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Strength and conditioning for combat sports athletes
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CHAPTER 4
Developing muscle power for combat sports athletes

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Abstract
In combat sports, the specificity of the training requires that the athlete improve all performance indicators associated with the match. For this reason, muscle power seems to be determinant during the application of the techniques that result in scores, specifically punches, kicks, elbows, knees, throwing techniques, transitions to the groundwork and some groundwork techniques and sometimes, the win match by knockout. Based in these information's, the present chapter will approach items referring to the muscle power manifestation and monitoring, and to the training prescription of exercises for the grappling, striking and mixed combat sports.

Keywords: Martial arts; combat sports; strength; strength conditioning; strength training.

1. Introduction

In combat sports muscle power seems to be determinant during the application of the techniques that result in scores, specifically punches, kicks, elbows, knees, throwing techniques, transitions to the groundwork and some groundwork techniques. Power is defined as the product of force (mass multiplied by acceleration) divided by velocity (distance/time). Therefore, the increase of any of these components will improve the athlete's performance in this capacity, provided that the others remain constant [1,2]. For example, if the goal is to improve power during the vertical jump, the athlete should be able to: [1] jump higher with the same load over the same time; [2] jump with the same overload in a shorter time; [3] jump with additional load over the same time; or [4] any combination mentioned above. Thus, it is appropriate for the trainer to check in which of these characteristics the athlete has a better chance of improving performance, i.e., whether he/she is more likely to improve in the force or in the velocity component [3].

Knowing that there is a linear and positive relationship between maximal strength and muscle power, athletes will not achieve the highest power level without first reaching higher levels of strength [4,5]. This assertion can be demonstrated by cross-sectional studies that show that stronger individuals manifest more muscle power than the weaker ones [6–9]. It is also known by sports professionals that strength training programs improve the muscle power performance of untrained or moderately trained individuals. However, this influence between strength and muscle power seems to decrease when the athlete is already highly trained in this physical component [10]. This happens because with increased maximum strength the "window for future adaptations" decreases [11]. Therefore, the more trained the athlete is, less trainable he/she will be. This happens because there are biological limits for adapting the body and consequently for the muscle strength and power development [12].

In addition to the influences mentioned above, muscle power is also affected by acute training variables, including the type of exercise, the order in which the exercises are performed, number of sets and repetitions, and the rest interval between sets and repetitions or group of repetitions

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(cluster) [13,14]. Additionally, the training means and methods applied to the combat sports athletes have also been a topic of investigation [15,16]. However, the intensity to be used is the greatest topic of debate concerning the muscle power training prescription. A great variation is observed in the recommendations of the intensity, and in some cases, the variation is between 30-60% of 1 repetition maximum (1RM), whereas in other cases, the recommended loads are around 80% of 1RM [17] and in another cases, it is mentioned that only high loads should be used [18]. The proponents of the use of higher loads (80% of 1RM) are based on the "size principle",' which suggests the application of higher loads for the recruitment of motor units with higher activation threshold, fast twitch muscle fiber type, which generate greater force than the slow twitch muscle fiber type, with lower activation threshold. Muscle power training with this characteristic results in repetitions with slower velocity, however, it has been emphasized that the athlete should have the intention of performing the movement more as fast as possible, even if this is not possible, so that there is an improvement in performance. On the other hand, lighter loads are based on the "specificity principle", in which suggests that the athlete can generate greater muscle power and better adaptations when using the optimal load. A third group advocates the use of loads with greater amplitude, between 10-80% of 1RM. This group assumes that training for the development of muscle power involves the use of several exercises [19,20], which in turn, generate the greatest power at different intensities. For example, during the jump the maximal power is achieved unload whereas the maximum power for the squat, power clean and hang power are achieved with loads of ~50%, 70% and 80% of 1RM, respectively. Values of optimal load for specific combat sports athletes such as Brazilian jiu-jitsu (BJJ) athletes have been determined for exercises frequently used in their training routine [21,22]. The optimal load for bench press throw was around 42% of 1RM for both advanced and non-advanced BJJ [21], whereas for the prone bench pull the optimal load varied between 45% and 50% of 1RM for different power-related variables [22].

Another aspect that deserves attention regarding muscle power training is the possibility of transference and consequent improvement of the performance in specific gestures of the modality practiced, in our case combat sports, by using strength and power exercises [23]. Nowadays, it is not possible to determine in which extent the load that maximizes power output performing a general exercise is related with power in a specific combat sport action. However, it is inferred that the greater the biomechanical similarity of movements and recruitment patterns of muscle fibers, greater the specificity and the possibility of transference of performance [13]. Additionally, multi-articular exercises are more specific and had more possibility of transference in comparison with mono-articular exercises [13]. Recent studies have investigated the acute effect of strength, plyometric and complex exercises on performance in specific taekwondo [16,24–26] and judo tasks [15,27]. The effect of training using specific gestures with overload has also been investigated [28,29].

The understanding of the strength manifestation in the form of muscle power of the athletes is important for the correct elaboration of the training sessions that will compose the training planning. More and more, training programs should be based on scientific evidence and principles, leaving aside beliefs and conceptions that contribute very little to the athlete's development [12,30]. Therefore, this chapter will approach items referring to the muscle power manifestation and monitoring, and to the training prescription for the grappling and striking combat sports.

