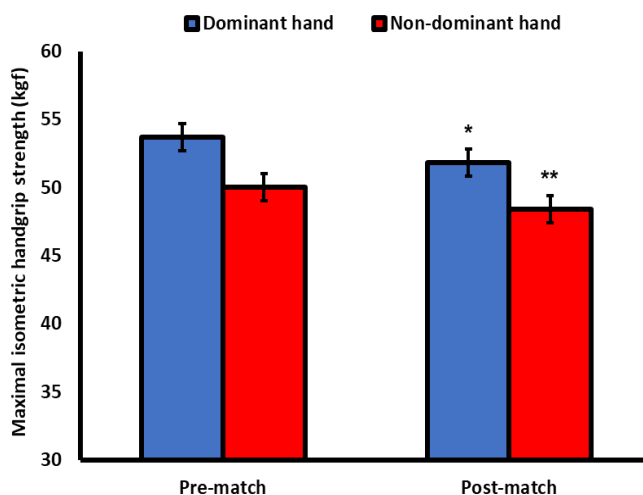
Chiodo et al. [53] studied the maximal isometric handgrip strength of 15 Italian high-level taekwondo athletes, including four women and eleven men. The criteria for inclusion in the study were participating in international competitions (European Championships, World Championships, and Olympic Games) and weekly training frequency equal to 6 weekly sessions. On the first day, the maximal isometric handgrip strength at rest (among other measures) was measured. On the second day, the matches were executed during an official competition, consisting of three rounds of 2 min interspersed with 1 min of passive rest. The measures were implemented shortly after the end of the match. Figure 22 shows the values of the athletes' maximal isometric handgrip strength before and after the taekwondo competition. These results indicate differences in the maximal isometric handgrip strength between both male and female athletes. Moreover, there were decreases in the maximal isometric handgrip strength of both males and females after the match. The authors attributed the reduction of the maximal isometric handgrip strength (8% of reduction) to hand-to-hand contact, protection of opponents' kicks, and punches' execution. However, the use of the handgrip test does not seem to be specific to evaluate the upper-body actions and specifically the wrists and forearm solicitation during the combat, as the use of the lower-body is predominant in the taekwondo match, with 98% of the actions executed by these muscular groups [13]. The match's activities did not involve grappling moves, except for the wrists' closing to maintain the guard and prepare eventual punches.

Therefore, Tassiopoulos and Nikolaidis [54] sought to identify the maximal isometric handgrip strength's acute effect during an official national level kickboxing in winners and losers. The combats were composed of three rounds of 2 min interspersed by 1 min of passive rest. Thirty-one Greek athletes with  $4.8 \pm 3.1$  years of practice of the modality participated in the study. The maximal isometric handgrip strength was measured in two moments: before and after the official kickboxing matches. Figure 23 shows the maximal isometric handgrip strength values before and after the official kickboxing matches.



**Figure 22:** Maximal isometric handgrip strength at rest, before and after a taekwondo official match (adapted from Chiodo et al. [53]).

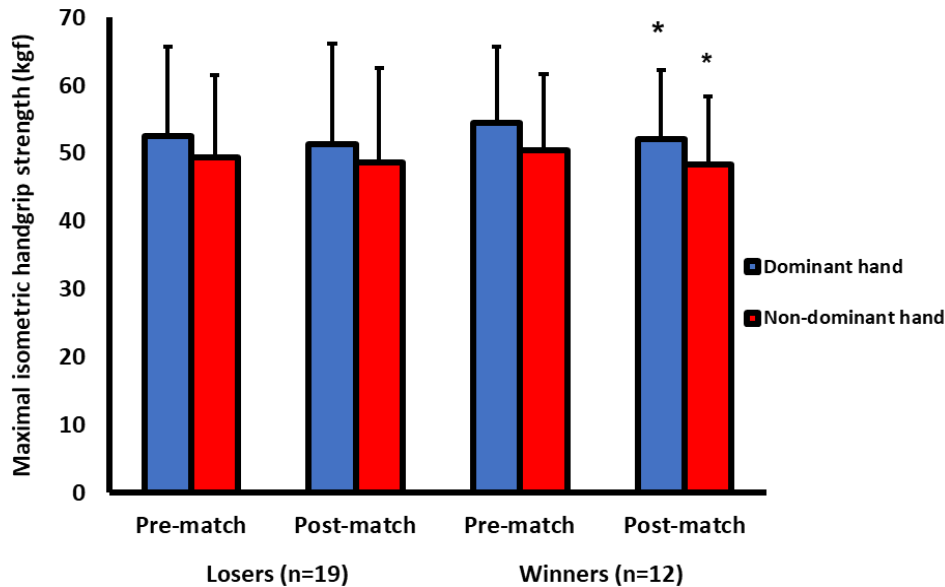
Note: the data represent the mean and standard deviation; \* = difference between the sexes ( $p < 0.001$ ); \*\* = difference of measurements performed at rest condition ( $p < 0.01$ ).



**Figure 23:** Maximal isometric handgrip strength after and before an official kickboxing match (adapted from Tassiopoulos and Nikolaidis [54]).

Note: the data represent the mean and standard deviation; \* = different of pre-match values of dominant hand ( $p < 0.001$ ); \*\* = different of pre-match values of non-dominant hand ( $p < 0.05$ ).

The results indicated decreases in the maximal isometric handgrip strength after official kickboxing matches for both the dominant and non-dominant hands in these athletes. Figure 24 presents the maximal isometric handgrip strength values before and after the combats of winning and losing athletes.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.001$ ) of pre-match values of the winners' athletes.

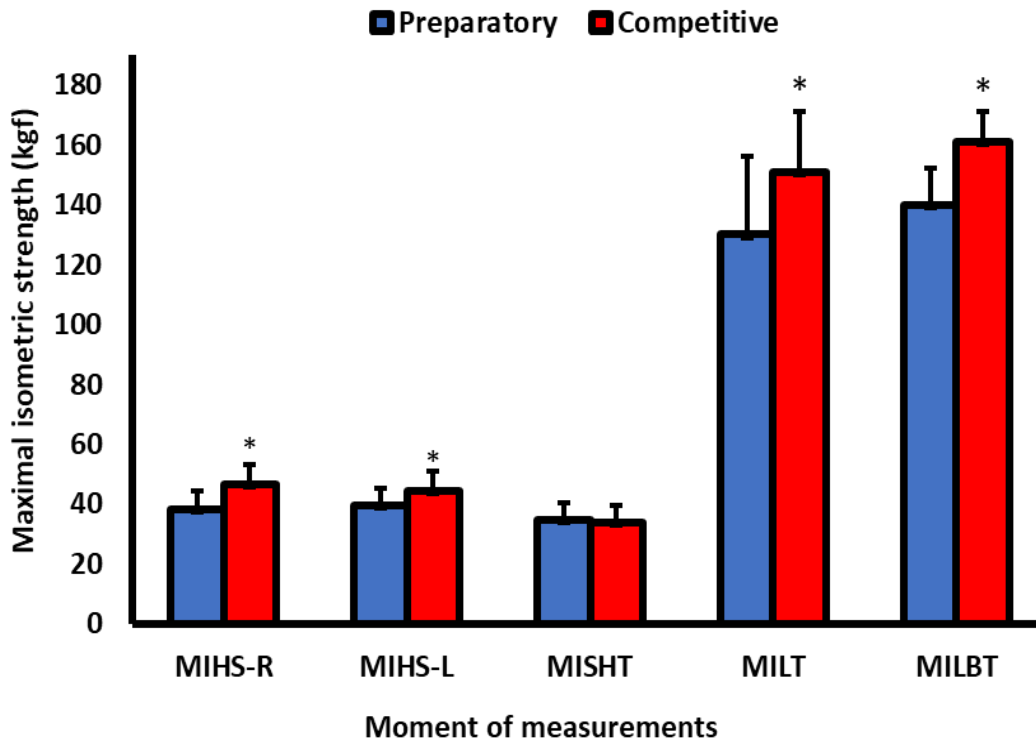
**Figure 24:** Maximal isometric handgrip strength of the winners and loser's kickboxing athletes (adapted from Tassiopoulos and Nikolaidis [54]).

The results presented in figure 24 indicate decreases in the maximal isometric handgrip strength of the winning athletes. However, no differences were identified among the defeated athletes. Moreover, the authors reported that the decrease in the maximal isometric handgrip strength could be associated with high neuromuscular fatigue. This factor was not supported by the results identified in the loser athletes. Moreover, the maximal isometric handgrip strength was shown to differentiate the athletes according to the performance obtained in the matches (victory or defeat). However, because it is striking combat sport, that is, a sport that involves the execution of kicks, punches, elbows, and knees, the measurements of the maximal dynamic and isometric strength in other exercises, such as bench press, squat, chin-up, and stiff, appear to be more specific than the use of handgrip strength, which is usually performed in the grappling combat sports. This occurs because the muscular demand in the handgrip's execution is substantially greater in the grappling modalities than in the striking modalities. However, for the MMA, using the dynamometer to measure the maximal isometric handgrip strength is valid since the forearm musculature is needed to perform throwing techniques, immobilizations, and finalizations during the matches. The authors also consider that coaches and physical trainers may use this study's results during training and competitions. However, the study has caveats (regarding the dynamometer's use as an instrument for evaluating kickboxing athletes). Based on these aspects, new research should be carried out, considering that the study mentioned above was the first to assess the differences in the maximal isometric handgrip strength between winners and losers during an official kickboxing competition.

#### 4. Longitudinal studies on the development of maximal strength in combat sports athletes

To verify the influence of the training period on the maximal isometric strength in different tests, body composition, and somatotype (these two last ones are not part of this chapter), Franchini et al. [55] submitted 8 juvenile judo athletes (15-16 years old) to a series of maximal isometric strength tests: 1) right and left handgrip; 2) lumbar traction; 3) lower-body traction and 4) scapula-humeral traction. The measurements were performed one month after the start of the preparation period. In contrast, after the fourth month, the follow-up occurred 20 days after the beginning of the competitive period. The athletes performed the same training model during the four months, which

consisted of the judo-specific training 3 to 4 times a week with a duration of approximately 2 hours per training session and physical preparation in the weight room 2 to 3 times a week, which aimed to improve muscle power (3 to 4 sets of 6-8 repetitions were performed at 80% of 1RM for the main muscle groups). Additionally, in this study, no athlete reported to be using rapid weight loss procedures. Figure 25 shows the values of the maximal isometric handgrip strength, lumbar traction, lower-body traction, and scapula-humeral traction of the athletes in the preparatory period and 20 days after the start of the competitive period.



Note: the data represent the mean and standard deviation; \* = different of measured values in the preparatory period when compared to competitive period of the judo athletes ( $p < 0.01$ ); MIHS-R = maximal isometric handgrip strength of right hand; MIHS-L = maximal isometric handgrip strength of left hand; MISHT = maximal isometric scapulo-humeral traction; MILT = maximal isometric lumbar traction; MILBT = maximal isometric lower-body traction.

**Figure 25:** Maximal isometric strength in different dynamometers (adapted from Franchini et al. [55]).

According to figure 25, there were increases in the measurements obtained during the competitive period for the right and left handgrip strength, lumbar traction, and lower limb traction compared to the athletes' measures in the preparatory period. However, no differences were found for scapula-humeral traction at the two measurement moments. It is plausible to note that this study did not present a control group since the sample was composed of adolescents. Consequently, it is difficult to consider the increase only because of the training's adaptations. The tests performed to measure the athletes' gains were not specific to the training program since they performed dynamic exercises. In contrast, the measurements of maximal strength were performed using isometric tests.

