

## CHAPTER 5

# Developing strength-endurance for combat sports athletes

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### Abstract

Strength-endurance is one of the trainable physical capacities that could determine the success in some combat sports and its inclusion is obligatory in the training periodization of high-level athletes. In striking combat sports, such as boxing and taekwondo, it seems likely that increases in dynamic strength-endurance improve the ability to execute combat movements repeatedly. On the other hand, grapplers need to develop high levels of strength-endurance because during the match much time is spent in grip dispute and the success in this phase may determine the possibility to execute scoring techniques. Furthermore, in mixed combat sports, where a combination of striking and grappling are required, athletes need to have the capacity to maintain dynamic or static muscular actions during prolonged periods during the match, and the strength-endurance is one key element. Therefore, this chapter presents the strength-endurance requirements during the match, the specific tests for its evaluation, scientific evidence of longitudinal studies on the development of strength-endurance in combat sports athletes and the methods for its development.

**Keywords:** Martial arts; combat sports; muscular endurance; training; performance; core zone.

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## 1. Introduction

Strength-endurance is one of the trainable physical capacities pertaining to the necessary requirements for the sports performance, and its inclusion is obligatory in the training periodization of high-level athletes [1]. Strength-endurance is characterized by the ability of the individual to perform a certain number of repetitions of an exercise or a technical gesture during a certain period or until the failure, by the time of maintenance of a certain movement in the same prescribed rhythm and with the same efficiency [2], or by the ability to develop strength for a prolonged period and maintain a high-intensity muscular effort between thirty seconds and two minutes [3].

For Martin et al. [4], strength-endurance performance depends on two fundamental characteristics, which would be the maximum force - related to the domain of a particular load and the duration of the domain of this load - that would depend on the performance of the metabolism of the musculature in terms of energy transfer. Thus, the longer the tension time with a certain load that promotes the increase in muscle fatigue, the better the gains in relation to strength-endurance due to the great metabolic mobilization [5].

Each sport has its particularities that determine the types of strength that are most required. In countless sports, strength-endurance is one of the physical capacities that determine success, as in the case of some combat sports, especially those of grappling [6].

In striking combat sports, as in the case of boxing, it seems likely that increases in dynamic strength-endurance improve the boxer's ability to execute combat movements repeatedly, such as, for example, the direct and the cross, which are attack movements, influencing the number of hits made, and consequently the score of points in favor of the attacker [7,8].

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In judo, a grappling combat sport, which intends to keep the opponent under control, dominating the distance between them, and thus throw the opponent down, the athletes need a combination of maximum strength and strength-endurance during the match. In fact, strength-endurance differences, with the objective of performing the movements of pulling and pushing more effectively, can influence and be potential predictors of performance in judo [9].

On the other hand, for wrestlers who execute grappling techniques like the clinch (i.e., control of the adversary's neck and head using the arms), such measures can provide useful information in relation to individual performance parameters [3], both in Greco-Roman and freestyle [10,11].

In mixed combat sports, such as mixed martial arts (MMA), where striking techniques are used with arms and legs, and predominantly with the upper body, the ability to maintain dynamic or static muscular actions for prolonged periods during a combat resisting to the fatigue is also a relevant physiological characteristic, and it is desirable that the athlete presents high levels of strength-endurance for success in this modality [12].

Therefore, in this chapter, we will discuss strength-endurance and its application, the responses of this variable during the matches, the specific tests for its evaluation, the scientific evidence of longitudinal studies on the development of strength-endurance in combat sports athletes and the methods for its development.

## 2. Strength-endurance response during striking and grappling matches

Knowing the response of a certain physical capacity, whether neuromuscular or metabolic, during a simulated match or a competition is important to identify the athlete's behavior and determine its degree of influence on the success of the modalities. Therefore, based on its determination, coaches and/or physical trainers can periodize the training more consistently.

### 2.1. Striking Combat Sports

In simulated matches (S) or official competition (O), karate athletes use upper body ( $S = 73.2 \pm 24.4\%$ ;  $O = 73.2 \pm 19.6\%$ ) and lower body ( $S = 26.8 \pm 19.6\%$ ;  $O = 26.8 \pm 24.4\%$ ) to attack and counter-attack. Both attack and counter-attack actions are mainly executed with the upper body (Table 1) [13].

**Table 1:** Percentage of upper and lower body karate techniques according to karate combat conditions (adapted from Chaabène *et al.* [13]).

Situation		Attack (%)	Counter-attack (%)
Simulated condition	Upper body	54.6 ± 28.9	84.9 ± 26.6
	Lower body	45.4 ± 28.9	15.1 ± 26.6
Official condition	Upper body	63.1 ± 23.7*	82.7 ± 32.8
	Lower body	36.9 ± 23.7	17.3 ± 32.8

\*= significantly different ( $P < 0.05$ ) from simulated combat condition; the values are presented as mean ± standard deviation.

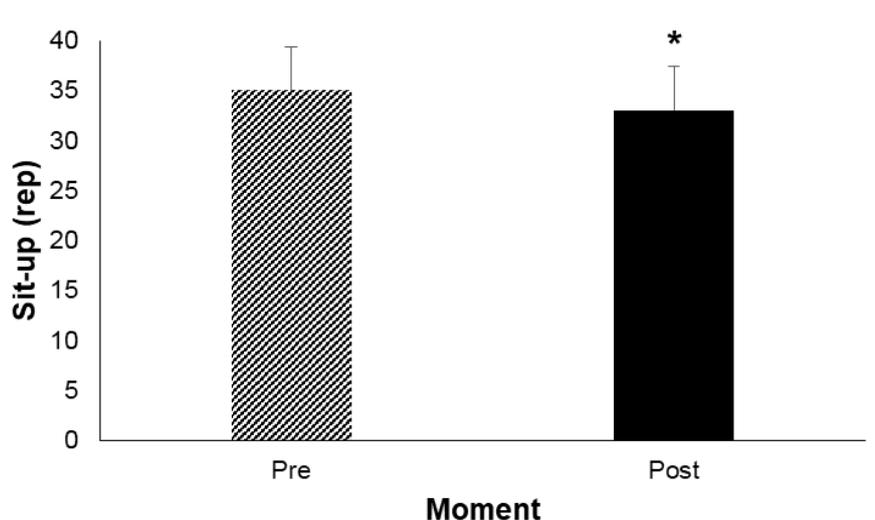
However, regardless of the predominance of the upper body for these actions, when evaluating the rating of perceived exertion in specific areas of the body (LRPE), Chaabène *et al.* [13] identified that after simulated and competition match conditions, karate athletes presented greater perceived effort in the lower-body (Table 2), suggesting that the musculature of this region was more requested during the combat in terms of strength-endurance, and that the training should be aimed at improving these muscle groups with the goal of delaying fatigue and allowing the athletes to perform combats with a better performance.