2. Muscle power solicitation during the match

2.1. Striking combat sports

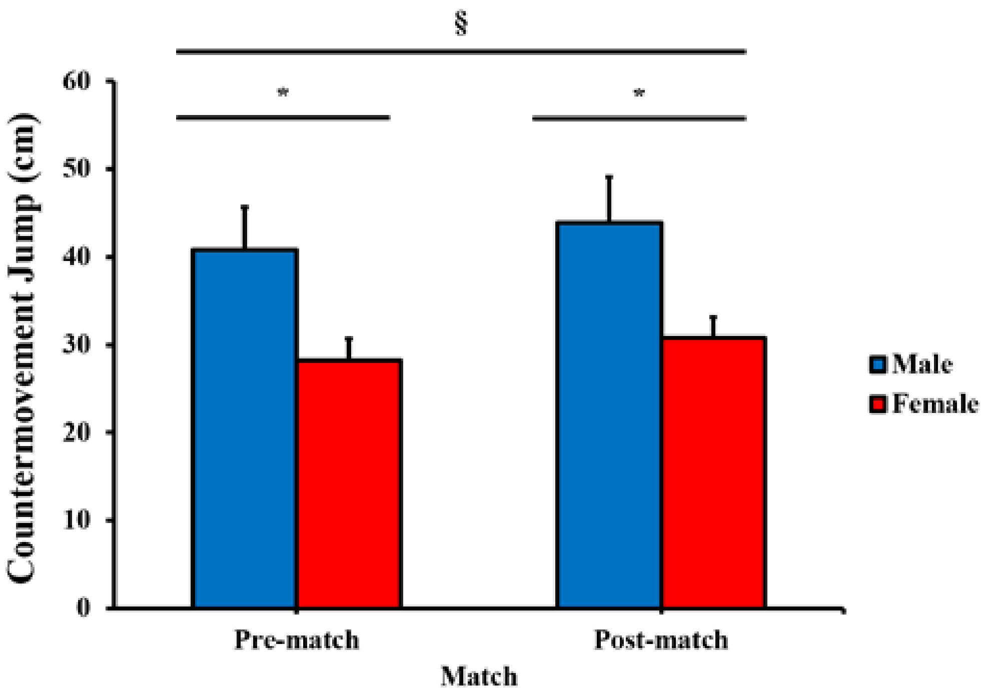
In striking combat sports, muscle power manifests itself mainly at the moment of a technique execution and, during a match, several techniques are applied. Therefore, in addition to the condition to apply blows with these characteristics, the athlete must be able to do this throughout the match. Studies that investigated the time-structure of striking combat sports (taekwondo, karate, muay-thai) presented an effort and pause ratio of 1:6 to 1:9 [31–33]. This relationship was investigated both during competitions and during the match simulation.

In taekwondo competitions, World Taekwondo (WT) style, the effort and pause ratio is ~1:7 [33,34]. During a match simulation, the average time of each attack lasts ~1s [34]. Athletes perform on average 18 attacks per round. The average time spent with attack actions during each round is

~13s. Throughout the match, the athletes perform ~52 attacks, with a total duration of ~39s, as one round lasts 120s and the match lasts 360s. Thus, it is possible to understand that the time intended for the attack represents ~11% of the duration of each round and, consequently, of the total time of the match. During international taekwondo competitions, such as the Olympic Games and the World Championships, the average duration of each attack was 1.3s [33].

In combat sport studies, the power output is widely assessed via indirect tests like vertical jump or countermovement jump (CMJ). It is known that factors such as arm or leg length and body mass can limit the performance and interpretations of the results [13,35]. This is a limitation about combat studies and tests choices, but is important to highlight that combat sport athletes are more homogeneous (because they are well trained and compete in specific weight categories) than the non-athlete population, reducing the bias of the use of jump tests as indirect tools to assess the power output generated.

However, it seems that the muscle power manifestation is not adversely affected during the taekwondo match. A study that aimed to investigate the muscle power manifestation of high-performance taekwondo athletes (15 subjects, 4 females and 11 males) during a national level competition described higher values, as measured by countermovement jump (CMJ) after the match, compared to the measure obtained prior to the match [36]. We can suggest that there was a potentiation of CMJ performance when the pre- and post-match moments were compared, as shown in Figure 1, generated by the stimulus of the match.



Note: § difference between pre- and post-match moments (p <0.001); * difference between the sexes (p <0.001).

Figure 1: Performance during counter-movement jumping performed pre- and post-match by taekwondo athletes of both sexes (Adapted from Chiodo et al. [36]).

Additionally, the muscle power manifestation in striking combat sports may vary during the match simulation in comparison to the official match. Chaabène et al. [37] investigated whether there was a difference in the performance of karate athletes during a simulation compared to an official match. It was observed that athletes applied more attacks using upper limbs during the official competition (6 ± 3) compared to the match simulation (3 ± 1). Concerning the match intensity, higher blood lactate concentrations and rating of perceived exertion were observed after the official match in comparison to the simulation. Thus, the physiological responses may differ considerably between the simulation and the official match, and it is necessary to analyze case by case, considering the combat sport practiced, the competitive level of the athlete and the condition in which the analysis is being performed.

When a top-level karate athlete - double World champion - was analyzed [38], small improvements of 1.1% and 2.9% were observed in the squat jump (SJ) and CMJ performances, respectively, after the combat simulation compared to pre-combat. For jump squat, an increase in power output was detected after the match simulation compared to pre-match, with values varying from 0.6% (when using an additional load of 40% of body mass) up to 7.4% (when the additional load was 80% of body mass). Conversely, for bench press throw a decrease in power output was found after the match compared to pre-match, with values varying from -0.5% (for a load of 30% of body mass) to -8.3% (for a load of 40% of body mass). A decrease in rate of force development (for the period between 0-100ms) was revealed for both half-squat (-3.6%) and bench press (-9.8%) exercises. The increase in jump squat exercise can be a result of a post-activation potentiation (PAP) effect or like named recently as post-activation performance enhancement (PAPE), likely due to the small use of kick techniques during the combat and to the long interval observed between successive kicks. The term PAPE was suggested recently as alternative to PAP and is applied when enhancements of measures of maximal strength, power, and speed are detected following conditioning contractions and PAP when exist an increase in muscular force/torque production during an electrically-evoked twitch) [39,40]. Conversely, as this athlete used frequent punching techniques, the decrease in bench press throw performance likely resulted in fatigue in these muscle groups. However, it is important to consider that even this decrease can have a small negative effect in punching techniques, as lower-body muscle power is a key element for punching power. Consequently, the lower-body post-activation effect observed should counteract the decrease in upper-body muscle power.