The study by Blais and Trilles [56] analyzed the performance of judo athletes submitted to a specific device strength training program, in which 20 experienced French judokas (black-belts) were randomly assigned to two groups: control (age  $23 \pm 2.4$  years old,  $n = 10$ ) and experimental (age  $22 \pm 3.6$  years,  $n = 10$ ). The strength training program lasted 10 weeks. The control group did not perform other training, for example, strength training in the judo-specific equipment. The experimental group completed strength training twice per week with 5 sets of 10 repetitions in the judo-specific equipment, combined with the same number of throwing technique executions (*nage-komi*) with the training partner. The specific exercises simulated the technique *morote-seoi-nage* and *o-soto-gari*, and the throwing techniques were performed from these exercises. A video recording was performed before and after the groups' training period to evaluate the quality of the throwing techniques. To this end, 23 expert coaches from the French judo team evaluated each athlete's performance, assigning scores from 0 to 20. Figure 26 shows the maximal dynamic loads for the *o-*

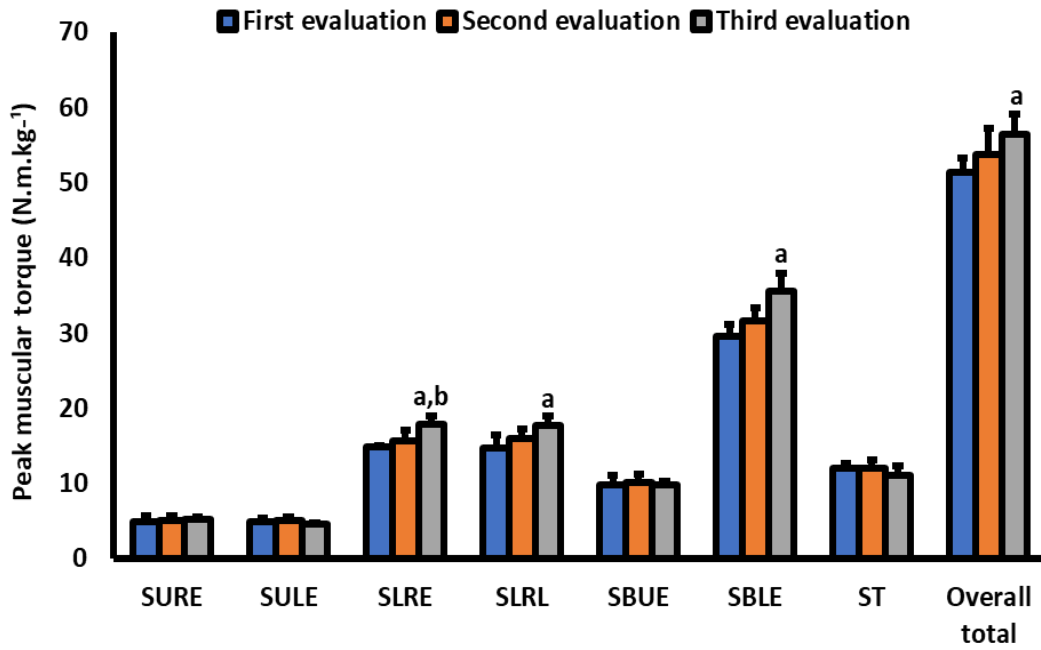
*soto-gari* and *morote-seoi-nage* techniques in the specific equipment before and after 10 weeks of training. The results showed improvements for the *o-soto-gari* and *morote-seoi-nage* techniques compared to the training period's measurements. Besides, the group that performed strength training in the judo-specific equipment and throwing techniques showed an improvement in the quality of the two techniques in the grades attributed by the experts (*o-soto-gari*:  $6.4 \pm 2.5$  for  $9.4 \pm 2.4$ ; *morote-seoi-nage*:  $8.2 \pm 2.7$  for  $9.6 \pm 2.6$ ), whereas the control group did not show an improvement in the grades attributed to the throwing techniques. Thus, the progress after the experimental group athletes' training period was quantitative, with the increase of the loads in the exercises and qualitative, through the experts' grades.



Note: the data represent the mean and standard deviation; \* = different of measured values before the training period ( $p < 0.05$ ).

**Figure 26:** Maximal dynamic strength for the techniques: *o-soto-gari* and *morote-seoi-nage* in specific apparatus after and before training period (adapted from Blais and Trilles [56]).

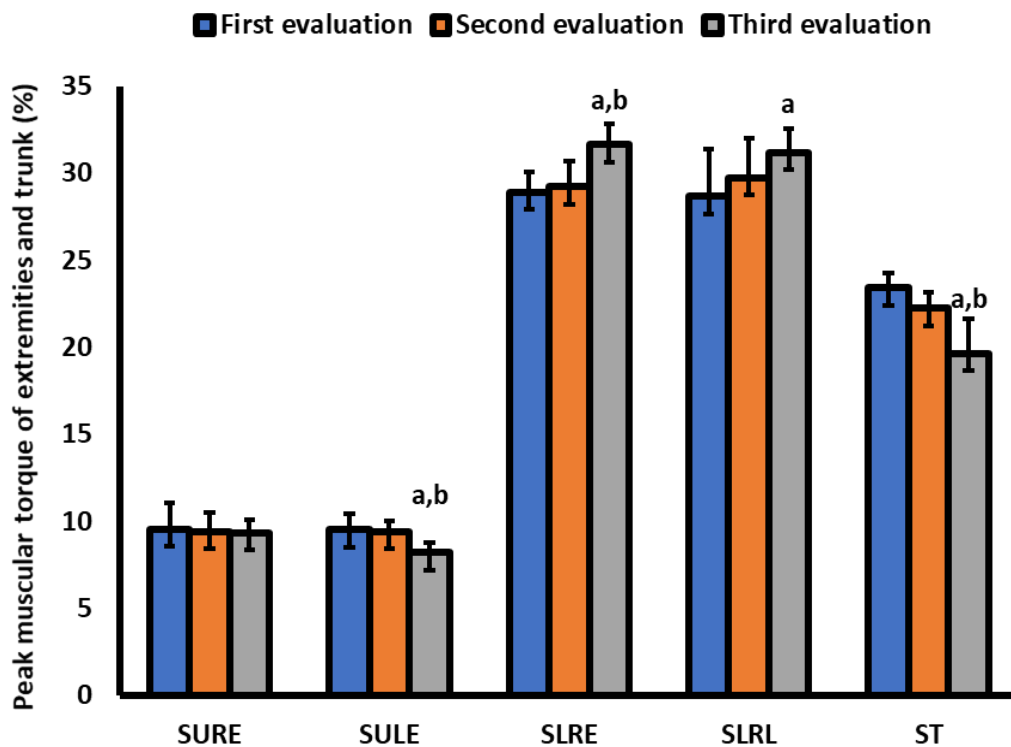
The research developed by Buško and Nowak [57] aimed to examine the peak torque differences in judo athletes during the pre-competitive period. The study participants included 5 athletes from the Polish judo team who performed a battery of tests on isokinetic equipment. The measurements were performed in three moments: 1) before the pre-competitive period, 2) immediately after the strength training mesocycle, and 3) immediately after the pre-competitive period. Peak torque was measured in 10 muscle groups: flexors and extensors of elbow and knees, shoulders, hip, and trunk. All measurements occurred in static conditions. For the shoulders, the  $70^\circ$  angle for flexion and the  $50^\circ$  angle for extension were used, for the knees and hip, the test occurred at  $90^\circ$ , and for the elbows, knees, and hip, the angles tested were at  $0^\circ$ . The athletes were instructed to perform the tests in the highest possible power, and all measurements were performed in the morning. Figure 27 shows the sum of the maximal peak torque values for the elbows, knees, shoulders, hip, and trunk of the evaluated athletes. The findings indicated an increase in the sum of the right lower extremity in the 3<sup>rd</sup> assessment (immediately after the pre-competitive period) compared to the 1<sup>st</sup> (before the pre-competitive period) and 2<sup>nd</sup> (immediately after the strength training) measurements. Similarly, the present results showed a marked increase in the 3<sup>rd</sup> evaluation for the lower-left extremity summation than the 1<sup>st</sup> evaluation performed. Specifically, regarding the sum of both lower limbs, the findings showed marked increases in the 3<sup>rd</sup> evaluation compared to the 1<sup>st</sup> evaluation. Finally, there were accentuated elevations for the total and the total sum in the 3<sup>rd</sup> evaluation compared to the 1<sup>st</sup> evaluation. Figure 28 shows the sum of the peak torque values for the right and left upper extremities, right and left lower extremities, and summation of the trunk with values expressed in (%), before the pre-competitive period, immediately after the strength training mesocycle, and immediately after the pre-competitive period.



Measurements in different muscle groups

Note: the data represent the mean and standard deviation; a = different of first evaluation ( $p < 0.05$ ); b = different of second evaluation ( $p < 0.05$ ); SURE = sums of the upper right extremities; SULE = sums of the upper left extremities; SLRE = sums of the lower right extremities; SLRL = sums of lower left extremities; SBUE = sums of both upper extremities; SBLE = sums of the both lower extremities; ST = sums of the trunk.

**Figure 27:** Peak torque of different body regions after the mesocycle strength training and after the mesocycle pre-competitive period (adapted from Buško and Nowak [57]).



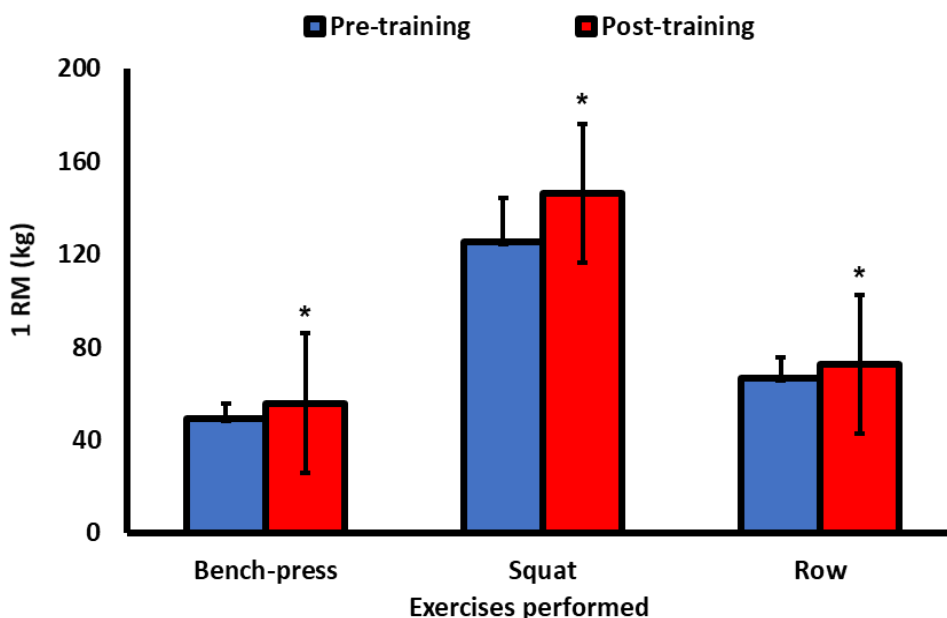
Measurements in different muscle groups

Note: the data represent the mean and standard deviation; a = different of first evaluation ( $p < 0.05$ ); b = different of second evaluation ( $p < 0.05$ ); SURE = sums of the upper right extremities; SULE = sums of the upper left extremities; SLRE = sums of the lower right extremities; SLRL = sums of lower left extremities; ST = sums of the trunk.

**Figure 28:** Peak torque of different body regions in percentages after the mesocycle strength training and after the mesocycle pre-competitive period (adapted from Buško and Nowak [57]).

The results indicated an absence of differences in all measurements obtained for the sum of the upper right extremity. However, significant decreases were found for the sum of the left upper extremity in the 3<sup>rd</sup> evaluation (immediately after the pre-competitive period) compared to the 1<sup>st</sup> and 2<sup>nd</sup> measurements. For the lower right extremity, marked elevations were found in the 3<sup>rd</sup> evaluation compared to the 1<sup>st</sup> and 2<sup>nd</sup> evaluations. Similarly, the findings showed marked increases for the 3<sup>rd</sup> evaluation compared to the 1<sup>st</sup> measurement. A sharp decrease was found in the 3<sup>rd</sup> evaluation compared to the 1<sup>st</sup> and 2<sup>nd</sup> evaluations about the trunk sum. We can verify that this study has some limitations as follows: 1) The relatively low number of participants ( $n = 5$ ); 2) The number of exercises, sets, muscle groups, and repetitions during the strength training mesocycle were not reported; and 3) The evaluations were conducted in an isokinetic equipment, in which the measures were performed unilaterally; thus, it does not reflect the demand of the real match, as the judo match uses multi-articular actions that solicited in different ways.