In a study conducted with Muay-Thai athletes to identify the acute effects of a combat on general strength indicators, Mortatti *et al.* [14] identified that after a ten 3-min rounds match, with rest intervals of 1 minute between rounds, the athletes had a reduction in the ability to execute sit-ups in 30s (Figure 1).

**Table 2:** Local of higher rating of perceived exertion in simulated and official competition conditions (adapted from Chaabène *et al.* [13]).

	Muscle	LRPE-S (%)	LRPE-O (%)
Upper body	Deltoid	4.76	0
	Triceps	9.52	0
	Biceps	9.52	7.69
	Forearms	4.76	0
Lower body	Quadriceps	23.81	30.77
	Hamstrings	19.05	23.08
	Triceps sural	28.57	30.77

LRPE = local rating of perceived exertion; S = simulated condition; O = official condition.



\* = significantly different ( $P < 0.05$ ) de pre-match.

**Figure 1:** Repetitions in a sit-up test before and after a Muay-Thai match (adapted from Mortatti *et al.* [14]).

## 2.2. Grappling Combat Sports

In wrestling, pulling, pushing and stabilizing the opponent using the upper body and trunk, as well as lifting the opponent using the legs are movements that occur regularly during a match [15]. Therefore, all the attack actions used in the Greco-Roman and freestyle wrestling are preceded by the control of the adversary, by means of control of support points to execute the throwing techniques (e.g., upper-body, head, waist, lower-body), resulting in a high demand for upper-body and trunk muscle groups strength-endurance [16,17].

In fact, these motor actions performed repeatedly during a combat or in a competition can promote a certain degree of fatigue and affect strength-endurance capabilities, as demonstrated by Nilsson *et al.* [18], in reporting fatigue in specific muscles perceived by the athletes who participated in the Greco-Roman Wrestling World Championship, which was especially high in the anterior region of the forearm and in the anterior deltoid.

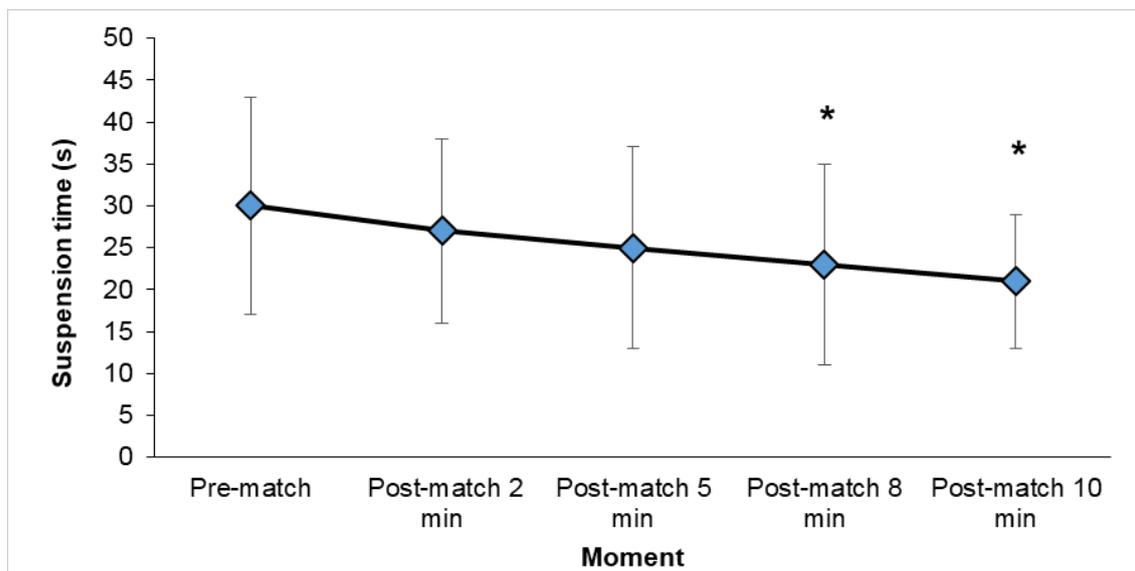
In a judo match, the actions can be developed both in standing (*tachi-waza*) combat and on the ground (*ne-waza*). Most of the match time during stand actions is spent in grip dispute ( $14 \pm 15$ s), corresponding to 58% of the standing combat time and 28% of the total combat time - including the pauses - [19], which requires a great upper-body isometric and dynamic strength-endurance with an emphasis on the forearm muscles [20]. In addition, immobilization actions on the ground also require this capacity [21].

In order to verify the effects of judo matches with different durations (1, 2, 3, 4 and 5 min) on upper-body dynamic strength-endurance, Julio *et al.* [22] assessed twelve male judo athletes who performed the dynamic strength-endurance judogi chin-up test before and 6 minutes after each match. The results demonstrated that upper-body strength-endurance was reduced after match

when compared with pre-match values. However, there was no effect of match duration on upper-body strength-endurance.

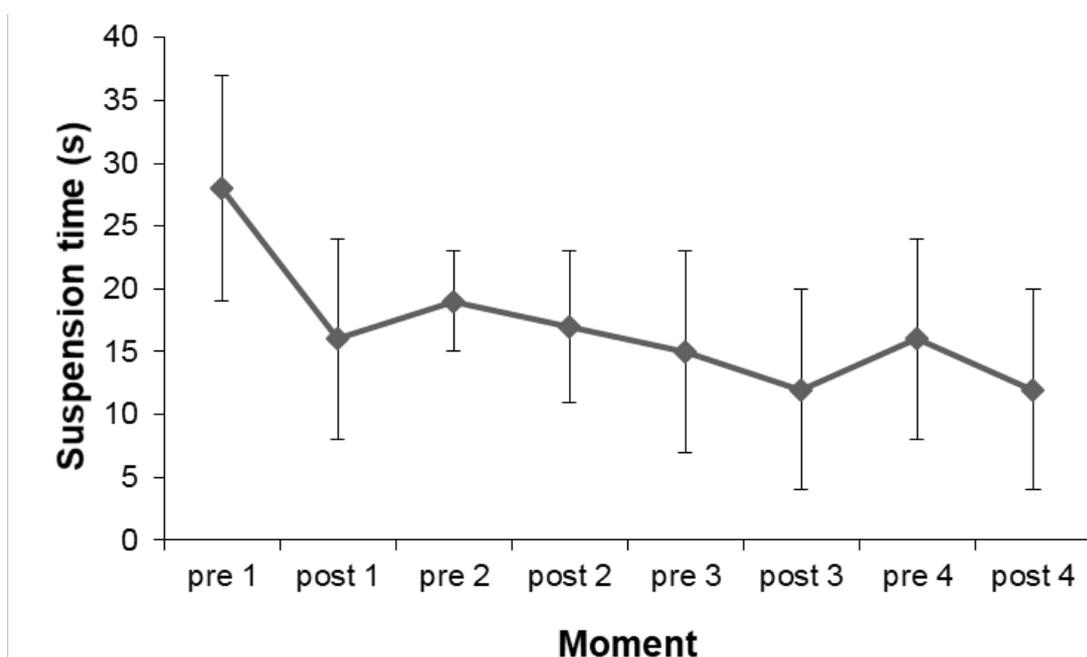
Moreover, Kons et al. [23] revealed that medalists and non-medalists in an official tournament did not differ concerning the rating of perceived local exertion, but both groups reported higher values for upper-body compared to lower-body. Medal winners reported the fingers, abdomen and anterior tibia as the most cited areas, whereas non-medalists reported the forearms and fingers as the most cited areas presenting muscle fatigue after the matches.