Ouergui et al. [41] compared winners and defeated athletes before and after a kickboxing match concerning muscle power variable. Winners and defeated kickboxers did not differ in CMJ. However, decrease was observed for CMJ (pre: 39.3 ± 4.7; post: 35.7 ± 5.0 cm) suggesting that match-induced fatigue impaired muscle power performance.

2.2. Grappling combat sports

In grappling combat sports, muscle power is manifested during throwing techniques and in the attempts to displace the opponent. During the throwing technique execution, the athlete must frequently throw himself/herself to generate very high-power values to be successful to throw his/her opponent. Some studies on the match temporality indicate that the grappling combat sports (judo, BJJ, wrestling) present an effort-pause ratio of 2:1 or 3:1 [42–45].

Two studies that aimed to investigate the effects of the Olympic wrestling competition simulation on vertical jump performance [46,47]. In the first study, conducted with the freestyle, the athletes performed a simulation composed of a total of five matches: three in the first day and two in the second day [47]. As shown in Figure 2, the performance generated after match 1, 2 and pre-match three was higher than that generated in pre-match four.

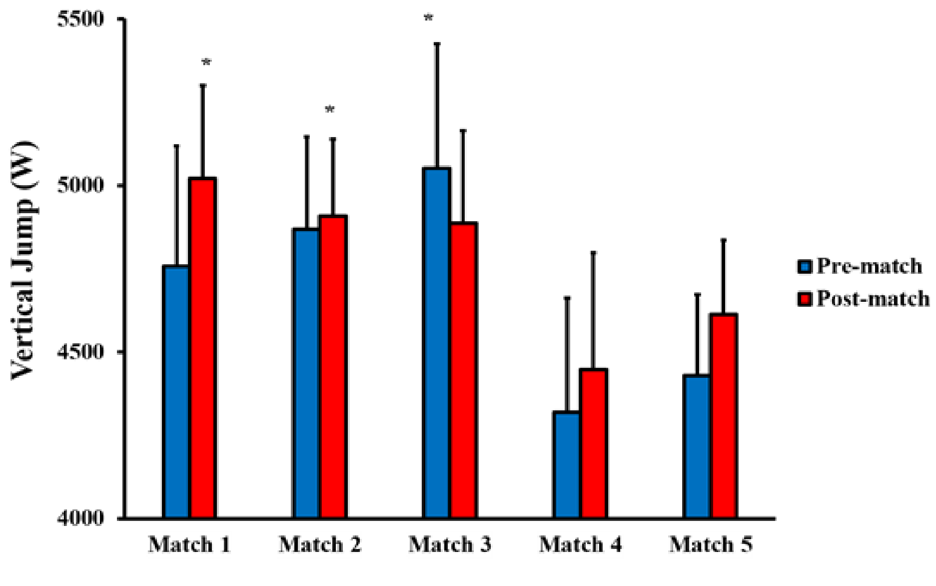
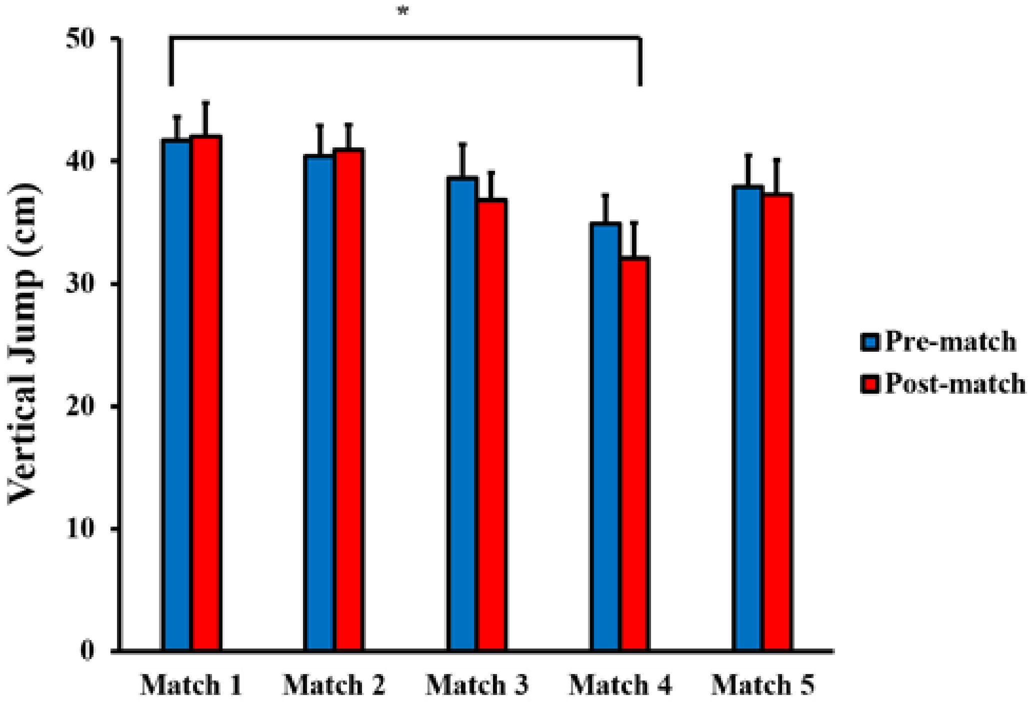


Figure 2: Vertical jump performance performed pre- and post-matches by freestyle wrestlers (Adapted from Kraemer et al. [47]).