Still, the study conducted by Stojanovic et al. [58] aimed to increase the performance of judo athletes through an 8-week training program with strength, aerobic and anaerobic exercises (these last two aspects are not part of this chapter) during the pre-competitive period. To this end, 11 junior and senior female athletes who belonged to the Serbian judo team were recruited with high international experience. The training was divided into two 4-week mesocycles, as a 3:1 periodization model; that is, 3 weeks of training were performed with a gradual increase of the load, followed by a week of reduction (recovery). For the first mesocycle, 60% of the exercises performed were non-specific, and 40% were judo-specific exercises; that is, strength training was conducted 3 times a week for four weeks. The exercises performed were as follows: bench press, squat, and row. Two sets were performed for each exercise between 7-10 repetitions with loads between 70 and 80% of 1RM. There was inversion between judo-specific and non-specific exercises for the second mesocycle, with 60% of judo-specific exercises and 40% for non-specific exercises; strength training was performed twice per week four weeks. The non-specific exercises performed were as follows: strength training (in the weight room), high-intensity interval exercise, and high-intensity anaerobic exercise (these two last aspects are not part of this chapter), whereas the specific exercises had a technical-tactical nature. Figure 29 shows the values of 1RM for bench press, row, and squat before and after 8 weeks of training.



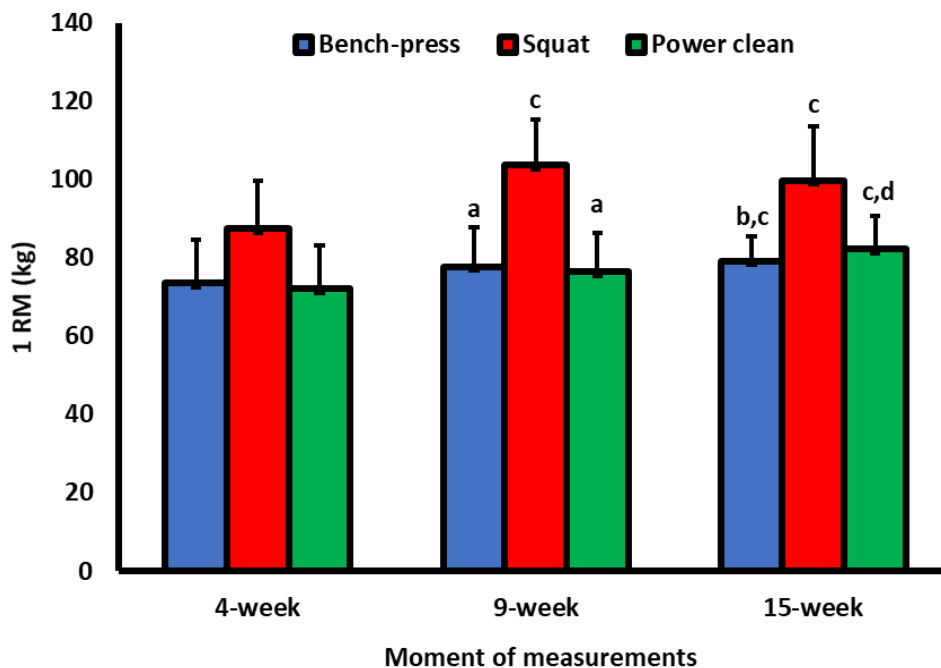
Note: the data represent the mean and standard deviation; \* = different pre-training values ( $p < 0.05$ ).

**Figure 29:** One repetition-maximum (1 RM) values for the bench-press, squat and row after and before 8-week strength training (adapted from Stojanovic et al. [58]).

The results showed marked elevations after 8 weeks of training for the bench press (13.7%), squat (16.5%), and row (8.8%) compared to the measurements obtained before the training period. Also, it is noteworthy that the low volume of the exercises performed during the 8 weeks of training

promoted large increases in the trained judoka's maximal strength in the pre-competitive period. Thus, the exercises used in this study can serve as a reference for the prescription of training by professionals responsible for the physical preparation of athletes to maximize the competitive performance.

Passelergue and Lac [59] recruited 15 French Olympic wrestlers (aged:  $17.9 \pm 0.2$  years) with international experience. Most of the athletes were trained in Greco-Roman and freestyle ( $n = 10$ ), while others ( $n = 5$ ) trained only in the Greco-Roman style. The athletes trained, on average, 12 to 15 hours per week. The training periodization was carried out between September and December, which was carried out before the competitive period. The training was divided into 3 periods: 1) P1- Consisted of maximal strength exercises for 7 weeks (and other exercises that are not part of this chapter; 2) P2- Athletes had a week of rest because of school vacations; and 3) P3- Maximal strength and power exercises were executed for 6 weeks (among other exercises not related to the purposes of this chapter). The first training session consisted of 5 sets of 8-12 repetitions between 70 and 80% of 1 RM. The second session was performed using 5 sets of 2-5 repetitions with 85 to 95% of 1RM, with an approximate duration of 45 min per training session. The third session comprised the execution of sets for maximal strength maintenance, composed of 1-3 sets of 2-5 repetitions with loads between 85 and 95% of 1RM. Exercises, such as bench press, military press, front pull, squat, leg-press, deadlift, biceps, triceps, and trunk exercises, were performed during the training period with approximately 2 to 3 min of rest between sets. Also, weightlifting exercises, such as clean, snatch, deadlifting, and weight-bearing exercises that mimicked Olympic wrestling's specific actions, were prescribed. Figure 30 presents the maximal strength values for the bench press and squat.



Note: the data represent the mean and standard deviation; a = different of the measures performed in the 4<sup>th</sup> training week ( $p < 0.05$ ); b = different of the measurements performed in the 9<sup>th</sup> training week ( $p < 0.01$ ); c = different of the measurements performed in the 4<sup>th</sup> training week ( $p < 0.01$ ); d = different from the 9<sup>th</sup> training week ( $p < 0.05$ ).

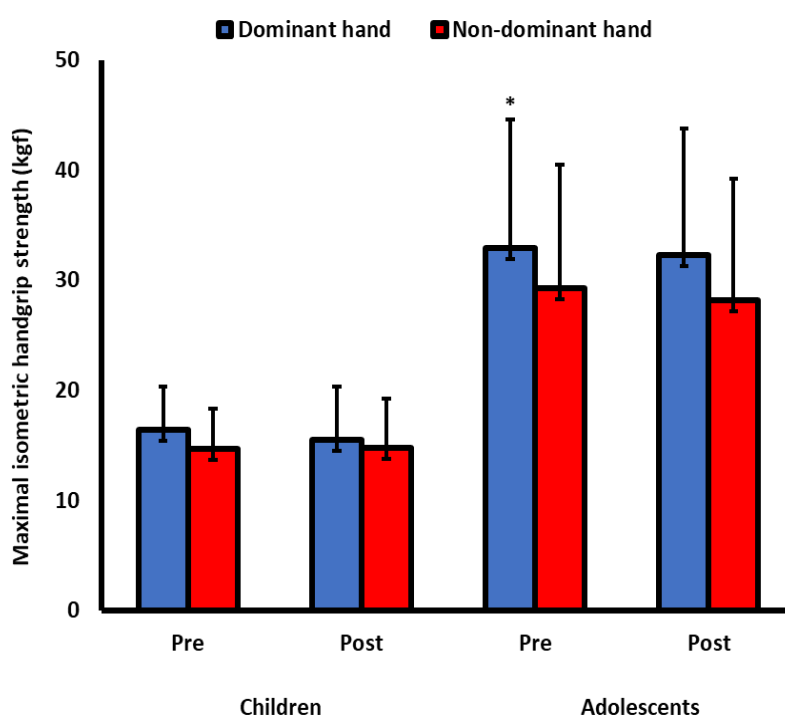
**Figure 30:** One repetition-maximum (1 RM) for the bench-press, squat, and power clean for the French junior judo athletes of wrestling submitted to 15<sup>th</sup> of strength training (adapted from Passelergue and Lac [59]).

Concerning figure 30, the presented results indicated elevations in the bench press's maximal strength at the 9<sup>th</sup> week compared to the measurements obtained in the 4<sup>th</sup> week. Similarly, marked elevations were identified in the evaluations conducted in the 15<sup>th</sup> week compared to the 4<sup>th</sup> and 9<sup>th</sup> weeks, respectively. The findings indicated marked gains for 1RM in the evaluations performed in the 9<sup>th</sup> and 15<sup>th</sup> weeks compared to the squat's 4<sup>th</sup> week. Regarding the power clean, the results showed increases in the maximal strength for week 9 compared to the measurements obtained in week 4. Similarly, the results showed high gains in the evaluations conducted at the 15<sup>th</sup> week compared to the 4<sup>th</sup> and 9<sup>th</sup> weeks of training.



One limitation of this study is the lack of evaluations in the first week of training since the results could indicate the athletes' initial level of physical conditioning and tests of 1RM in the other exercises used in the training program. Although this study was conducted concomitantly with aerobic training, as it could characterize it as a concurrent training and potentially minimize the benefits resulting from strength training, the findings indicated marked increases in 1RM tests in all exercises measured. However, the proposed periodization may be a relevant alternative for professionals working in Olympic wrestlers' training because strength, power, strength-endurance, and aerobic and anaerobic fitness are significant for maximizing and maintaining performance in the matches. It is also worth mentioning that the adoption of complementary training methods must be continuously monitored. In many instances, recovery between training sessions is neglected. Therefore, the insertion of questionnaires for monitoring training and the use of heart rate variability (HRV) [60] to assess autonomic activity and performance tests, such as the countermovement jump, may be used to monitor athletes.

In turn, the research conducted by Fukuda et al. [61] had as objective to verify the physiological adaptations during four weeks of training in children and adolescents during the competitive period in judo. The adolescent athletes were in the intensive preparation phase for the Junior American National Championship, and all participants underwent a test battery before and after the training period. Judo practitioners (male,  $n = 10$ , female,  $n = 10$ ) participated in the study as follows: 1) children 7 to 12 years old ( $n = 8$ ) and 2) adolescents: 13-19 years old ( $n = 12$ ). Besides, the judo athletes performed the maximal isometric handgrip strength (among other tests that are not part of this chapter). The physical, technical, and tactical preparation consisted of eight training sessions, which lasted approximately 16 hours of training a week. The morning and evening training sessions were conducted four times a week (morning workouts: Tuesday, Wednesday, Thursday, Saturday, and Monday; evening workouts, Tuesday, Wednesday, and Thursday). The morning training routine involved the execution of stretching exercises (~10 min), interval running (~20 min), weight-bearing exercises, plyometrics, bearings and *ukemi* (~20 min), throwing techniques (~10-15 min), groundwork combat or *ne-waza uchi-komi* (~20 min) and *randori* (~20 min). Also, at the end of each training, the participants were instructed to climb a 9 m rope (2 x per training). The afternoon training routine comprised the execution of rapid and dynamic warm-up exercises (~15 min), specific throwing techniques exercise (~15-20 min), static *nage-komi* or static *uchi-komi* (15-20 min), groundwork combat or *ne-waza uchi-komi* (~20 min), static and moving throwing techniques (~20 min) and the execution of interval sprint exercises in circuit (~10-15 min). Figure 31 shows the maximal isometric strength values for children and adolescents before and after 4 weeks of training.