Investigations conducted with Brazilian jiu-jitsu athletes analyzed the isometric strength-endurance response in Brazilian jiu-jitsu matches with varied durations (2, 5, 8 and 10 minutes) [24], and in simulated competition [25]. In matches lasting 8 and 10 min, isometric strength-endurance post-match decreased when compared to pre-match (Figure 2). Differently, in simulated competition there were no significant differences for the values pre and post-matches (Figure 3).



Pre-match: values mean of pre-match of 2, 5, 8, and 10 min matches. \* Significantly different from pre-match ( $P < 0.05$ ).

**Figure 2:** Suspension time in the kimono grip isometric strength-endurance test before and after Brazilian jiu-jitsu matches with varied durations (adapted from Andreato et al. [24]).



**Figure 3:** Suspension time in the kimono grip isometric strength-endurance test during a simulated Brazilian jiu-jitsu competition (adapted from Andreato et al. [25]).

When the upper-body isometric strength-endurance response after a 10-min duration Brazilian jiu-jitsu match simulation was examined, Silva et al. [26] found a decrease in upper-body strength-endurance performance in the suspension time in the kimono grip isometric strength-endurance test (pre=  $65.5 \pm 16.78$  s; post =  $49.75 \pm 15.01$  s).

Detanico et al. [27] analyzed the effect of a Brazilian jiu-jitsu simulated tournament on strength parameters. Twenty-two non-advanced male Brazilian jiu-jitsu athletes participated in a simulated tournament consisting of three 7-min matches separated by 14 min of passive rest. Athletes showed a significant reduction in the number of repetitions in the kimono grip dynamic strength-endurance test (pre-match =  $11 \pm 4$  rep.; post-match 1 =  $8 \pm 4$  rep.; post-match 2 =  $7 \pm 3$  rep.; post-match 3 =  $7 \pm 3$  rep.). Authors concluded that a simulation of a Brazilian jiu-jitsu tournament generated a decrease in upper-body strength-endurance performance.

No studies were found that examined the influence of a MMA match on strength-endurance performance.

### 3. Test for strength-endurance assessment in combat sports athletes

The characterization of the physical fitness of an athlete, the evaluation of the effects of a training period on a given physical capacity or even the classification of athletes by their level of sporting excellence (e.g., elite or non-elite), can be done through the application of physical tests, and the more specific to the reality of combat sports are the protocols, the more reliable will be the evaluation of the combat sports athletes. Although there are specific tests for some combat sports, no indexed publications were found that report specific tests for mixed modalities. In any case, given the characteristics of these modalities, it is possible to adopt the proposed tests for grappling and striking combat sports to mixed combat sports.

#### 3.1. Striking combat sports

A battery of tests to evaluate the physical fitness of male Kyokushin karate athletes was proposed by Sterkowicz and Franchini [28]. Among the different tests presented, for the purpose of evaluating upper-body strength-endurance, clapping hand push-ups in the concentric phase of the movement was used.

As clinch occurs frequently during matches in this modality, the authors presented these specific fighting situations to justify the use of a test that assesses the local muscular endurance and established some reference points (Table 3), considering the number of repetitions performed frequently in the test. These values could be used to compare the individual performance of an athlete or to make comparisons between athletes.

**Table 3:** Performance classification according to clapping hands push-ups (adapted from Sterkowicz and Franchini [28]).

Classification	Push-ups (n)
Excellent	$\geq 44$
Good	31-43
Regular	25-30
Poor	10-24
Very poor	$\leq 9$

Taekwondo can be distinguished from other combat sports since its main focus is the kicking techniques, so during a match, numerous strikes are carried out with the legs against the thorax and the head of the opponents, which implies explosive movements like jumps and turns with changes of direction. The kicks correspond to 100% of all the techniques that were used to score points in an Olympic competition [29], and this can contribute to the appearance of fatigue in the lower extremities due to the number of strikes that are carried out during the match, influencing thus the sport performance [30]. It is important to note that after the introduction of the electronic body protector, some points have been obtained through punching techniques.

However, although the main focus is on the lower extremities due to the ability to apply kicks, studies can be found in the literature that attempted to analyze both upper-body and abdominal muscles strength-endurance, since athletes can use the upper-body to execute punches against the trunk of the opponent, and mainly to defend themselves, avoiding that the opponent scores. In this way, trunk muscles are involved in various taekwondo movements, such as turning kicks, and in the absorption and assimilation of the impact suffered in the trunk by the strikes received during combat [31].

For example, in order to evaluate the strength-endurance of female Croatian taekwondo athletes, and compare them to each other, based on sports success, Markovic et al. [32] evaluated 13 athletes divided into two groups using push-ups and sit-ups in 60 s tests. The authors did not find any significant differences between the groups for both tests and suggested that upper-body muscle endurance seems to be of less importance for taekwondo performance, but that abdominal strength-endurance may be of some importance.

In another study, which aimed to evaluate and compare Malaysian taekwondo athletes' motor skills in the junior ( $n = 10$ ) and adult categories ( $n = 10$ ), Suzana and Pieter [33] did not identify any differences in the number of repetitions in the 60s sit-up test between athletes in the adult and those in the junior categories.

Although these tests are general and not combat-specific, this protocol of assessment for upper extremities and trunk seems to have a good acceptance by investigators as a method to analyze strength-endurance of taekwondo athletes, since similarly, it was adopted by Antunez et al. [34] to evaluate high-level athletes, which corroborates the findings of Markovic et al. [32] because these authors concluded that elite taekwondo athletes have well-developed abdominal endurance. Table 4 shows some of these results.

**Table 4:** Strength-endurance in push-up and sit-up tests in taekwondo athletes (the values are presented as mean  $\pm$  standard deviation or mean and amplitude).