Note: * different from the 4th pre-match ($p < 0.05$).

In the second study, conducted with the Greco-Roman style, the five matches were performed in the same day [46]. Before and after each simulation the athletes performed the vertical jump. It was observed a reduction of jump height in the fourth match compared to the first match, as can be observed in Figure 3.



Note: *different from the respective values of the first fight ($p < 0.05$).

Figure 3: Vertical jump performance performed pre- and post-matches by Greco-Roman wrestlers (Adapted from Barbas et al. [46]).

Among judo athletes, no power reduction was observed during a day of competition simulation. Before and after each match the athletes performed the concentric phase of the squat exercise. As can be seen in Figure 4, there was no statistically significant change in performance. Thus, despite trying to associate high blood lactate concentrations with a metabolically unfavourable environment for the muscle power manifestation, there is currently no evidence to confirm this [48,49].

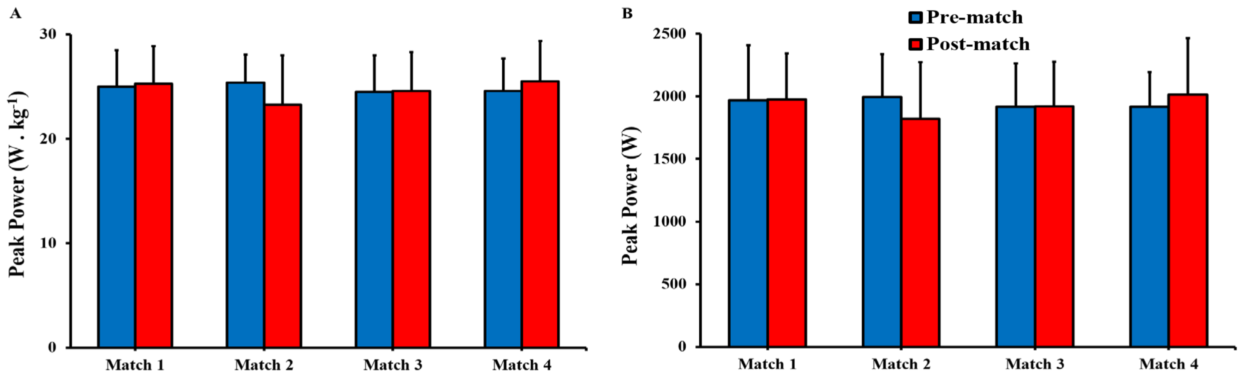
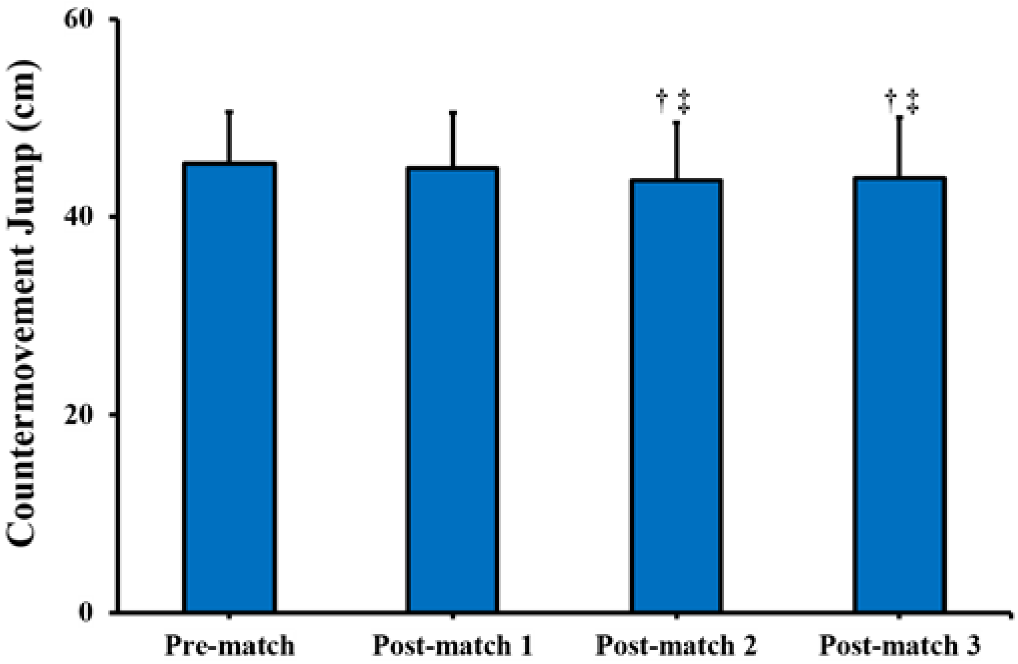


Figure 4: Relative (A) and (B) absolute power generated during the concentric phase of the squat performed pre and post-match by judo athletes (Adapted from Bonitch-Domínguez et al. [48]).