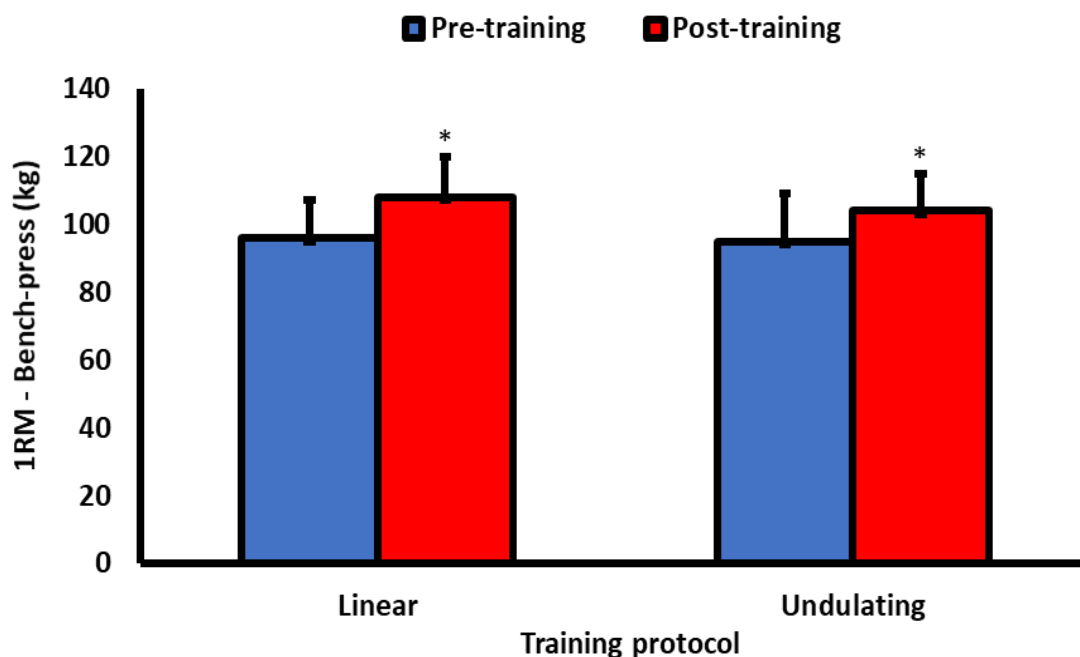


**Figure 31:** Maximal isometric strength in children and adolescents after and before 4-week strength training (adapted from Fukuda et al. [61]).

Note: the data represent the mean and standard deviation; \* = different of the pre-training measures between children and adolescents ( $p < 0.05$ ); pre = pre-training; post = post-training.

The results showed differences in the maximal isometric handgrip strength in the evaluations performed before the training period, with higher values for adolescents than those for children. However, no differences were found for the maximal isometric handgrip strength between measurements before and after the groups' training period (children and adolescents). Consequently, the results are not surprising since the judo-specific training involves grip disputes, and the rope climbing is predominantly related to strength-endurance. As a result, we can understand the absence of differences between the evaluations performed before and after the training period for the maximal isometric handgrip strength. In this respect, the maximal dynamic and isometric *judogi* chin-up seem to be more specific for assessing the handgrip strength-endurance than the test using the dynamometer since the flexor's strength-endurance and extensor muscles of the forearm are very important for maintaining the grip during the match [62]. A substantial limitation of the study is the control group's absence, as athletes were developing. The authors also noted that the children's gains could not be measurable through the tests used. Finally, the study carried out by Fukuda et al. [61] was the first to analyze body composition and specific measures of performance in judo athletes in these age groups (7 to 12 and 13 to 19 years old) and can be used as a reference for professionals involved in children's and adolescents' training in this sport.

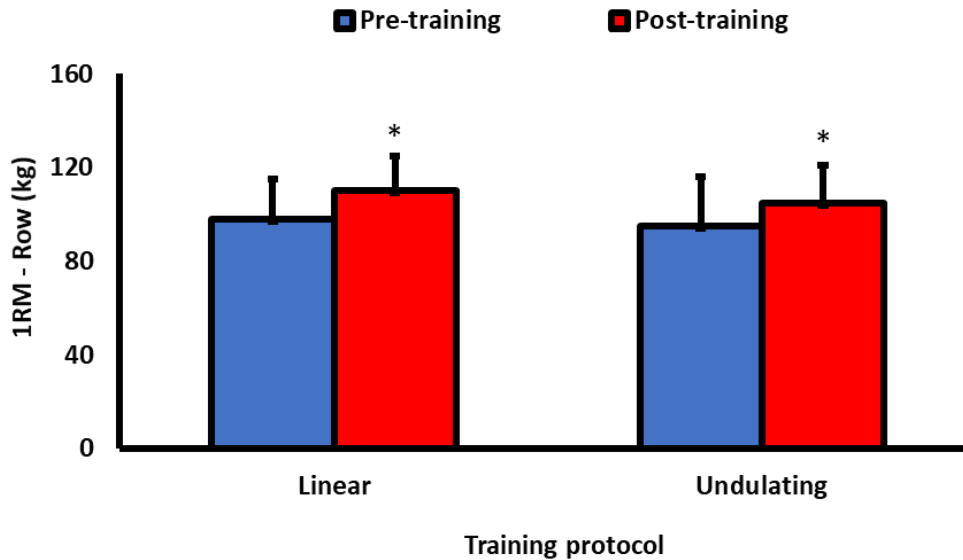
The research developed by Franchini et al. [63] had the purpose of investigating the effects of linear and undulating periodization during 8 weeks of training in judo athletes. Thirteen athletes were randomly divided into linear ( $n = 6$ ) and undulating ( $n = 7$ ) groups. The athletes were submitted to maximal strength tests of 1RM for bench press, row, and squat, among other measures not included in this chapter. Four sets were performed for all exercises, and the two groups trained 3 times a week with the following exercises: 1) bench press, 2) squat, 3) bar lying row, 4) arm-curl, 5) lying triceps extension, 6) leg curl, 7) barbell wrists curl, 8) dumbbell frontal raise, 9) dumbbell lateral raise, 10) good-morning, 11) reverse wrist curl and 12) Smit standing leg calf raise. The training division was performed as follows: 1<sup>st</sup> training day: exercises from 1 to 8; 2<sup>nd</sup> training day: exercises 5 to 12; and 3<sup>rd</sup> training day: exercises 1 to 4 and 9 to 12 for both groups. The periodization for the linear group was conducted as follows: the 1<sup>st</sup> and 2<sup>nd</sup> weeks of training included exercises from 3 to 5 RM, the 3<sup>rd</sup>, 4<sup>th</sup>, and 5<sup>th</sup> weeks included power exercises (between 6 and 8 repetitions), and in the 6<sup>th</sup>, 7<sup>th</sup> and 8<sup>th</sup> weeks, the 15-20 RM exercises were performed. For the undulating training group, stimuli of 3 to 5 RM, power, and 15-20 RM were alternated. Figure 32 presents the values of 1RM for the bench press of the athletes who performed the linear and undulating periodization.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) of pre- and post-training period.

**Figure 32:** One repetition-maximum (1 RM) for the bench-press after and before 8-week linear and undulating strength periodization in judo athletes (adapted from Franchini et al. [63]).

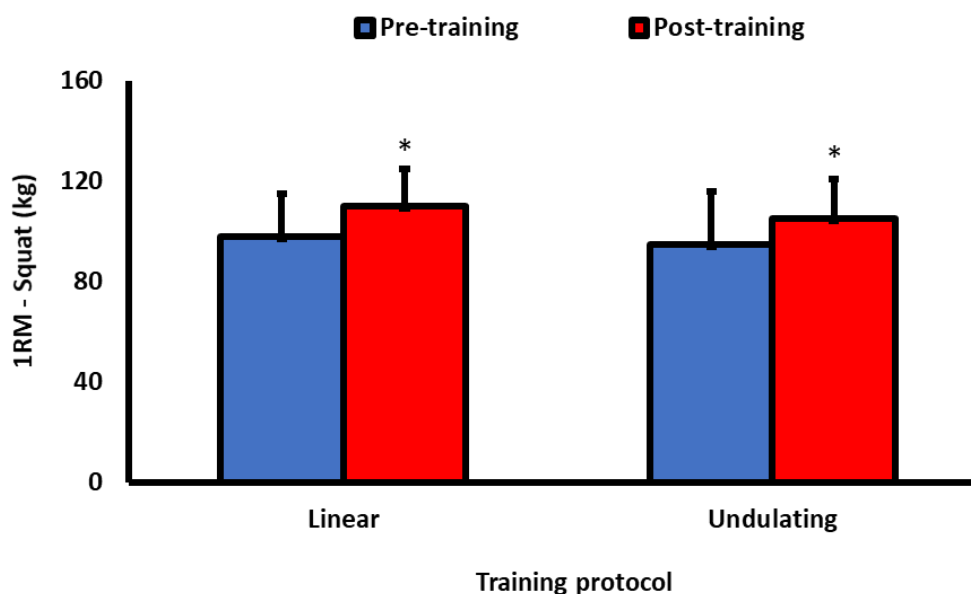
The results presented indicated marked increases in the maximal strength test for the bench press after the athletes' training period submitted to the linear and undulating protocols compared to the measurements performed before the training period for both groups. The increase in the maximal strength on the bench press for both groups was 11.6% after the training period concerning the measurements performed before this period. Figure 33 shows the values of 1RM for the squat exercise for the athletes who completed the linear and undulating periodization.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) of pre- and post-training period.

**Figure 33:** One repetition-maximum (1 RM) for the row after and before 8-week of linear and undulating strength periodization in judo athletes (adapted from Franchini et al. [63]).

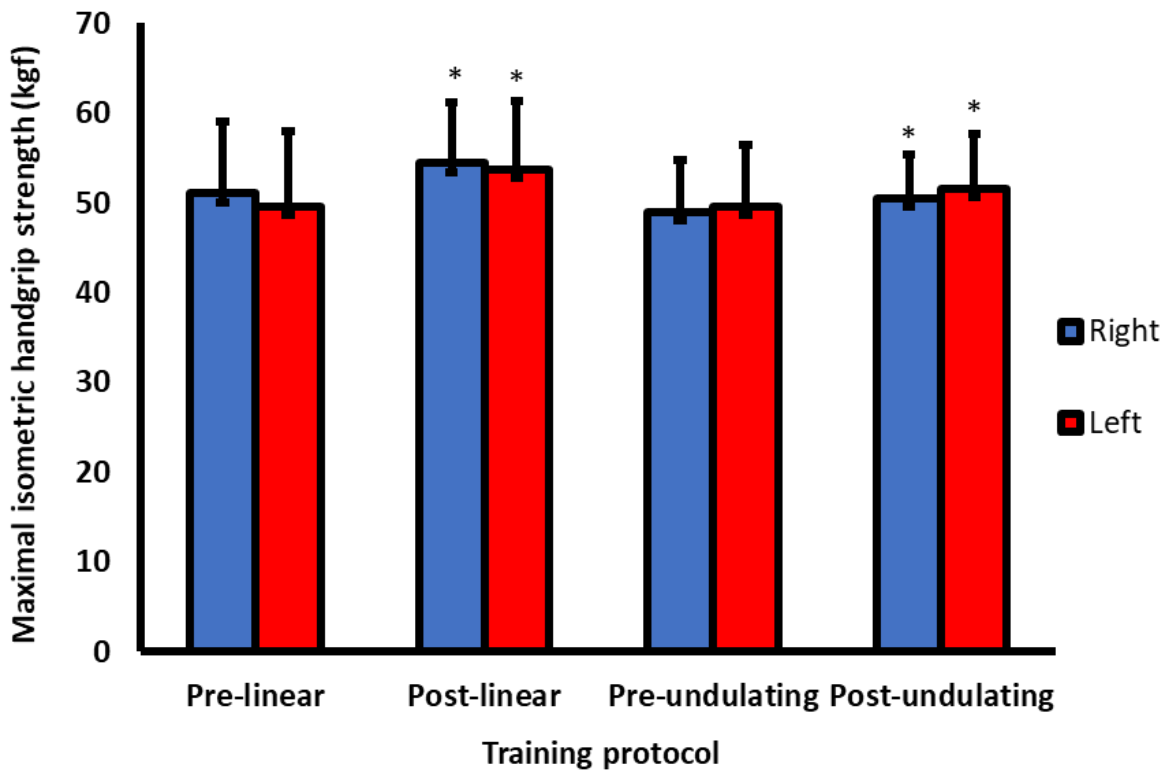
Regarding figure 33, the presented results indicated marked increases in the maximal strength test for squat after the athletes' training period submitted to the linear and undulating protocols compared to the measurements performed before the training period for both groups. Additionally, the increase in the maximal squat strength for both groups was 7.1% after the training period about the training period's measurements. Figure 34 presents the values of 1RM for the bar lying row of the athletes who performed the linear and undulating periodization.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) of pre- and post-training period.