Study		Push-up (rep in 60s)	Sit-up (rep in 60s)
Markovic <i>et al.</i> [32]	Elite (Female; n=6)	25.8 $\pm$ 8.5	58.7 $\pm$ 7.0
	No elite (Female; n=7)	23.1 $\pm$ 7.7	52.2 $\pm$ 3.5
Antunez <i>et al.</i> [34]	(Male; n=7)	60.57 $\pm$ 13	54.14 $\pm$ 5.24
Suzana and Pieter [33]	Junior (Male; n=10)	—	39.50 (36.75 – 43.00)
	Adult (Male; n=10)	—	33.50 (29.50 – 40.25)

In an attempt to assess the lower-body fatigue index of taekwondo athletes, Valente et al. [30] used a test based on the analysis of vertical jumps, which had as protocol the execution of 4 sets of 15s of intermittent jumps in a contact platform. Based on the literature, the authors of this study suggested that the measurement of vertical jump height is of great interest, since with this measure the fatigue index can be estimated, and from the time of flight and the number of jumps made in a certain set in a time interval, it is possible to obtain the degree of reduction of the strength-endurance capacity and the maintenance of sports performance.

The equations used to evaluate the performance in the test are proposed by Bosco et al. [35] and are described below:

$$MP = (g^2 \cdot Tt \cdot 15) / (4 \cdot n) \cdot (15 - Tt)$$

Where, MP = Mean power output (W/kg);  $g$  = Gravity acceleration ( $9,81\text{m/s}^2$ );  $Tt$  = Total flight time (ms); and  $n$  = Number of jumps.

$$FI = PP (45-60) / PP (0-15)$$

Where, FI = Fatigue index (%); PP (45-60) = Average power output in the last set of 15s (W/kg); and PP (0-15) = Average power output in the first set of 15s (W/kg).

The authors identified a high fatigue index ( $FI = 81 \pm 12\%$ ) in the test. However, they suggested that since the maximum intensity of effort during the 4 sets of 15s of jumps cannot be controlled directly during the execution of the test, this could be a limitation of the protocol.

### 3.2. Grappling combat sports

The specific motor actions in wrestling are incorporated in a test proposed by Utter et al. [36], in which throwing exercises are carried out such as those performed during combat. The protocol consists of the execution of five repetitions of five technical movements used during the match in a circuit, being three exercises only of freestyle and two that can be used both in freestyle and Greco-Roman wrestling. The test runs in pairs and the participants must be of the same weight category, one of the athletes will be the performer and the other will only receive the actions, which allows the performer to execute all movements, returning as soon as possible to the initial position to allow the performer's actions at their maximum pace. The techniques used were double-leg takedown, single-leg takedown, fireman's carry, stomach-to-back lift, and hip toss. The count of the time starts at the order of "go" of the evaluator, the performer must execute the 5 repetitions of the first movement and then move on to the next, at the end of the fifth repetition of the fifth exercise the time will be recorded. The classification of the fitness level of the athlete evaluated is related to the time necessary to execute the 25 repetitions and the shorter the time the better is the conditioning of the wrestler. The number of repetitions executed and the time used in the test could be used as a tool for the evaluation of specific strength-endurance in both wrestling styles. However, general classification tables are not available by class, gender, and weight category.

Upper-body strength-endurance is a determining factor for sporting success in judo since the action of gripping the judogi of the opponent and its maintenance during combat is related to the outcome of the match [37]. To assess this physical capacity in judo, two specific tests for judo athletes were proposed by Franchini et al. [38]. The tests are related to the upper-body isometric handgrip and dynamic strength-endurance. One test analyzes the maintenance time executing the judogi grip, whereas the other analyzes the number of repetitions of the exercise in the dynamic chin-up executed with the judogi grip. The performance of the isometric test, represented by the time of suspension gripping the judogi was correlated with the maximum handgrip isometric strength relative to the body mass ( $r = 0.73$ ) and with maximal strength (1RM) in a seated row exercise relative to body mass ( $r = 0.71$ ). In turn, the performance in the dynamic test, represented by the number of chin-up repetitions gripping the judogi, was correlated with the maximum isometric handgrip strength relative to body mass ( $r = 0.86$ ), with the maximum strength in seated row (1RM) relative to body mass ( $r = 0.81$ ) and the upper-body Wingate test mean power ( $r = 0.69$ ). These results indicate that the two tests have a good relationship with the tests commonly used to determine both maximal isometric strength (handgrip), as well as maximal dynamic strength (1RM in seated row) and variables associated with muscle strength. In addition, the results of both chin-up tests also correlated ( $r = 0.75$ ), indicating that the two tests basically evaluate the same variable, and can be used to evaluate strength-endurance with the use of grip in the judogi, similar to what happens in judo. Another important aspect to consider is that the reliability of the isometric chin-up test gripping the judogi was high (ICC = 0.98) [38].

With the objective of identifying the differences in the upper-body strength-endurance among the Brazilian judo athletes' team and state level athletes, Franchini et al. [9] applied tests of the maximum time of suspension gripping the judogi and the number of repetitions in the chin-up gripping the judogi. No significant differences were found between the groups for the isometric strength-endurance test gripping the judogi. However, for the dynamic strength-endurance test gripping the judogi, the athletes of the Brazilian team performed more repetitions than the state-level team (Table 5).

**Table 5:** Isometric and dynamic strength-endurance chin-up tests in judo athletes (Adapted from Franchini et al. [9]).

	Maximal isometric time gripping the judogi (s)	Dynamic strength endurance gripping the judogi (rep)
Brazilian team (n=16)	35 ± 18	12 ± 5
Barueri team (n=16)	39 ± 14	9 ± 4*

\* $p < 0.05$  vs. Brazilian team.

Recently, studies have suggested classificatory tables for both judogi grip isometric strength-endurance and judogi grip dynamic strength-endurance tests to judo male [39, 40] and female

athletes [39, 40] assessed Brazilian athletes from state, national and international levels, between 18 and 40 years old. On the other hand, the study of Agostinho et al. [40] presents data from high-level cadet and junior athletes from Brazil and Serbia. Table 6 summarizes the values presented in both studies.