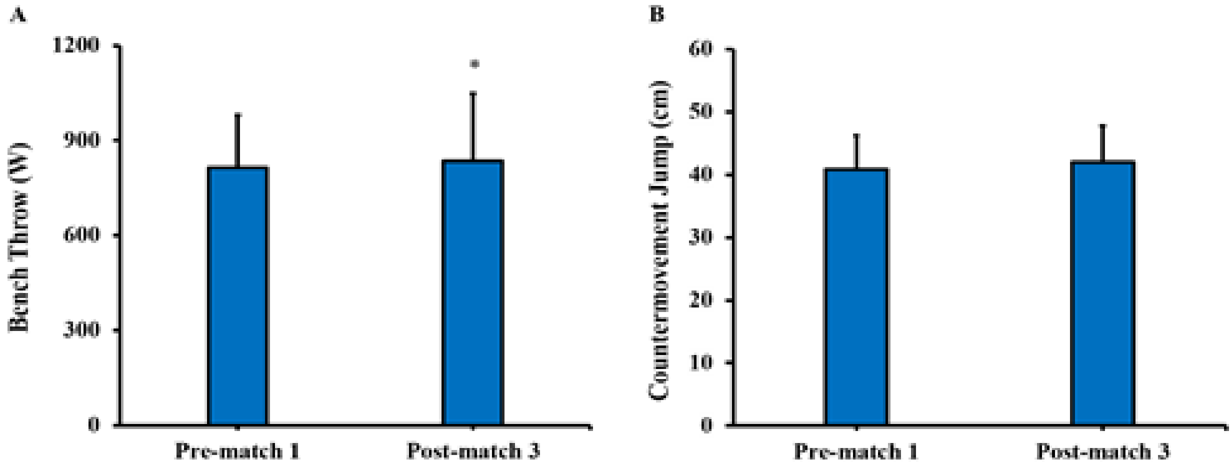
In another study carried out with judo athletes, there was a statistical difference in CMJ height pre-match compared with post second and third matches, and post first match compared with post second and third matches (Figure 5) [50]. The authors mention that the performance drop was ~3%. However, it is worth noting that the authors of this study did not present the coefficient of variation of the athletes for the CMJ test, therefore it is possible to attribute the difference found to the variation of each athlete to the performance of the CMJ.



Note: † different (p <0.05) from the pre-match moment; ‡ different (p <0.05) from post-match moment 1.

Figure 5: Performance in the countermovement jump of judo athletes before and after successive matches (Adapted from Detanico et al. [51]).

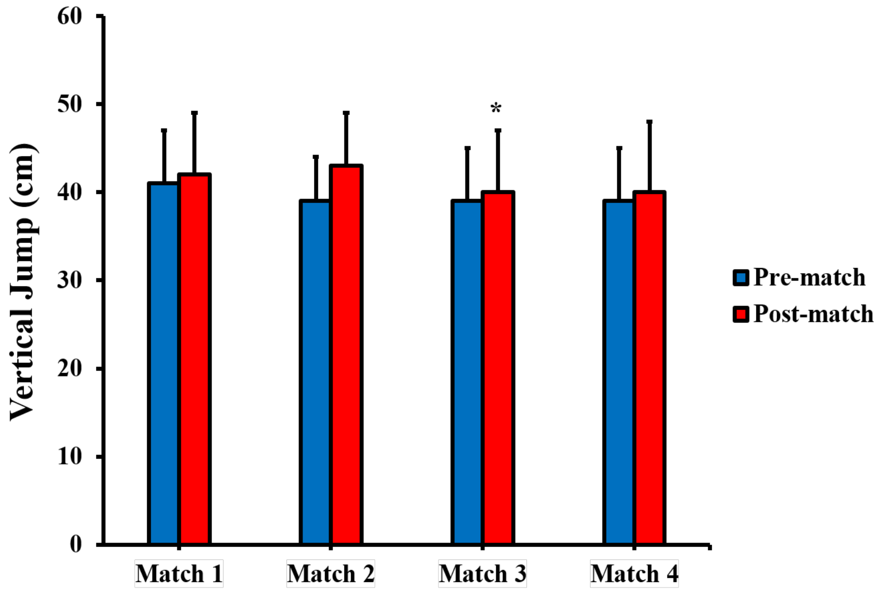
The neuromuscular performance was also investigated among BJJ athletes after successive matches. In one of the studies, the athletes performed three matches with a 15-minutes rest interval between them [49]. The performance tests were applied in two moments, pre-match 1 and post-match 3. As can be seen in Figure 6, there was an improvement in CMJ, but there was no change in ballistic bench press performance.



Note: * different from pre-match 1 (p <0.05).

Figure 6: Performance in the countermovement jump and ballistic bench press performed by Brazilian jiu-jitsu athletes before and after successive matches (Adapted from Silva et al. [49]).

In another study, performed with BJJ athletes, there was a decreased performance in the vertical jump after a match and before the next match [52]. This difference may be a result of the post-activation potentiation generated during match 2 and manifested during the test performed after the end of the match and the return of the performance to the resting values, presented before the match three. This effect is possible since between the end of a match and the beginning of the next the athletes went through a sufficiently long rest so that the effects of the PPA dissipated. Thus, although BJJ is a modality in which athletes perform powerful gestures to throw their opponents, it is possible to affirm that the match, or successive matches carried out on the same day, does not affect or affect positively the muscle power of lower limbs and does not affect the muscle power of upper limbs, as can be observed in Figure 6 (A and B) and 7.