**Figure 34:** One repetition-maximum (1 RM) for the squat after and before 8-week linear and undulating strength periodization in judo athletes (adapted from Franchini et al. [63]).

The results presented indicated increases in the maximal strength test for the bar lying row after the athletes' training period submitted to the linear and undulating protocols compared to the measurements performed before the training period for both groups. The increase in the maximal resting strength for both groups was 11.5% after 8 weeks of training to the measurements performed before this period.



Note: the data represent the mean and standard deviation; \* = different ( $p < 0.05$ ) of pre and post-training period.

**Figure 35:** Maximal isometric handgrip strength for right and left hands after and before 8-week of linear and undulating strength periodization in judo athletes (adapted from Franchini et al. [63]).

Regarding figure 35, the findings show an increase in the maximal isometric handgrip strength for the right and left hands after the training period compared to the measurements performed before the training period for both training models (linear and wave). The maximal isometric strength increases were 4.6% for the right hand and 6.1% for the left hand. From the data presented, no differences were detected between the two training models, and it should be emphasized that further longitudinal studies of longer duration should be performed. The authors also suggest that incorporating other training methods, such as weightlifting exercises, complex training connecting strength exercises to specific actions of judo, could be investigated. These methods can be tested to determine the most efficient model to maximize athletes' performance during training and competitions.

Studies analyzing periodized judo training for longer than three months are not frequently conducted [64,65]. Franchini et al. [64] submitted state-level judo athletes to a general phase, for 7 weeks, involving strength training directed to muscle hypertrophy for the main muscle groups (8 to 12 exercises, 3 sessions a week, 4 x 8-12 repetitions at 70-80% of 1RM), together with other exercises (*randori*: 4 times a week at 60% of maximal perceived effort, 6-8 5-min matches with 5 to 10 min intervals; aerobic conditioning: running, 2 sessions a week, for 40 to 60 min, at 60% of heart rate reserve). After this general phase, athletes executed the following training for 11 weeks: (A) Strength training - the first 8 weeks with basic strength training exercises and the last 3 weeks with complex training (3 sessions a week). Basic strength was developed by using wrist flexion exercises, triceps and back pulley machines exercises, rowing, squat, Olympic-type lifts (e.g., power clean, high pull, clean and jerk, snatch), performed at high-intensity (4 x 3-5 repetitions at ~90% of 1RM, and the highest speed possible, with 3 min intervals between sets). Complex training was composed of

Olympic-type lifts, squat and bench press exercises, at the same intensity and volume used in the previous 8 weeks, but followed by specific judo actions (mainly throwing judo techniques, 3–5 repetitions with different partners, 3–5 min after the maximal strength exercise); (B) *Randori* - intensity during this phase was increased to 70–90% of maximal effort (7–9 in the 0–10 Borg scale), using 4 to 6 combats with longer intervals (5–10 min) between matches, using the same number of sessions per week; (C) Aerobic training - the intensity for the aerobic training also increased (90–100% of heart rate reserve, twice a week), performed intermittently (1:1 effort: pause ratio) and in a lower volume (30 min per session). Concerning maximal strength adaptation, after the 18 weeks of training, only row exercise 1RM significantly increased from pre- ( $85 \pm 23$  kg) to post- ( $92 \pm 26$  kg), whereas right (pre:  $61 \pm 13$  kgf; post:  $60 \pm 13$  kgf) and left (pre:  $54 \pm 12$  kgf; post:  $55 \pm 10$  kgf) maximal isometric handgrip strength, and bench press 1RM (pre:  $88 \pm 24$  kg; post:  $91 \pm 23$  kgf) did not change significantly. The authors attributed the only change in the row exercise to the frequent execution of pulling actions during judo matches. Despite the constant grip dispute, the changes were observed in strength-endurance variables and not in maximal isometric handgrip strength (see chapter about strength-endurance). Therefore, the adaptation to this type of training was related to the specificity of actions and the match physical demand.

Marques et al. [65] applied block periodization concepts to national and international level judo athletes and compared their responses to such training process, with five weeks of accumulation phase, five weeks of transmutation phase, and three weeks of realization phase. During the accumulation phase, athletes executed strength exercises and conditioning workouts to develop judo-specific strength (i.e., muscle power in lower- and upper-body and strength-endurance in upper-body - especially the forearm muscles - and core regions). For the transmutation phase, training was directed to develop muscle power, including weight training, plyometrics, and judo-specific actions. During the realization phase, the training was like the transmutation phase, but the volume was reduced, and judo technical actions were the main focus of the training phase. Among muscle power, judo-specific test performance, row 1RM test was the only maximal strength-related variable assessed. For this variable, lower relative values were observed after the accumulation phase (national level:  $0.76 \pm 0.22$  kg/kg of body mass; international level:  $0.77 \pm 0.15$  kg/kg of body mass) compared to before the accumulation phase (national level:  $1.05 \pm 0.24$  kg/kg of body mass; international level:  $1.09 \pm 0.17$  kg/kg of body mass) and after the transmutation phase (national level:  $1.08 \pm 0.26$  kg/kg of body mass; international level:  $1.13 \pm 0.17$  kg/kg of body mass).

However, no effect of competitive level was detected. This result indicated that the row exercise maximal strength test was sensitive to detecting the training content changes imposed during the block periodization. Therefore, the findings provided evidence to support the suggestion for isolating voluminous physical training content (i.e., similar to that used in the accumulation phase in the study) and intensive sport-specific training into appropriate block mesocycles, and that the row exercise can be used to monitor changes in the maximal strength of judo athletes submitted to such periodization.

Øvretveit and Tøien [66] assessed the short-term effects of strength training on 14 male Brazilian jiu-jitsu (BJJ) athletes' generic performance. In this chapter, we focused only on strength response; the athletes performed a 1 RM test for bench-press and squat (in addition to other exercises that are not part of this chapter). The athletes were randomized into two groups: an experimental and a control group. For four weeks, the athletes carried out 4 x 4 repetitions at > 85% of 1 RM in the squat and bench-press, and pull-ups until failure, three times a week. The athletes presented different BJJ experience levels (white belt, blue belt, or purple belt). During the training planning, both groups performed the same BJJ training routine. After four weeks, an improvement of  $15 \pm 9\%$  was identified for the bench-press 1RM and  $11 \pm 3\%$  for the squat 1RM. The authors concluded that strength training's low-volume training could improve BJJ athletes' maximal strength.

#### 4.1 Final considerations on longitudinal studies in combat sports

Finally, it is pertinent to consider that scientific studies remain scarce for combat sports. Thus, it is deemed essential to develop longitudinal studies that contemplate each modality's peculiar characteristics to aid coaches and physical trainers in the prescription of the training and, consequently, improve the competitive performance.

## 5. Maximal strength tests for combat sports athletes

### 5.1 Maximal dynamic strength tests

Maximal dynamic strength tests are performed to measure the maximum load an athlete can perform in each exercise, which is described as a 1 RM [10]. Exercises such as bench press, squat, and row may be used to assess the maximal strength [27] and the snatch and the clean and jerk Olympic weightlifting exercises, commonly used in the physical preparation of combat sports athletes [7,67]. The maximal strength exercises can be performed in the weight room using bars, dumbbells, and other accessories, with specific modality gestures/movements [11]. To complete the 1RM test, it is recommended that the athlete follows the American Society of Exercise Physiologists (ASEP) procedures described by Brown and Weir [68]. A specific warm-up should be performed for the exercises, which will be tested using a 5-rep set with a load of 50% of the estimated 1RM and a 3-rep set with 70% of the estimated value for the 1RM, with a 2 min interval between the sets. The testing of 1RM should be performed at least three times and at most five times, with rest intervals of 3 to 5 min.

### 5.2 Isokinetic test

To perform the maximum torque evaluations, specialized equipment considered as the gold standard is used to analyze the balance of different muscle groups. Measurements can be completed in physical conditioning programs and physical therapy rehabilitation, which provide highly accurate and reliable data [19]. It is worth mentioning that the isokinetic test has been widely used to measure muscle imbalances between the right and left sides, as well as between the antagonistic muscle groups in certain actions and, are usually indicated after injuries or surgeries that keep athletes away from training and competitions [43–45,69].

### 5.3 Maximal isometric strength tests

The maximum isometric strength tests can be performed on the following devices: 1) In bar, when coupled to a load cell connected to a computer, the results are sent to a specific software as executed in the study of Fernandez et al. [37]; 2) In one particular dynamometer for handgrip, lumbar, lower-body or scapula-humeral traction, as described by Franchini et al. [55]. During isometric exercise, there are no stretching and shortening muscles' actions. Moreover, the tension exerted may be higher than eccentric and concentric muscle activity [1,70]. In the topic intended for the prescription, the angles maximal isometric strength development will be indicated in some exercises.

### 5.4 Safety, injury prevention, and soreness during strength training

Injuries during strength training have been associated with failure to establish safety guidelines. Athletes and/or coaches who avoid performing strength training in the physical preparation routine were probably misguided in the physical sports training process [71]. The same authors also point out that qualified instruction and adherence to the proper technique promote a low risk of injury. In the same direction, the systematic review with meta-analysis published by Lauersen et al. [72] indicates the existence of a dose-response relationship between strength training and injury prevention. It is worth mentioning that supplementary strength training and the physical, technical, and tactical training of athletes should be monitored. Indirect measures, such as the rating of perceived exertion, rating of perceived recovery, sympathetic and parasympathetic responses, via heart rate variability, and performance tests, such as the countermovement jump, could be conducted [60]. Direct measures can also be undertaken, such as blood collections to determine biomarkers, anabolic and catabolic hormones. However, these measures have a higher cost, sometimes making direct analyzes limited to professional clubs or research centers [60]. Thus, the monitoring of physical-sports training can provide the technical commission and staff with tools to control the training load and reduce the risk of possible injuries.

The literature also points out that strength training is essential for athletes' rehabilitation in pre- and post-surgical sports injuries [73,74]. A general warming up can be performed via aerobic exercises, such as jogging, cycling on a cycle ergometer and even, performing exercises that mimic

specific gestures used in the respective combat sport to increase athletes' arousal, attention, and likely performance during the subsequent tasks [11]. According to Harmon et al. [71], exercises such as: walking knee hugs, cross-knee hugs, skip series, walking lunges, walking hamstrings and quadriceps stretches, inch worms, high knees, and butt kickers may be conducted to promote general warming up. The same authors recommended that this warm-up method be performed in series of 10 to 20 meters. These authors also emphasized that light loads (~50% of 1RM) can be used to perform specific dynamic warming up of the muscle groups to be targeted during the training session. However, the aspects mentioned above discussed about warming up are not a rule but could be a direction to promote an increased body temperature and prepare the muscles for exercise training. The choice of exercise type, order and training methods will depend on the general and specific cycle or training phase. Muscle soreness is sometimes reported at the beginning phases of strength training due to unfamiliar stress [71]. The scientific literature still investigates the physiological mechanisms involved in muscle soreness; until the moment, it is believed that muscle soreness is related to muscle cells microscopic tears, resulting in the following symptoms: swelling, pain, inflammation, and reduced function with a peak between 48-72h later exercise, varying from individual to individual being associated with *delayed-onset muscle soreness* (DOMS) [71]. Because of this, the load control should be carried out to promote muscle groups' physical recovery and minimize injuries [60].

### 5.5 Reference maximal strength (dynamic and isometric exercises) values in several exercises

Tables (2, 3, and 4) show the values of a maximal repetition (1RM) for bench press, squat, and power clean. These reference tables were elaborated through the results obtained by testing 161 Japanese judo university athletes. According to the tests' load, the classifications sought to distinguish the athletes into categories: very weak, weak, average, good, and very good [75]. Physical trainers can use these values to classify athletes of other combat sports, e.g., Olympic wrestling, since the modality is like judo in terms of physical and physiological demands. Table 2 shows the values of 1 RM for the bench press exercise, as described by Aruga et al. [75].

**Table 2:** One repetition-maximum (1 RM) for bench-press (kg) test of Japanese judo athletes of different weight categories (Aruga et al. [75]).