**Table 6:** Classificatory table for both dynamic and isometric strength-endurance chin-up tests gripping the judogi.

			LEVEL						
			Very poor	Poor	Regular	Good	Excellent		
Dynamic judogi chin-up test	Absolute (reps)	Branco et al. [39]	≤1	2 – 6	7 – 16	17 – 19	≥20		
		Agostinho et al. [40].	Male	Cadet (n=80)	≤2	3 – 13	14 – 25	26 – 31	≥32
	Junior (n=47)			≤3	4 – 15	16 – 28	29 – 30	≥31	
	Female		Cadet (n=60)	≤1	2 – 5	6 – 16	17 – 22	≥23	
			Junior (n=35)	0	1 – 3	4 – 20	21 – 23	≥24	
	Relative (reps.kg)	Branco et al. [39]	≤121	122 – 474	475 – 1,190	1,191 – 1,463	≥1,464		
		Agostinho et al. [40].	Male	Cadet (n=80)	≤226	227 – 784	785 – 1,737	1,738 – 2,244	≥2,245
				Junior (n=47)	≤411	412 – 1,158	1,159 – 2,026	2,027 – 2,366	≥2,367
			Female	Cadet (n=60)	≤144	145 – 350	351 – 799	800 – 1,142	≥1,143
				Junior (n=35)	≤58	59 – 306	307 – 1,056	1,057 – 1,296	≥1,297
Isometric judogi chin-up test		Absolute (s)	Branco et al. [39]	≤10	11 – 25	26 – 55	56 – 62	≥63	
	Agostinho et al. [40].		Male	Cadet (n=83)	≤7	8 – 40	41 – 69	70 – 89	≥90
		Junior (n=43)		≤6	7 – 34	35 – 65	66 – 75	≥76	
		Female	Cadet (n=52)	≤12	13 – 26	27 – 55	56 – 74	≥75	
			Junior (n=30)	≤2	3 – 17	18 – 57	58 – 71	≥72	
	Relative (s.kg)	Branco et al. [39]	≤1051	1,052 – 2,041	2,042 – 3,962	3,963 – 4,008	≥4,009		
		Agostinho et al. [40].	Male	Cadet (n=83)	≤626	627 – 2,744	2,745 – 4,506	4,507 – 5,856	≥5,857
				Junior (n=43)	≤822	823 – 3,158	3,159 – 4,732	4,733 – 5,713	≥5,714
			Female	Cadet (n=52)	≤554	555 – 1,514	1,515 – 2,932	2,933 – 3,405	≥3,406
				Junior (n=30)	≤243	244 – 1,232	1,233 – 3,216	3,217 – 3,933	≥3,934

Therefore, judo coaches and strength and conditioning professionals can evaluate their athletes and provide them with a clear comparison with their peers, and use them to evaluate the evolution along the different training phases. It is important to consider that lighter athletes likely perform better in absolute terms (i.e., number of repetitions and time of suspension) whereas heavier athletes present higher values multiplied by their body mass. Therefore, caution is needed when comparing athletes from different weight categories.

Another method was used by Bonitch-Góngora et al. [41], who assessed differences and similarities between young elite judokas and those who were not considered elite in concerning

isometric handgrip strength-endurance. Following the test protocol, participants performed 8 sets of 10s of muscle contraction on an electronic dynamometer with 10s passive rest intervals. Seventy-three athletes of both sexes were evaluated. The results suggest that elite judo athletes are able to develop higher levels of handgrip strength and also presented better strategies to maintain successive contractions, which are common actions during the judo match.

Silva et al. [42] conducted a study to evaluate the reliability of two tests to evaluate strength-endurance gripping the kimono grip in Brazilian jiu-jitsu athletes. The tests are the same tests used to evaluate judo athletes [38] and consisted of: a) maximum time of suspension in the chin-up exercise (MSL), with total flexion of the elbow and gripping the kimono rolled around the bar, and b) the maximum number of repetitions (MNR) of complete flexion and extension of elbow in the fixed bar gripping the kimono. For the analysis of reliability of these tests, the athletes were submitted to test and re-test, and the data found in the study allowed to affirm that both tests are reliable for the evaluation of isometric strength-endurance (intraclass correlation coefficient = 0.971 and the limits of agreement = - 6.9 and 2.4s) and dynamic strength-endurance gripping the kimono (intraclass correlation coefficient = 0.987 and the limits of agreement = - 2.9 and 2.3 rep), and can be used to differentiate the jiu-jitsu athletes from different levels (i.e., elite and non-elite) (Table 7).

**Table 7:** Isometric and dynamic strength-endurance chin-up tests gripping the kimono in elite and non-elite Brazilian jiu-jitsu athletes (Silva et al. [42]).

	Elite (n = 10)	Non-elite (n = 10)
MNR (rep)	15 ± 4	8 ± 3*
MSL (s)	56 ± 11	38 ± 11*

\*P < 0.05 Non-elite vs. Elite. MSL: maximal static lift; MNR: maximal number of repetitions

Silva et al. [43] examined if there were differences between Brazilian jiu-jitsu practitioners from different levels (advanced, non-advanced, recreational and beginners), in both isometric and dynamic strength-endurance chin-up tests gripping the kimono. Authors concluded that the isometric strength-endurance chin-up test was able to discriminate isometric strength-endurance between the four levels of Brazilian jiu-jitsu practitioners. However, the dynamic strength-endurance test was able to discriminate strength-endurance only between the groups with larger differences concerning practice levels (advanced and non-advanced versus recreational and beginners).