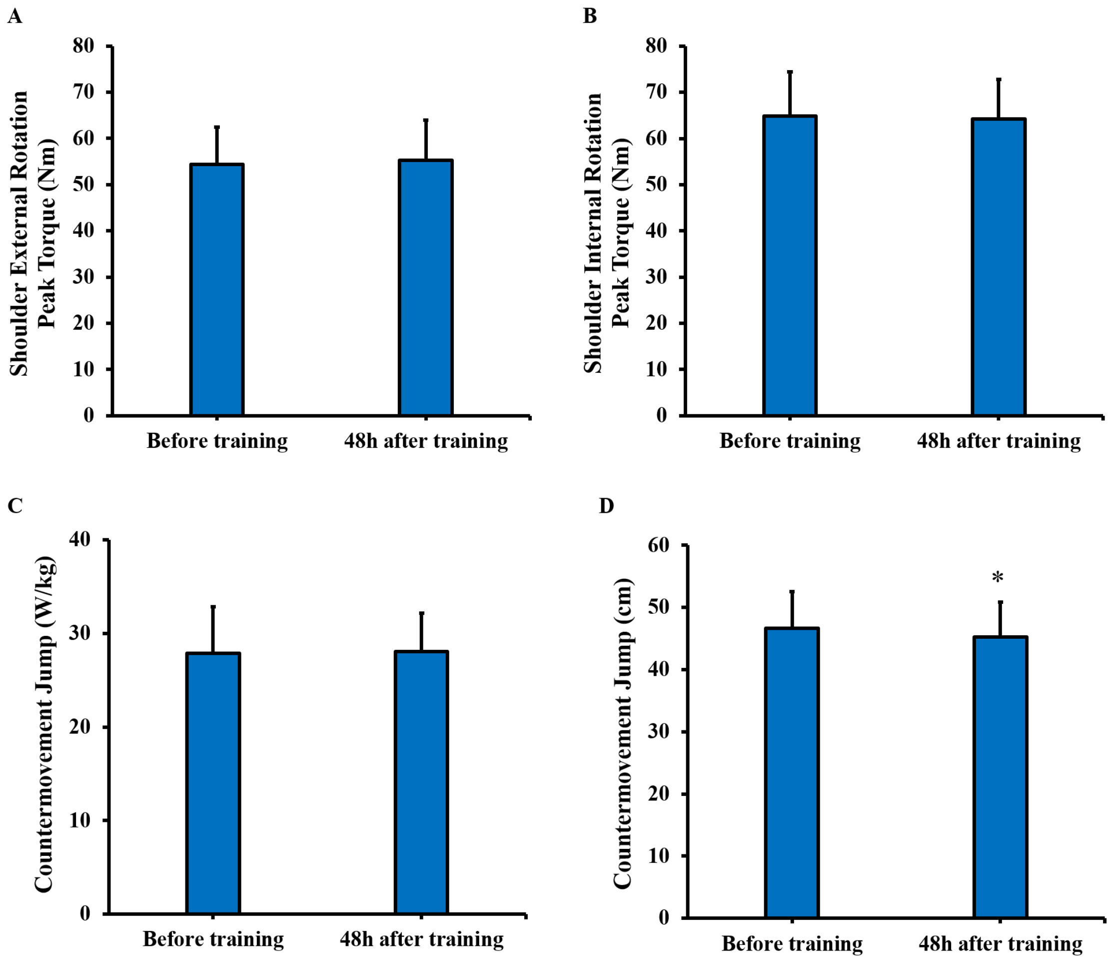
Note: * different from post-match moment 2 (p <0.05).

Figure 7: Vertical jumping performance pre- and post-match Brazilian jiu-jitsu athletes (Adapted from Andreato [52]).

Andreato et al. [53] investigated the effects of different simulated match durations on CMJ performance. These authors reported that CMJ height did not change after matches of 2 min (40 ± 4 cm), 5 min (40 ± 5 cm), 8 min (40 ± 2 cm) and 10 min (41 ± 4 cm) compared to a control condition (39 ± 3 cm). Additionally, CMJ did not differ between the different match durations. Indeed, a non-significant variation of 1 ± 1 cm/min was observed between pre-match and 2-min matches and 0 ± 0 cm/min for matches lasting 5, 8 and 10 min. Therefore, it was concluded that the lower-body overload is small during BJJ matches, which is confirmed by the low report of fatigue for the muscle groups in this segment, and this can explain the absence of decreased lower-body muscle performance along matches with different durations.

In a similar approach, Julio et al. [54] analyzed the effects of different simulated judo match durations (1, 2, 3, 4, or 5 min) on CMJ height, and found increased values post-match compared to pre-match, although no differences were found between matches with different durations. This result was attributed to the high-level of the athletes tested, which may have not developed lower-body fatigue during the matches, and especially due to a post-activation potentiation effect because the tests were executed 7-min post-match, an interval considered optimal for the potentiation to occur [55].

No many studies analyzed the effect of combat sports specific training on muscle power-related variables [56]. This knowledge is quite relevant to improve training organization, as muscle damage and recovery processes affect the subsequent performance, which consequently may impact training adaptation. Detanico et al. [56] investigate the effects of a 90-min typical judo training session on shoulder internal and external rotation peak torque and CMJ height. These variables were measured before the training session and 48 after its completion. They did not observe any change in shoulder rotation external peak torque (Figure 8, part A) or internal peak torque (Figure 8, part B), or CMJ peak power (Figure 8, part C). However, CMJ height decreased after the training session compared to before (Figure 8, part D). The authors considered that as upper-body judo gestures involve mainly concentric and isometric actions and judo athletes are adapted to the judo-specific demand, muscle damage was not elevated. Moreover, to avoid fatigue in such a long session it is likely that the judo athletes executed their actions in a lower intensity than during official matches or isolated simulated matches. Another possibility is that the long recovery period (i.e., 48h) allowed a full recovery and, therefore, no change was observed for shoulder internal and external rotation peak torque. Conversely, the decrease in CMJ height is probably related to the high eccentric-concentric load (i.e., stretch-shortening cycle) during lower-body actions executed in the training session, which can induce muscle damage and performance decrement.



Note: * different from before training ($p < 0.05$).

Figure 8: Neuromuscular parameters of shoulder external and internal rotation torque and vertical jump performance obtained before and 48 hours after the training (Adapted from Detanico et al. [56]).