Category	Very poor	Poor	Regular	Good	Excellent
<60 kg	≤85.0	87.5-90.0	92.5-97.5	100.0-105.0	≥107.5
<66 kg	≤87.5	90.0-97.5	100.0-115.0	117.5-125.0	≥127.5
<73 kg	≤90.0	92.5-100.0	102.5-117.5	120.0-127.5	≥130.0
<81 kg	≤92.5	95.0-105.0	105.0-120.0	122.5-132.5	≥135.0
<90 kg	≤95.0	97.5-107.5	110.0-122.5	125.0-135.0	≥137.5
<100 kg	≤97.5	100.0-110.0	112.5-125.0	125.5-137.5	≥140.0
>100 kg	≤100.0	102.5-120.0	122.5-145.0	147.5-165.0	≥167.5

Table 3 presents the 1 RM squat values of Japanese judo athletes of different weight categories (Aruga et al. [75]).

**Table 3:** One repetition-maximum (1 RM) for squat (kg) test of Japanese judo athletes of different weight categories (Aruga et al. [75]).

Category	Very poor	Poor	Regular	Good	Excellent
<60 kg	≤102.5	105.0-117.5	120.0-135.0	137.5-152.5	≥155.0
<66 kg	≤107.5	110.0-122.5	125.0-142.5	145.0-157.5	≥160.0
<73 kg	≤110.0	112.5-125.0	127.5-145.0	147.5-160.0	≥162.5
<81 kg	≤112.5	115.0-127.5	130.0-150.0	152.5-165.0	≥167.5
<90 kg	≤115.0	117.5-132.5	135.0-165.0	167.5-185.0	≥187.5
<100 kg	≤117.5	120.0-140.0	142.5-172.5	180.0-200.0	≥202.5
>100 kg	≤127.5	130.0-165.0	167.5-200.0	202.5-235.0	≥237.5

Table 4 shows the values of a 1RM for the power clean exercise, as described by Aruga et al. [75].

**Table 4:** One repetition-maximum (1 RM) for power clean (kg) test of Japanese judo athletes of different weight categories (Aruga et al. [75]).

Category	Very poor	Poor	Regular	Good	Excellent
<60 kg	≤57.5	60.0-65.0	67.5-72.5	75.0-80.0	≥82.5
<66 kg	≤60.0	62.5-70.0	72.5-82.5	85.0-92.5	≥95.0
<73 kg	≤62.5	65.0-72.5	75.0-85.0	87.5-95.0	≥97.5
<81 kg	≤67.5	70.0-80.0	82.5-92.5	95.0-105.0	≥107.5
<90 kg	≤70.0	72.5-82.5	85.0-95.0	97.5-107.5	≥110.0
<100 kg	≤72.5	75.0-85.0	87.5-97.5	100.0-110.0	≥112.5
>100 kg	≤75.0	77.5-87.5	90.0-102.5	105.0-115.0	≥117.5

Table 5 shows the values of a 1RM for the bench-press exercise in combat sports athletes in different studies.

**Table 5:** One repetition-maximum (1 RM) for bench-press in different combat sports studies.

Sample	Load (kg)	Author
<b>Wrestling</b>		
Iranian 4x world champion Greco-Roman style (-55kg)	85.00	Mirzaei et al. [76]
Junior Greco-Roman Olympic wrestling Polish team (n=46)	93 ± 19	Starosta et al. [77]
Junior Greco-Roman Olympic wrestling Polish team (n=61)	108 ± 23	Starosta et al. [77]
<b>Brazilian jiu-jitsu</b>		
State-level jiu-jitsu athletes (n=20)	86 ± 18	Costa et al. [78]
State-level jiu-jitsu athletes (n=20)	78 ± 18*	Costa et al. [78]
<b>Judo</b>		
Canadian judo team (n=22)	100 ± 21	Thomas et al. [79]
High-level Finnish judo athletes (n=7)	96 ± 20	Fagerlund and Hakkinen [80]
National level Finnish judo athletes (n=7)	96 ± 12	Fagerlund and Hakkinen [80]
Recreational Finnish judo athletes (n=7)	87 ± 20	Fagerlund and Hakkinen [80]
Brazilian men's team (2002) holders (n=7)	110 ± 25	Franchini et al. [81]
Brazilian men's team (2002) reserves (n=13)	110 ± 23	Franchini et al. [82]
Italian men's Olympic team (2004) (n=6)	160 ± 30	Sbriccoli et al. [82]
Italian women's Olympic team (2004) (n=6)	74 ± 13	Sbriccoli et al. [82]
National level judo athletes	102 ± 10**	Branco et al. [83]
<b>MMA</b>		
Regional level athletes (n=8)	76 ± 11	Del Vecchio and Ferreira [84]
North-American MMA athletes (n=11)	93 ± 8	Schick et al. [85]
<b>Karate</b>		
Brazilian karate team - winners	76 ± 17	Roschel et al. [86]
Brazilian karate team - losers	70 ± 11	Roschel et al. [86]
High-level Japanese athletes (n=7)	87 ± 12	Imamura et al. [87]
Beginner Japanese athletes (n=9)	74 ± 7	Imamura et al. [87]
Brazilian high-level athletes (n=9)	89 ± 19	Loturco et al. [9]
<b>Taekwondo</b>		
Experienced athletes (n=7)	84 ± 24	Toskovic et al. [88]
Beginner athletes (n=7)	86 ± 27	Toskovic et al. [88]
Female experienced athletes (n=7)	37 ± 13	Toskovic et al. [88]
Female beginner athletes (n=7)	36 ± 8	Toskovic et al. [88]
Croatian women's team - medalists (n=6)	56 ± 12***	Markovic et al. [89]
Croatian women's team - medalists - non-medalists (n=6)	48 ± 8***	Markovic et al. [89]

Note: the data are expressed as the mean ± standard deviation; \* = test performed stretching before the one-maximum repetition test; \*\* = unpublished data; \*\*\* = test performed with dumbbells.



Table 6 shows the values of a 1RM for squat exercise in combat sports athletes in different studies.

**Table 6:** One repetition-maximum (1 RM) for squat in different combat sports studies.

Sample	Load (kg)	Author
<b>Wrestling</b>		
Iranian 4x world champion Greco-Roman style (-55kg)	112	Mirzaei et al. [76]
Junior Greco-Roman Olympic wrestling Polish team (n = 46)	112 ± 22	Starosta et al. [77]
Junior Greco-Roman Olympic wrestling Polish team (n = 61)	117 ± 30	Starosta et al. [77]
<b>Judo</b>		
National level Finnish judo athletes (n = 7)	185 ± 25	Fagerlund and Hakkinen [80]
National level Finnish judo athletes (n = 7)	166 ± 32	Fagerlund and Hakkinen [80]
Recreational Finnish judo athletes (n = 7)	140 ± 36	Fagerlund and Hakkinen [80]
Brazilian women's team (2002) holders (n = 7)	104 ± 27	Franchini et al. [81]
Brazilian women's team (2002) reserves (n = 13)	104 ± 18	Franchini et al. [81]
State-level athletes (n = 8)	129 ± 13*	Branco et al. [83]
<b>MMA</b>		
North-American MMA athletes (n=11)	108 ± 8	Schick et al. [85]
<b>Karate</b>		
Brazilian karate team - winners	113 ± 15	Roschel et al. [86]
Brazilian karate team - losers	129 ± 20	Roschel et al. [86]
High-level Japanese athletes (n = 7)	137 ± 12	Imamura et al. [87]
Beginner Japanese athletes (n = 9)	120 ± 13	Imamura et al. [87]
High-level Brazilian athletes (n = 9)	201 ± 31**	Loturco et al. [9]
<b>Taekwondo</b>		
Croatian women's team - medalists (n = 6)	89 ± 18	Markovic et al. [89]
Croatian women's team - medalists – non-medalists (n = 6)	72 ± 15	Markovic et al. [89]
Brazilian team - losers	129 ± 20	Roschel et al. [86]

Note: the data are expressed as the mean ± standard deviation; \* = unpublished data; \*\* = test conducted in the smith machine.

Table 7 shows the values of a 1 RM for power clean, snatch and row exercises in combat sports athletes in different studies.

**Table 7:** One repetition-maximum (1 RM) for power clean, snatch, and row in different combat sports studies.

Sample	Load (kg)	Author
<b>Power clean:</b>		
North-American wrestling athletes (n = 10)		Schmidt et al. [90]
Early season	79 ± 15	
Half the season	76 ± 15	
End of season	80 ± 14	
<b>Snatch:</b>		
Junior Greco-Roman Olympic wrestling Polish team (n=46)	58 ± 8	Starosta et al. [77]
Junior Greco-Roman Olympic wrestling Polish team (n = 61)	63 ± 13	Starosta et al. [77]
<b>Row</b>		
Brazilian men's team (2002) holders (n=7)	116 ± 21	Franchini et al. [81]
Brazilian men's team (2002) holders (2002) reserves (n = 13)	115 ± 24	Franchini et al. [81]
State level judo athletes (n = 8)	104 ± 11*	Branco et al. [83]

Note: the data are expressed as the mean ± standard deviation; \* = unpublished data.

Table 8 shows the maximum repetition (1RM) values for leg-press, deadlift, and leg curl exercises in combat sports athletes in different studies.



**Table 8:** One repetition-maximum (1 RM) for deadlift and leg curl in different combat sports studies.

Sample	Load (kg)	Author
<b>Deadlift</b>		
Italian Olympic judo team (2004)		
Males (n=6)	127 ± 11	Sbriccoli et al. [82]
Females (n=5)	94 ± 6	Sbriccoli et al. [82]
<b>Leg curl</b>		
Italian Olympic judo team (2004)		
Males (n=6)	77 ± 4	Sbriccoli et al. [82]
Females (n=5)	40 ± 4	Sbriccoli et al. [82]

Note: the data are expressed as the mean ± standard deviation.

Table 9 presents the maximal isometric handgrip strength in combat sports athletes in different studies.

**Table 9:** Maximal isometric handgrip strength in different combat sports studies.

Sample	MIHS-R (kgf)	MIHR-L (kgf)	Author
<b>Judo</b>			
Brazilian athletes (n=84)			Brito et al. [78]
Right-handed	58 ± 12	53 ± 11	
Left-handed	54 ± 11	56 ± 10	Franchini et al. [55]
Brazilian cadet-athletes (n=8)			
Before training periodization	38 ± 6	38 ± 5	
After training periodization	47 ± 7	44 ± 7	
Brazilian athletes			Franchini et al. [91]
Elite (n=26)	51 ± 10	49 ± 10	
Non-elite (n=66)	42 ± 11	40 ± 10	Franchini et al. [91]
Brazilian University team 2000 (n=13)			
Experienced Brazilian judo athletes			Franchini et al. [63]
Before linear protocol	51 ± 8	50 ± 8	
After linear protocol	54 ± 7	54 ± 8	
Before undulating protocol	49 ± 6	50 ± 7	
After undulating protocol	50.5 ± 5	52 ± 6	
<b>Jiu-Jitsu</b>			
Experienced athletes (n=14)	52 ± 12	51 ± 12	Silva et al. [92]
Beginner athletes (n=14)	47 ± 6	47 ± 6	Silva et al. [92]
Experienced athletes (n=50)	50 ± 9	47 ± 9	Oliveira et al. [93]
International level athletes (n=11)	44 ± 5	40 ± 4	Andreato et al. [14]
Athletes – different competitive levels (n=35)			Andreato et al. [50]
Blue-belt athletes (n=12)	38 ± 6	32 ± 6	
	(dom. hand)	(dom. hand)	Andreato et al. [51]
	49 ± 6	47 ± 6	
Experienced athletes (n=10)	(dom. hand)	(dom. hand)	Andreato et al. [49]
	53 ± 6	50 ± 9	
Experienced athletes (n=10)	(dom. hand)	(dom. hand)	Andreato et al. [41]
	53 ± 6	50 ± 9	
<b>Wrestling</b>			
American University Athletes (n=18)			Ratamess et al. [94]
<b>Spanish female athletes</b>			
Experienced athletes (≤ 57 kg; n=6)			Pallares et al. [95]
	31 ± 5	30 ± 6	
	(dom. hand)	(dom. hand)	
	27 ± 5	26 ± 4	
Amateur athletes (≤57 kg; n=7)			
	(dom. hand)	(dom. hand)	
	35 ± 6	34 ± 6	
Experienced (≤70 kg; n=7)			
	(dom. hand)	(dom. hand)	
	33 ± 6	30 ± 3	
Amateur athletes (≤70 kg; n=10)			
	(dom. hand)	(dom. hand)	

Note: Data are expressed by mean and ± standard deviation; MIHS-R maximal isometric handgrip strength for right hand; MIHR-L = maximal isometric handgrip strength for left hand. dom. hand = dominant-hand

Table 10 presents an option to classify absolute and relative maximal isometric tests for judo athletes of state, national and international level (n = 102).