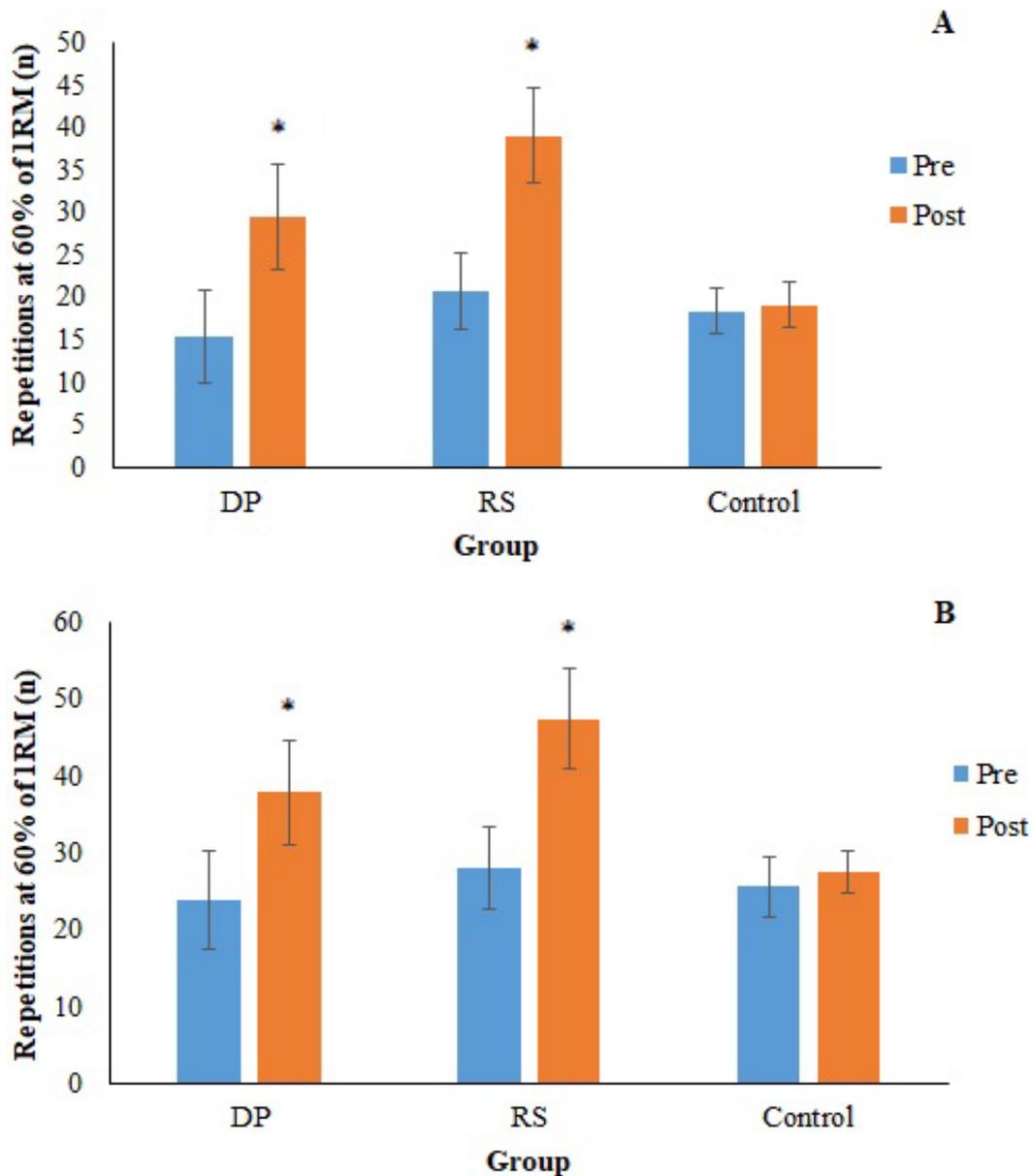
The assessment of strength-endurance has also been carried out with exercises commonly used in the training process of the combat athletes, using training loads between 60 and 80% of 1 RM [44,45], with comparisons throughout the season or with classificatory tables [46].

#### 4. Longitudinal studies on the development of strength-endurance in striking, grappling and mixed combat sports athletes

Mirzaei et al. [47] evaluated the impact of 4 weeks of training, corresponding to the general preparation phase in physiological parameters of 15 young wrestlers (15.2 ± 0.94 years). Strength-endurance of arms and abdominals was evaluated from a number of repetitions performed in the pull-up (pre: 16.53 ± 9.60 rep, post: 18.66 ± 10.93 rep) and 1-min sit-up tests (pre: 45.66 ± 6.21 rep, post: 48.53 ± 5.24 rep), respectively, but no differences were found between the periods, suggesting that the training was not enough to promote the improvement of this physical capacity in this group.

Another study conducted by Mirzaei et al. [48], with 22 young wrestlers, aimed to investigate the effect of 8 weeks of strength training with two load patterns in strength-endurance of the upper (bench press) and lower body (leg press). The chosen loading patterns were the double pyramid (DP) and the reverse pyramid (RP). For DP loading pattern the athletes performed 4 rep with 80%, 3 rep with 85%, 2 rep with 90%, 1 rep with 95%, 1 rep with 95%, 2 rep with 90%, 3 rep with 85% and 4 rep with 80% of 1RM. RP loading pattern consisted of 2 rep with 90%, 10 rep with 70%, 15 rep with 60%, 2 rep with 90%, 10 with rep 70% and 15 rep with 60% of 1RM. The athletes were divided into three groups: control (C, n = 8), DP (n = 7) and RP (n = 7). The two experimental groups had their training volume equated. The athletes performed a maximal load test for both exercises, and the load

corresponding to 60% of 1 RM was selected as a reference for the dynamic endurance test before and after the intervention. As a result, it was found that athletes who performed the training of both load patterns showed an improvement in upper- and lower-body strength-endurance compared to the control group, measured from the number of repetitions in the bench press (Figure 4A) and leg press (Figure 4B) exercises, respectively. However, the authors found no significant differences between the training models used, but both resulted in a greater strength-endurance, which did not occur for the control group. It is not clear, however, if the load used in the post-test is related to the value of 1 RM after training or pre-training, which would undoubtedly influence the result since as the groups increased the maximum strength, the use of pre-training load would represent values lower than 60% of 1RM.



\* $p < 0.05$  pre and post for the same group. DP: double pyramid; RS: reverse pyramid.

**Figure 4:** Number of repetitions at 60% of 1RM for bench press (A) and leg press (B) in young wrestlers (Adapted from Mirzaei et al. [48]).

In a study conducted with judo athletes, Fukuda et al. [49] investigated the impact of 4 weeks of training for the competition. The athletes were divided into two groups according to age, children ( $n = 8$ ) and adolescents ( $n = 12$ ). In order to improve grip strength-endurance, the participants performed at the end of the morning training session, which was performed four times a week, two sets of exercises of climbing a 9-m rope, nailed to the roof. The researchers used as a procedure to

evaluate strength-endurance a 30s rope pull test in a specific equipment that recorded the pulled length in meters. No differences were found between the pre- and post-training evaluations for both children (pre:  $24.7 \pm 1.2$  m, post:  $25.7 \pm 1.7$  m) and adolescents group (pre:  $30.0 \pm 0.7$  m, post:  $30.6 \pm 0.5$  m), which shows that the exercises of climbing the rope during four weeks of pre-competitive training did not promote significant adaptations in handgrip strength-endurance in youth judo athletes.

A study carried out by Franchini et al. [45] investigated the influence of two models of resistance training periodization, linear and undulating, on some performance capabilities of judo athletes. Athletes in the adult male category were divided into two groups and underwent eight weeks of strength training following one of the two periodization models. One group followed the linear model ( $n = 6$ ) and the other followed the undulating model ( $n = 7$ ), simultaneously with the judo training. Isometric and dynamic strength-endurance were assessed through isometric judogi chin-up and dynamic judogi chin-up tests, both gripping a judogi rolled around the bar. For the linear training routine, the athletes performed in the first two weeks exercises with a load of 3-5 maximal repetitions (RM), from the third to the fifth week power exercises of 6-8 repetitions with a load of  $\sim 80\%$  of 1RM, and from the sixth to the eighth week the objective was the development of strength-endurance, while the undulating group carried out the same training program for the sets and loads, varying the daily training and not per week as in the linear one, performing strength exercises (3-5 RM), power (6-8 RM) and strength-endurance (15-20 RM) in the same week. At the end of the eight weeks, both groups had executed the same total training load, differing only in its distribution.