2.3. Mixed Combat Sports

The muscle power is also manifested in the mixed combat sports during the application of blows and attempts of displacements. The mixed combat sports present an intermediate effort-pause ratio compared to the grappling and striking combat sports, normally around 1:2 to 1:4 [50]. Although we did not find any investigation assessing muscle power changes over a MMA match, it was reported that for MMA athletes, those with high competitive level presented higher relative impulse with additional loads of 0% to 50% of body mass, relative impulse in 300 ms with additional loads of 25% to 100% of body mass, peak power and velocity, mean power and velocity with additional loads 0% to 100% of body mass, peak of rate of force development with additional loads of 0% to 100% of body mass, and mean rate of force development with additional loads of 25% to 100% of body mass during the SP compared with lower level athletes [57]. These results indicate that muscle power is a key variable to properly discriminate higher and lower levels MMA athletes.

3. Muscle power requisition during combat sports-specific situations

During the performance of striking techniques, muscle power has been considered an important parameter for obtaining the knockout or to score [58,59]. Studies with muscle power analysis in specific actions have confirmed this idea. The muscle power during the execution of the straight punches in a dynamometer specifically developed for the boxing was greater in elite boxers with both the rear (4800 ± 601 a.u.) and lead hands (2847 ± 596 a.u.) in relation to intermediate boxers (rear hand = 3722 ± 375 a.u., lead hand = 2283 ± 355 a.u.) and beginners in the modality (rear hand = 2381 ± 328 a.u.; lead hand = 1604 ± 273 a.u.) [58], indicating the importance of this variable in the boxers development or in their selection process.

During throwing techniques, muscle power has also been considered extremely relevant [60–62]. Iteya et al. [61] reported higher power values in the sleeve pull movement in Japanese elite judo athletes in relation to university and regional level athletes. As the pulling movement is important for the opponent's imbalance and can reach values of 3.0 N/kg in the pull of the sleeve and 1.5 N/kg in the pull of the collar [60], the improvement of muscle power for execution of these actions is paramount for the successful execution of throwing techniques. Confirming the relevance of the muscle power during the *kuzushi* (unbalance) phase, Helm et al. [63] reported that elite judo athletes generated higher levels of power in the pulling arm (power = 420.9 ± 49.1 W, 3.9 ± 1.0 W/kg) and lifting arm (power = 246.0 ± 66.3 W, 2.7 ± 0.7 W/kg) during a pulling action in a specific ergometer compared to sub-elite judo athletes (pulling arm power = 245.5 ± 72.7 W, 3.1 ± 0.8 W/kg; lifting arm power = 138.1 ± 82.3 W, 2.1 ± 0.7 W/kg). Additionally, during the execution of the throwing techniques, athletes need high power in the lower limbs [64]. In fact, Zaggelidis, Lazaridis, Malkogiorgos, and Mavrovouniotis [62] reported higher values of vertical ground reaction force in advanced-level judo athletes during *harai-goshi* (4.0 ± 0.6 times body weight) compared to beginners (3.3 ± 0.2 times body weight). Additionally, advanced athletes reached the peak force in less time in the two executed techniques (*harai-goshi* = 117 ± 33 ms; *uchi-mata* = 127 ± 20 ms) compared to beginners (*harai-goshi* = 178 ± 29 ms, *uchi-mata* = 197 ± 27 ms).

In addition to the aspects traditionally considered for the elaboration of strength training, it is necessary to consider, for combat sports athletes, some important additional aspects: (1) the determinant scoring actions during the matches involve recruiting different body segments in a different way, i.e., it is very common for the upper and lower limbs to perform asymmetrical actions, something that is uncommon in classical exercises used during strength training sessions; (2) many throwing and kicking techniques involve high power application with reduced support base, i.e., the completion of execution is done with only one foot - and often only the forefoot-in contact with the ground [1]. Thus, exercises that contemplate these characteristics must be incorporated into the training process.

4. Monitoring and control of the evolution of muscle power in combat sports athletes

As sport professionals, the first goal is to carry out the training planning and, in the sequence, to execute it aiming at the improvement of the athletic performance, mainly in competitions. The first goal seems to be a less complicated task. Efficient planning can be done if the principles of specificity, overload and progression are followed [1,65]. But unfortunately, it is not part of the planning of many coaches to monitor the most important physical capacities for competitive success in certain sports. Without a proper monitoring of the athlete throughout the season, it is very difficult to know if the athlete is responding to the training program in an expected way. Often this important step is neglected by lack of interest on the part of coaches or by lack of criteria for choosing and applying the tests. Therefore, in this section some criteria that should be considered for the choice of a test will be presented, later the tests used to measure muscle power in the grappling and striking combat sports will be presented, and finally, suggestions regarding the moment of throughout the competitive season of the athlete will be made.

4.1. Criteria for Test Choice

According to Kiss and Böhme [66], the following criteria must be considered when choosing a test, regardless of age, sex and sport:

- Definition of the objectives of the program: the initial phase, after defining the objectives of the program, it will be possible to choose the tests best suited to the needs and objectives proposed.
- Origin and year of publication of the test: in some cases, it may be that the test has undergone adaptations or that a new test, more appropriate to our needs, has been created.
- Test objective: does it offer the measure for the intended physical capacity?
- Age and gender to which the test is intended: Is it appropriate to apply this test to my athletes? Is there any way of comparison and classification?
- The scientific authenticity of the test: is the test valid and reliable?