**Table 10:** Classification for the absolute and relative maximal isometric tests for male judo athletes based in Branco et al. [96]

	SMIHS		MISHT		MILT		MILBT	
	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)
Very poor	≤ 76	≤ 0.81	≤ 31	≤ 0.34	≤ 109	≤ 1.14	≤ 110	≤ 1.15
Poor	77-83	0.82-0.96	32-35	0.35-0.41	110-123	1.15-1.41	111-130	1.16-1.44
Regular	84-111	0.97-1.51	36-47	0.42-0.62	124-167	1.42-2.0	131-169	1.45-2.15
Good	112-133	1.52-1.79	48-49	0.63-0.73	168-169	2.1-2.5	≥ 170	2.16-2.62
Excellent	≥ 134	≥ 1.80	≥ 50	≥ 0.74	≥ 170	≥ 2.6	≥ 170	≥ 2.63

Note: SMIHS = sum of maximal isometric handgrip strength (right and left hand); MISHT = maximal isometric scapular humeral traction; MILT = maximal isometric lumbar traction; MILBT = maximal isometric lower body traction.

The maximal isometric handgrip strength is frequently measured three times for each hand, alternately, with a 1 min interval between attempts. Athletes are instructed to stay in a standing position, with fully extended elbow and self-selected wrist positions. They are encouraged to produce the greatest possible force during 3–5 s, and measurements are conducted using a dynamometer. Absolute and relative to body mass highest values are registered and considered [97,98]. Therefore, coaches and strength and conditioning professionals with access to a handgrip dynamometer and interested in the maximal isometric handgrip strength can also classify their male adult judo athletes (Table 11) [97]. Table 12 shows maximal isometric handgrip strength from different weight categories based in Franchini et al. [97].

**Table 11:** Maximal isometric handgrip strength classificatory table for male adult judo athletes (n = 406) based in Franchini et al. [97].

	SMIHS		Left hand		Right hand	
	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)
Very poor	≤ 71	≤ 0.92	≤ 36	≤ 0.45	≤ 36	≤ 0.47
Poor	71-85	0.92-1.10	36-41	0.45-0.54	36-43	0.47-0.55
Regular	86-115	1.11-1.48	42-57	0.55-0.73	44-58	0.56-0.75
Good	116-132	1.49-1.68	58-66	0.74-0.85	59-66	0.76-0.84
Excellent	≥ 132	≥ 1.68	≥ 66	≥ 0.85	≥ 66	≥ 0.84

Note: SMIHS = sum of maximal isometric handgrip strength between right and left hand.

**Table 12:** Maximal isometric handgrip strength for male adult judo athletes from different weight categories based in Franchini et al. [97].

	Right hand		Left hand		Sum	
	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)
60 kg (n = 69)	43 ± 7 <sup>a,b,c,d,e,f</sup>	0.73 ± 0.12 <sup>c,d,e,f</sup>	42 ± 8 <sup>a,b,c,d,e,f</sup>	0.70 ± 0.13 <sup>c,d,e,f</sup>	85 ± 15 <sup>a,b,c,d,e,f</sup>	1.43 ± 0.24 <sup>c,d,e,f</sup>
66 kg (n = 73)	48 ± 6 <sup>c,d,e,f</sup>	0.71 ± 0.09 <sup>c,d,e,f</sup>	47 ± 6 <sup>c,d,e,f</sup>	0.70 ± 0.09 <sup>c,d,e,f</sup>	95 ± 11 <sup>c,d,e,f</sup>	1.41 ± 0.07 <sup>c,d,e,f</sup>
73 kg (n = 83)	51 ± 8 <sup>d,f</sup>	0.68 ± 0.11 <sup>d,e,f</sup>	50 ± 8 <sup>d,f</sup>	0.66 ± 0.11 <sup>e,f</sup>	101 ± 16 <sup>d,f</sup>	1.34 ± 0.22 <sup>d,e,f</sup>
81 kg (n = 70)	54 ± 7 <sup>f</sup>	0.65 ± 0.09 <sup>e,f</sup>	52 ± 7 <sup>f</sup>	0.64 ± 0.08 <sup>e,f</sup>	106 ± 13 <sup>f</sup>	1.29 ± 0.16 <sup>e,f</sup>
90 kg (n = 52)	56 ± 8	0.62 ± 0.09 <sup>f</sup>	55 ± 9	0.61 ± 0.10 <sup>f</sup>	111 ± 17	1.23 ± 0.19 <sup>f</sup>
100 kg (n = 29)	56 ± 8	0.56 ± 0.08	54 ± 8 <sup>f</sup>	0.54 ± 0.08	110 ± 15	1.10 ± 0.15
> 100 kg (n = 30)	61 ± 11	0.49 ± 0.09	60 ± 11	0.49 ± 0.09	121 ± 20	0.98 ± 0.17

Note: the values are presented as mean ± standard deviation; kgf = kilogram-force; a = different from 66 kg (p<0.05); b = different from 73 kg (p<0.05); c = different from 81 kg (p<0.05); d = different from 90 kg (p<0.05); e = different from 100 kg (p<0.05); f = different from > 100 kg (p<0.05).

Table 13 shows the maximal isometric handgrip strength for male judo athletes from different age groups based in Franchini et al. [98].

**Table 13:** Maximal isometric handgrip strength for male judo athletes from different age groups based in Franchini et al. [98].

	Right hand		Left hand		Sum	
	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)	Absolute (kgf)	Relative (kgf/kg)
Cadet (n = 58)	41 ± 11 <sup>a,b,c,d,e</sup>	0.64 ± 0.13	40 ± 11 <sup>a,b,c,d,e</sup>	0.62 ± 0.14	81 ± 22 <sup>a,b,c,d,e</sup>	1.25 ± 0.26
Junior (n = 113)	51 ± 9	0.67 ± 0.11	49 ± 10	0.64 ± 0.11	99 ± 19	1.31 ± 0.22
Senior (n = 220)	51 ± 10	0.65 ± 0.11	50 ± 10	0.64 ± 0.12	102 ± 19	1.29 ± 0.22
Master 30-39 years (n = 108)	53 ± 8	0.64 ± 0.14	54 ± 8 <sup>a,b</sup>	0.65 ± 0.14	107 ± 16 <sup>a</sup>	1.29 ± 0.27
Master 40-49 years (n = 31)	50 ± 8	0.63 ± 0.11	54 ± 8	0.68 ± 0.14	104 ± 14	1.31 ± 0.23
Master 50-59 years (n = 16)	51 ± 7	0.64 ± 0.09	54 ± 6	0.68 ± 0.11	105 ± 12	1.32 ± 0.18

Note: the values are presented as mean ± standard deviation; kgf = kilogram-force; a = different from junior ( $p < 0.05$ ); b = different from senior ( $p < 0.05$ ); c = different from master 30-39 ( $p < 0.05$ ); d = different from master 40-49 ( $p < 0.05$ ); e = different from master 50-59 ( $p < 0.05$ ).

## 6. Training prescription

Training sessions that involve 1 to 5 repetitions of 90 to 100% of 1 RM are indicated for a maximal strength increase and can be a relevant strategy for athletes who are at the limit of their respective weight categories, as this method is not associated with an increased muscle cross-sectional area (hypertrophy). However, when the athlete is below the limit of their respective category, the performance of 8 to 12 repetitions between 60 to 85% of 1 RM is recommended to obtain hypertrophy, increasing the cross-sectional muscle area [1,19,99,100]. It is worth mentioning that the work of maximal strength and muscle hypertrophy must be performed on a stable surface, i.e., on the ground, benches, or appliances. Considering that instability leads to an increase in the work of the antagonist muscles, a decrease in strength production, and a lower activation of the muscles that perform the movement/exercise are not a desired training goal [101].

Working with free weights and bars is more suitable for athletes' training. These exercises' execution involves multi-articular actions requiring greater motor coordination, stabilizing and synergistic muscle actions, and developing inter and intramuscular coordination [99]. We highlight several limitations regarding the exercises conducted in machines: limiting the exercises' amplitude and smaller muscles' restricted work, restricting stabilizing and synergistic muscles. However, the machines may be used when there is a need to isolate specific muscles and rehabilitation processes and correct muscular imbalance [99,100].

In turn, Franchini and Del Vecchio [11] emphasize that strength training should be directed to the movements, gestures, actions, and movements performed during the matches. Therefore, the training prescription should be required for each specific athlete to correct any shortcomings, i.e., the "weaker" muscles' work to improve performance during training and competitions.

Besides, strength training may help increase muscle strength, increase total body mass (when possible), reduce the risk of sports injuries, and strengthen core muscles, e.g., rectus abdominal, transverse abdominal, internal and external abdominal obliques, as well as lumbar and gluteus muscles. However, the transfer of non-specific strength training to athletic performance may be limited to athletes. Therefore, training should be as specific as possible, especially about the pattern of movement and speed of muscle contraction to improve inter-muscle coordination and muscle synchronization with the required movement pattern in the modality [102].

### 6.1 Considerations for training muscle hypertrophy

According to Kraemer [103], muscle hypertrophy is a complex physiological, biochemical, and immunological process related to the repair and remodeling of muscle fibers' different mechanisms. Moreover, during resistance training, the muscle fibers are stimulated by motor units' recruitment. The same author points out that muscle mass growth is associated with muscle tissue damage resulting from external stimulus, following inflammation and actions of cytokines and other immune cells' responses. Muscle hypertrophy occurs by increasing protein synthesis and decreasing protein breakage. Thus, a positive protein balance promotes muscular hypertrophy [33]. It is essential to highlight that protein synthesis is related to the level of training of athletes/practitioners, i.e., a higher level of training results in less muscle damage caused by the exercise. Scientific evidence has also indicated that protein synthesis begins 4 hours after training in muscle hypertrophy [1]; nonetheless, 16 training sessions for each muscle group, on average, are necessary so that the results are detectable [104]. Nevertheless, for more satisfactory results, training directed to hypertrophy must be maintained for more than 8 uninterrupted weeks [27]. Thus, the main recommendations for the training conducted to muscle hypertrophy to be more effective are as follows:

The performance of exercises that include large muscle masses (Olympic weightlifting exercises, squat, deadlift, row, and bench press, among others) at the beginning of the training; as these exercises stimulate acute increases in the total circulating testosterone concentrations and because the training of smaller muscle groups at the beginning of training may result in a decreased performance in exercises with large muscle groups [27]. Another justification for this order is that multi-articular exercises require more neural demand and more intense, resulting in greater total energy expenditure than smaller exercises performed isolated [33]. Besides, exercising larger muscle groups first provides greater stimulation for all muscles involved in training and may provide a greater potential for remodeling the muscle tissue [70];

The control of the recovery time (pause) between sets and exercises should be continuously monitored for performance maintenance [105] (if it is the purpose of training), as well as for maximizing hormonal responses during training. As a result, research has indicated that pauses less than 60 s favored lactate accumulation, associated with increased growth hormone secretion (GH) after training sessions [70,106–110].