The results (Table 8) show no effects of time, the training protocol and the interaction of both for the number of repetitions in the chin-up test gripping the judogi. However, there were differences in the time of suspension in the chin-up test gripping the judogi post-training in relation to the pre-training values, for both models of periodization. As a result, eight weeks of linear or undulating training induced an increase in isometric strength-endurance gripping the judogi grip, and this improvement is an important adaptation for the judogi grip during the judo match since it represents a large part of the actions during the combat. As the 1RM percentage tests were performed with the maximum load of each moment, there were no alterations in the number of repetitions in the different exercises. However, when considering the volume performed (load times the number of repetitions), there was an increase in bench press and squat for both models of load progression, without differences between them.

**Table 8:** Strength-endurance performances of judo athletes before and after eight weeks of linear or undulating strength training programs (Adapted from Franchini et al. [45]).

Variables	Linear (n = 6)		Undulating (n = 7)	
	Before	After	Before	After
Row at 70% de 1RM (rep)	21 $\pm$ 5	21 $\pm$ 4	21 $\pm$ 6	21 $\pm$ 5
Bench-press at 70% de 1RM (rep)	19 $\pm$ 3	20 $\pm$ 3	21 $\pm$ 7	22 $\pm$ 5
Squat at 70% de 1RM (rep)	23 $\pm$ 4	25 $\pm$ 3	25 $\pm$ 7	25 $\pm$ 6
Total load lift, row at 70%1RM (kg)*	1468 $\pm$ 461	1576 $\pm$ 330	1428 $\pm$ 552	1563 $\pm$ 542
Total load lift, bench-press at 70%1RM (kg)*	1266 $\pm$ 323	1479 $\pm$ 304	1397 $\pm$ 578	1590 $\pm$ 492
Total load lift, squat at 70%1RM (kg)*	1898 $\pm$ 527	2117 $\pm$ 434	1923 $\pm$ 691	2076 $\pm$ 713
Dynamic judogi chin-up (rep)	13 $\pm$ 6	14 $\pm$ 8	14 $\pm$ 8	17 $\pm$ 8
Isometric judogi chin-up (s)*	32 $\pm$ 18	41 $\pm$ 21	41 $\pm$ 14	46 $\pm$ 13

Total load lift = load multiplied by the number of repetitions; \* moment effect ( $P < 0.05$ )

## 5. Methods for development of strength-endurance in striking, grappling and mixed combat sports athletes

### 5.1. Striking combat sports

It is up to the trainer and/or strength and conditioning professional to choose the main methods for the development of the physical qualities that are essential to differentiate winners and losers in combat sports.

The current format of the boxing matches has led to changes in the training methods, giving greater emphasis on improving the performance of the dynamic actions related to the frequency of attacks made in the first stages of the rounds, affecting the total amount during combats [50]. In fact, the ability to perform a higher number of punches on a sandbag in a pre-determined time is related to specific dynamic strength-endurance in boxing, and it is likely that strength-endurance training will improve this ability [7,8]. We still have no knowledge of studies that correlate the number of attacks made by an athlete in a combat with the sporting success in a boxing competition. However, it is possible to suggest that this improvement can be transferred to the performance of the athletes during the competition, which results in victory in the match.

Circuit training can be an effective tool for the development of dynamic strength-endurance for boxing, since there is a history in the literature mentioning that American athletes who participated in the Olympic Games in Atlanta (1996), performed circuit training for the various muscle groups, once per week, during the basic preparation period, with the aim of improving strength-endurance [51].

Based on the results of Chaabène et al. [13], which show that there is a greater sensation of fatigue in the lower-body muscles in karate athletes, it would be important to carry out a specific training for these regions, especially using motor actions characteristic of the modality and based on the temporal structure. As the match simulation results in a lower perception of fatigue in relation to the official competition, the inclusion of exercises (e.g., squats) involving strength-endurance during the break periods in the simulated match can help to improve the simulation to achieve the competition demand.

In turn, Turner et al. [52] suggest that plyometric training can also have a positive effect on endurance to maintain power actions since the efficient use of the stretch-shortening cycle results in the improvement of the propulsive force and conservation of energy. Therefore, this greater energy saving in each action would result in greater endurance throughout the repetition of these techniques.

## 5.2. Grappling combat sports

Grappling combat sports require high levels of dynamic and isometric strength-endurance, due to the intense nature of the actions during the combat and the short interval between actions, being recognized its importance in the sporting success and the necessity of its development during the competitive preparatory period for a competition [53].

Numerous strategies are used by coaches and strength and conditioning professionals in order to improve the performance of judo athletes concerning strength-endurance, mainly to improve the *kumi-kata* (judogi grip) during combat.

The changes in the judogi grip during judo matches are constant and correspond to a large part of the combat time, as verified by Miarka et al. [19]. Achieving and maintaining them efficiently can translate into the victory of combat [37], and the possibility of reducing the loss of performance of these actions during the matches or a competition, is a strategy that must be prioritized during preparation. Therefore, it is important that the training periodization be directed to make the judo athletes maintain their strength level during the matches, so it is important to develop the strength-endurance of the forearm flexor muscles [54].

The development of strength-endurance in a given muscle group depends on volume, and the literature indicates that multiple sets of moderate (10-15) to high (15-20 or more) number of repetitions are required, separated by rest intervals shorter than 1 min and from 1 to 2 min, respectively [55]. In addition, circuit strength training has been shown to be effective in increasing strength-endurance levels, due to the reduced rest time between exercises since it is the sufficient time to moving on to the next exercise in the circuit sequence. Regarding the frequency, the recommendation made for the advanced level athletes can be taken into consideration, being able to use a high frequency, from 4 to 6 training sessions per week with alternating muscle groups between sessions [2].

Therefore, exercises for the upper body, whose actions are to pull or to push, which are specific actions of the match, should be used in the physical preparation of judo athletes, considering the recommendations here presented. In fact, it is very common to use circuit training as a means to develop strength-endurance in judo athletes. The training sessions can be developed according to the specific demands of the modality, and therefore, considering the effort: pause ratio, it can be based solely on strength exercises or combined with conditioning exercises (i.e, sprint, shadow *uchikomi*, etc.) [56].

Lahart and Robertson [57] mention that a specific circuit for judo athletes can last for 5 minutes, consisting of 10 exercises with a duration of 20s and intervals of 10s for the change of exercise would be performed, and the exercise could be repeated two or three times with 10-minute intervals between each set.

For wrestlers, circuit training has also been employed in order to simulate the specific demands of the match with an environment close to the demands of combat, mainly to improve strength-endurance, which is vital for successful performance, being circuit strength-endurance training a convenient and effective tool, since it physiologically prepares the athlete for the conditions that occur during the competition [2].