Studies have also indicated that the pause of 60 s between sets tripled GH release after 30 min of training [108]. Moreover, a break of less than 120 s between sets was more effective for testosterone release during strength training [108,112]. Scientific evidence has shown that shorter intervals (less than 60 s) are more useful for anabolic promotion during training sessions directed to muscle hypertrophy [111];

Endocrine responses (hormone release) to hypertrophy training are dependent on the number of sets, repetitions, intervals, exercises, and muscle groups involved in the training [109,112,113]. Therefore, the training session should not exceed 1 hour since longer sessions can minimize the strength gain [114];

The rest interval of 48 hours for the same muscular group should be incorporated since this period is needed to repair and grow the contractile proteins. Thus, two or three weekly sessions per muscle group are satisfactory for the muscle hypertrophy development [115];

The incorporation of the eccentric work is relevant since, in this type of movement, there is an increase in muscular micro-damage incidence, which after the recovery period favors the increase of muscular hypertrophy [116]. Thus, incorporating strategies to increase the overload during the eccentric phase may be used to maximize muscle demand and favor eccentric work;

The training programs must be continuously modified to avoid stagnation of the stimuli resulting from training; that is, every 2-3 weeks of uninterrupted training, the stimuli must be changed [11];

The use of exercises for the same muscle group that contemplates different portions of the same musculature should be proposed for the recruitment and activation of available contractile tissue [1];

External aid can be an essential tool to overcome the point of greatest mechanical limitation in certain exercises, for example, the initial concentric phase of the bench press or arm-curl [117];

The addition of 2 to 10% of the total exercise load when the practitioner or athlete can perform one or two repetitions above the established load should be considered [70];

While detraining, the human body maintains part of the muscle hypertrophy program's adaptation for up to 32 weeks [1].

In the professional intervention, several training models are used to promote hypertrophy, such as: pyramidal, super-slow, paired-set, accentuated eccentric, pre-exhaustion, rest-pause, drop-set, among others [118]. According to these authors, the scientific literature does not show significant muscle hypertrophy differences between training methods. The same research group published an experimental study comparing the effects of crescent pyramid, drop-set systems, and traditional resistance training equalized by total training volume on physical and physiological variables in well-trained men [119]. The following variables were analyzed before and after 12 training weeks: 1 RM, cross-sectional muscle area (CSA), pennation angle (PA), and fascicle length (FL). The results showed a leg-press 1 RM improvement: for crescent pyramid with 16.4%, drop set system with 17.1%, and traditional training with 16.6%; a CSA improvement: for crescent pyramid with 7.5%, drop set system with 7.8%, and traditional training with 7.6%; a PA improvement: for crescent pyramid with 11.0%, drop set system with 10.3%, and traditional training with 10.6%; and a FL improvement: for crescent pyramid with 8.9%, drop set system with 9.1%, and traditional training with 8.9%. Thus, the authors concluded that the physical and physiological responses were similar when the total training volume was equalized. These responses suggest that muscle hypertrophy's central point is the total training volume per session and not the training method chosen. In table 14, we present the recommendations for the training directed to promote muscle hypertrophy for different groups according to Wernbom et al. [100].

**Table 14:** Recommendations for the training directed to promote muscle hypertrophy for different groups according to the recommendations of Wernbom et al. [100].

	<b>Moderate load slow-speed training</b>	<b>Conventional hypertrophy training</b>	<b>Eccentric (ecc) overload training</b>
Muscle action	Concentric and eccentric	Concentric and eccentric	Eccentric (concentric = optional)
Exercise	Single and/or multiple joint	Single and/or multiple joint	Single and/or multiple joint
Load	~50% of 1RM	8-10 RM (range 6-12) ~75-80% of 1RM	Eccentric = > 105% of 1RM Concentric = 60-75% of 1RM
Repetitions	8-14 to muscular failure	8-10 to muscular failure or near	4-6
Sets	1-3 per exercise. Progression from 1 to 3-4 sets in total per muscle group	Progression from 1-2 to 3-6 sets in total per muscle group	Progression from 1-2 to 3-5 sets in total per muscle group
Velocity and duration per repetition	Slow Eccentric = 2-3 seconds Concentric = 2-3 seconds	Moderate Eccentric = 1-2 seconds Concentric = 1-2 seconds	Slow/moderate Eccentric = 2-4 seconds Concentric = 1-2 seconds
Rest between sets	30-60 seconds	60-180 seconds	120-180 seconds
Frequency	2-3 sessions per muscle group/week	2-3 sessions per muscle group/week	1-3 sessions per muscle group/week
Comments	Suitable training method for beginners and individuals who cannot tolerate high forces	These recommendations are for novice to moderately trained individuals. Well trained athletes may need increased variation in intensity and volume	Mainly for advanced to elite athletes. Progressive but careful increase of the load and volume for the eccentric phase

The training programs must be continuously modified to avoid stagnation of the stimuli resulting from training; that is, every 2-3 weeks of uninterrupted training, the stimuli must be changed [11];

### *6.2 Considerations for maximal strength training*

Recommendations for maximal strength training should be directed at individuals at the upper limit of their respective weight categories. Thus, the primary suggestions for maximum strength training to be more effective are as follows:

Maximal strength training for the beginner or untrained practitioners should be performed 2-3 times a week on alternate days [33,114,115];

For moderately trained practitioners, training is indicated 3-4 times a week, with a greater volume, intensity, and diversity of exercises than those for beginners or non-trained [33,115];

For athletes, each muscle group should be worked, on average, twice per week, with a greater volume and intensity than for moderately trained practitioners. Emphasis should be placed on the exercises related to the specificity of the combat sport [11];

The period of the training session should be approximately 45-60 min [114];

From a physiological point of view, the optimal recovery time between sets should be 3-5 min [110]; however, authors suggest the adoption of 5-8 min for complete recovery in multi-articular exercises, such as Olympic weightlifting exercises [120];

Strategies such as using the circuit training method may reduce the session time to enable an ideal training volume [120]. Also, the circuit training method promoted increased activation of the cardiovascular system (71% of maximal heart rate), while the conventional strength training method promoted lower cardiovascular activation (62% of maximum heart rate) [121];

The use of 3 to 6 sets of 3-5 rep with loads equal to or greater than 85% of 1 RM are indicated for maximum strength training [122], and evidence also suggests that percentages between 90 and 95% of 1 RM can be used for maximum strength development [123]. The inclusion of training with 100% of 1 RM is also indicated, but to a lesser extent, and is dependent on the periodization model adopted [1,114];

The interval between training sessions for the trained muscle groups should be 72 hours [105];

External aid should be a valuable tool to overcome the point of greatest mechanical limitation, particularly in maximal strength exercises [117];

As discussed in the topic of muscular hypertrophy, exercises of large muscle groups should be performed at the beginning of the training session because fatigue generated by the activation of several muscles (such as in multi-articular exercises) can jeopardize the safety of its execution [99];

From two weeks of detraining, maximum strength reductions occur in previously untrained individuals (10 to 20%). However, in highly trained athletes, this variation is lower [1] (approximately 5%);

Studies have also indicated that the correct distribution of the training volume in the intensively strength/hypertrophy program, e.g., two daily sessions, can provide better hypertrophy and strength development conditions during short periods of intervention (3 weeks) [103-105,120-123].

### *6.3 Maximal isometric strength*

The maximal isometric strength is angle-dependent; that is, it occurs mainly at the angle that the stimulus is being performed [3,27,104,117]. The maximal isometric strength training may favor the mechanical point of least strength in particular exercises during eccentric and concentric dynamic actions [122-125], especially in very high loads and close to the maximum [126]. Studies have also indicated that isometric strength differs according to exercise angles used [127]. Therefore,

isometric actions should be performed at 10 to 20 degrees during the entire exercise range to transfer the dynamic activities [27].

It is recommended to use the following aspects for isometric training [117]: 1) The most vital angles of the exercises or movements should be trained; 2) The repetitions should be performed every 10 or 20<sup>o</sup> or with the extended muscle; 3) The isometric stimulus is between 3 and 10 s; 4) 15 to 20 actions are performed per training session, and external assistance is indicated for the safe accomplishment of isometric training [114-116].

Specific isometric exercises should stimulate the demand for each combat sport. For judo and jiu-jitsu, some exercises are indicated, such as handgrip with extended elbow (15 to 20 repetitions of 3 to 5 s at 100%) and support at the bar holding the gi with an external overload to induce fatigue in up to 10 s (following the previous recommendations). In Olympic wrestling, exercises such as the bear hug, using between 15 and 20 repetitions at 100% [120], are recommended for maximal isometric strength training.

### 7.Exercise prescription for grappling, striking, and mixed martial arts

The following body regions and exercises are indicated for combat sports athletes that can be performed with bars, cables, accessories, and dumbbells simultaneously and unilaterally [1,11,18,22,117,126–138].

- ✓ Multi-articular groups: weight-lifting exercises, such as power clean, hang clean, clean and jerk, jump shrug, snatch, military press, push-press;
- ✓ Back: bent-over row, pull-ups, seated high row, lying row, seated high row, smith bent-over row and straight back;
- ✓ Pectorals: bench press, chest dip, decline chest press and incline bench press;
- ✓ Upper-limbs: arm curl, triceps extension, pulley triceps, and triceps dip.
- ✓ Forearm\*: reverse curl, barbell wrist curl, cable roller wrist flexion, kimono or judogi chin-up (isometric and/or exercises with overload) \* = exercises indicated for the grappling combat sports and MMA;
- ✓ Erectors of the spine: good morning, barbell deadlift, Romanian deadlift and barbell back extension (on hyperextension apparatus);
- ✓ Anterior thigh: front and back squat, half-squat, lunges, lateral lunges, leg-press, and leg extension.
- ✓ Back of thigh: stiff, leg curl and leg-press (with angle adjustment);
- ✓ Back of the leg: standing calf raise in the Smith machine;
- ✓ Abdomen: barbell push sit-up or with medicine-ball, weighted crunch, front plank or/and lateral plank;
- ✓ Neck\*: neck flexion, neck rotation, weighted lying neck flexion, front neck bridge, wall front neck bridge, and wall side neck bridge; \* = grappling modalities and MMA.

The prescription of maximal strength training and muscular hypertrophy can include the characteristics described by Bird et al. [70], i.e., the proper program design needs to consider some points highlighted:

- *Acute program variables*: muscle action, rest periods, loading and volume, repetition velocity, exercise selection and order, and frequency;
- *Key training principles*: overload, specificity, progression, individualization, adaptation, and maintenance.

Specific training outcome:

- *Muscular endurance*: eccentric and concentric exercises, with 1-3 sets x 15-20 RM, using single and multi-joint exercises, varying exercises order, with 30-60 s of rest, and performed 2-3 times a week;



- *Hypertrophy training*: eccentric, concentric, and isometric exercises, with 4-6 sets x 8-15 RM, using single and multi-joint exercises, large to small muscle groups, with 1-2 min of rest, and conducted 3-5 times a week;
- *Maximal strength*: eccentric, concentric, and isometric exercises, with 3-5 sets x 1-3 RM, using single and multi-joint exercises, large to small muscle groups, with 3-5 min of rest, and performed 3-5 times a week;
- *Power training*: eccentric and concentric exercises, 3-5 sets x 6-8 RM, multi-joint exercises, large to small muscle groups, with 5-8 min of rest, and performed 4-6 times a week. The training details about muscular endurance and power training are discussed in the specific chapters about these contents.

## 8. Final consideration

It is important to emphasize that maximum strength training is essential for improving the subsequent phases of training periodization or training planning, such as muscle power and strength-endurance. Therefore, maximum strength should be included in the athletes' training process. The method can also be used for athletes in the upper limit of their respective weight categories since it is possible to increase the maximum strength without promoting muscle hypertrophy. Undoubtedly, maximum strength training should be prescribed based on each athlete's characteristics and needs; that is, the biological individuality should be considered and respected. It is emphasized that maximum strength training is established as a viable method to maximize athletes' performance in various sports. Nevertheless, acute and chronic studies that contemplate different strength training methods for combat sports athletes remain incipient. From this perspective, conducting studies seeking to consider different combat sports training methods is critical. Hypertrophy training is also used during training routines, considering the main muscle groups requested during combat in a given weight category, and physical assessment tests' responses (i.e., whether the athlete is above the weight category limit change his/her weight category). Finally, it is emphasized that training and monitoring should be analyzed and incorporated in the training routine based on the athletes and technical commission and staff available resources.

## Conflict of interest

None declare.

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