### 5.3. Mixed combat sports

Based on the analysis of the structure of the MMA combats, Del Vecchio et al. [58] suggested the use of a circuit composed of two low-intensity 15s segments, involving standing fighting actions, followed by 9s of high-intensity effort. In the sequence, the athlete would rest for 10s and perform three segments of 20s of low-intensity actions in ground fighting, followed by 15s of high-intensity actions in the ground, a new period of 10s of pause or 20s low-intensity actions on the ground. Another example presented by authors would be the execution of two blocks with the following sequence: 15s low-intensity upper-body actions; 9s of high-intensity upper-body actions; 15s of low-intensity lower-body actions; 9s of high-intensity lower-body actions; 10s of pause; three consecutive sets interspersing 3s high-intensity actions on the ground with 5s low-intensity actions. This reference can be used to create circuits with different exercises that contemplate the muscle groups that a certain athlete reports with the presentation of greater fatigue during the match.

## 6. Non-traditional training to improve strength-endurance for combat sports

Training that includes non-traditional exercises can be applied to improve performance and has been employed as a method of developing the required physical capabilities in combat sports, since the exercises performed in this type of training are intended for transfer to the sport, with movements similar to the motor actions involved in combat [6].

The unconventional strength training method employs the use of coordinated movements involving multiple muscle groups and joints with angles and planes of motion similar to those used in the aimed modality, which differ from the so-called conventional training method that is commonly used by bodybuilders, emphasizing the training of isolated muscle groups and in a single movement plane [6].

To improve strength-endurance in different combat sports, the training with functional movements of pushing, pulling and rotation, are those that should be used, since they are motor actions that are usually performed during combat, and strategies can be used for individual, pairs or group training, using only the body mass as loads. It is also possible to perform exercises with materials such as medicine ball, dumbbells, kettlebell, sandbag, ropes, tires, etc. (Table 9). Even so, they can be designed in circuit training, alternating functional exercises with other traditional movements used in strength training, such as squat exercise variations, among others.

The carrying out of activities follows the same recommendations in terms of the number of sets, loads, intervals and speed of execution or time-motion structure of the combat, as discussed above.

**Table 9:** Unconventional exercises recommended for combat sports athletes (Adapted from Santana & Fukuda [6]).

Exercise		Objective	Combat sport
Sit-up with trunk rotation holding a medicine ball		Abdominal strength-endurance	Striking; Grappling; Mixed
Pull-up	Gripping a kimono	Upper-body strength-endurance	Judo; Jiu-jitsu
	With a hook grip	Upper-body strength-endurance	Wrestling; MMA
Dragging tires	Pulling using ropes	Upper-body strength-endurance	Judo; Jiu-jitsu
	Pull with the rope tied to the body	Trunk and lower-body muscles strength-endurance	Wrestling; MMA
Push or flip tires	Supine position	Upper-body strength-endurance	Judo; Jiu-jitsu; Wrestling; MMA
	With a partner		
Car pushing		Trunk and lower-body muscles strength-endurance	Judo; Jiu-jitsu; Wrestling; MMA
Rope climbing		Trunk and upper-body muscles strength-endurance	Judo; Jiu-jitsu; Wrestling

## 7. Exercises for the core zone

In combat sports, the region near the center of mass is very important for the transfer of power from the lower extremities to the upper regions of the body [56]. This region has been designated as the central zone (core area or core zone), stabilization center (core stability) or power zone (power zone) and is composed mainly of the gluteus, abdomen, thigh and lumbar region muscles [59,60]. It has been considered that the strengthening of these muscle groups is important to prevent injuries, as well as to provide greater stabilization and protection of the spine and hip for the actions performed with high levels of strength or power [60]. Another important point to consider for the need to strengthen this region, refers to the need to execute (e.g., during the execution of a circular kick) and resist (e.g., during the defense of a throwing technique) the application of rotational force, and therefore, should be included in the training program for combat sports athletes [59, 61]. Indeed, international level judo athletes presented higher trunk extensor isokinetic strength and smaller trunk angular displacement after anterior trunk loading [62, 63]. Therefore, trunk extensor strength and trunk stability are discriminant variables and should be considered to improve judo athletes' performance. It is likely that these results also apply to other grappling combat sports.

McGill et al. [64] indicated that striking actions are dependent on impact and velocity. However, at the same time that some muscles act to accelerate a given body segment, the stiffness reduces the speed. Thus, in this phase the muscle relaxation can be an important factor to the action, but the for the increase in the effective mass the stiffness is important. Therefore, a double activation peak during these actions would be the best procedure to generate a higher speed, impact and power. Indeed, these authors indicated that high-level MMA athletes presented this profile for several techniques such as the back kick, the roundhouse kick, the jab with straight right combination, and for the ground and pound.

As core muscles were involved in this double peak profile, Lee and McGill [65] submitted Muay-thai athletes to six weeks of isometric core training, dynamic core training or to a control condition. The exercises included in the isometric core training were the plank, bird dog, torsional buttress (weeks 1 and 2), anterior pallof press, posterior pallof press, suitcase hold, anti-rotation pallof press (weeks 3 and 4), stir the pot, inverted row, kettlebell unilateral rack walk, half kneeling woodchop (weeks 5 and 6). During weeks 1, and 3 to 6, training sessions were executed four times per week, whereas in week 2 they were executed 7 times per week. Five to ten 10s sets were executed. The dynamic core training group executed the curl up, superman, side curl up, twisting curl up (weeks 1 and 2), advanced curl up, back extension, Russian barbell twist (weeks 3 and 4), curl up twitch, superman twitch, lateral medicine ball throw, and rotational medicine ball throw (weeks 5 and 6). Frequency was the same as for the isometric core group. Five sets of 5 to 10 repetitions were executed. Athletes executed the jab, cross, jab and cross combination, knee technique pre- and post-

training and analyzed peak force, peak velocity and EMG of several core muscles. They reported that the isometric core training resulted in higher impact force, whereas the dynamic core training resulted in higher speed during the techniques after the six weeks of training. EMG of core muscles increased after both training types, and there was a change from a one-peak pattern pre-training to a double-peak pattern post-training. Therefore, strength-endurance core training can improve impact force and velocity of striking techniques, but the changes vary between isometric and dynamic training approaches. These results suggest that coaches and strength and conditioning professionals should choose one of the approaches to induce specific change accordingly to their athletes' needs.

## 8. Final considerations

Strength-endurance is an important aspect for the success of combat sports, varying in terms of the most relevant muscle groups to be developed in grappling and striking combat sports. Therefore, the analysis of the requirements of the specific modality, as well as the individual needs of the athlete, and the evaluation of the initial condition of the athlete should be the starting point for conducting the development of strength-endurance. The specific procedures and exercise suggestions presented in this chapter are some recommendations for professionals, but innovation and the conduct of the process based on scientific evidence should be considered for the continuous improvement of this important performance component.

## Conflict of interest

None declare.

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