- Standardization of the test: is the test well described and standardized?
- By what means the results obtained can be interpreted and evaluated: how will the result be used? Is there a standard or will a comparison be made with the results of my athlete or group of athletes?
- The possibility of application: Do I have the material to apply the test? Is the space adequate? Are the evaluators prepared, do they know the procedures for applying the test? Is there time available?
- The degree of test difficulty: can my athlete understand the procedures and objectives of the test?
- Results offered: are the results accurate? How will the results be used to prescribe the training?

4.2. Tests used to measure muscle power in grappling and striking combat sports

Usually, four methods are used to calculate muscle power [67,68]: (1) The first method describes the displacement data; (2) The second involves the ground reaction force, given by a force platform; (3) The third method involves a combination of ground reaction force and displacement data; (4) The fourth method involves the use of an accelerometer.

The linear position transducer consists of a compact box, which contains a flexible steel cable wound in a coil, the end of which comes out through a hole in the box [69]. The end of the cable is attached to the bar so that it can only be monitored in the upright position. A spring on the coil keeps the cable under enough strain to return when there is no external pulling force. The linear position transducer and its use can be seen in Figure 9, 10 (A-F) and 11 (A-D).

Figure 9: Linear position transducer.

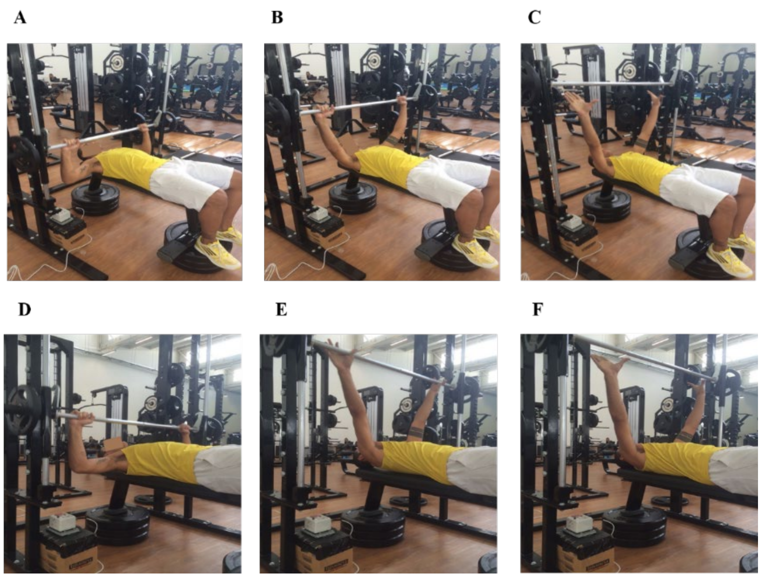


Figure 10: Exercise of the bench press exercise with a linear position transducer attached to the bar.

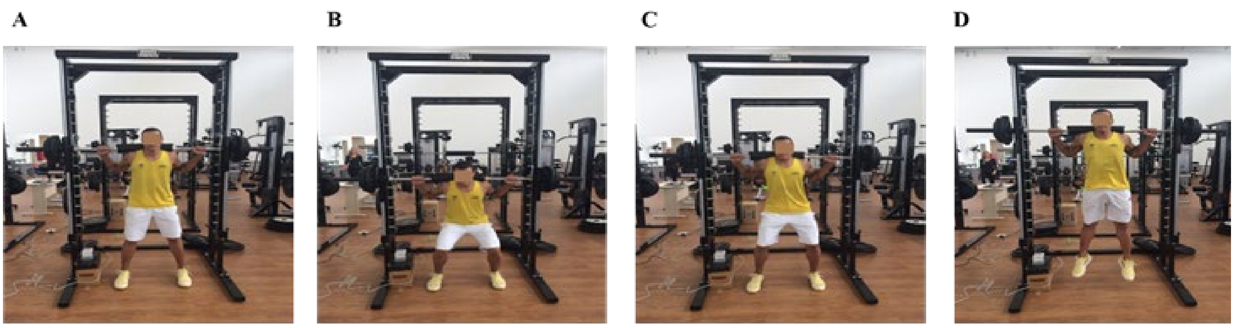


Figure 11: Execution of the loaded squat jump exercise with linear position transducer attached to the bar.

The force platform can capture the impact exerted on its surface, called the ground reaction force. Generally, the force platform is used in the horizontal position, however, it has recently been positioned in vertical so that it can be used by combat sports athletes during the application of a punch [59]. The use of the force platform in the horizontal and vertical position can be observed in Figure 12 (A-C) and 13 (A and B).

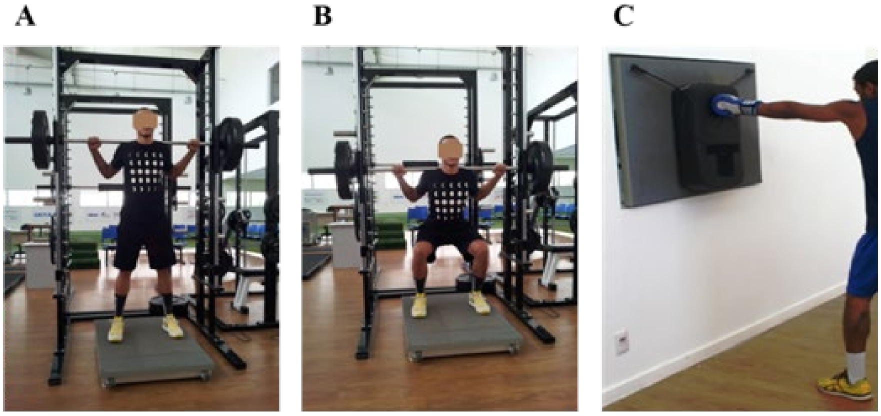


Figure 12: Force platform in the horizontal (A and B) and vertical (C) positions.

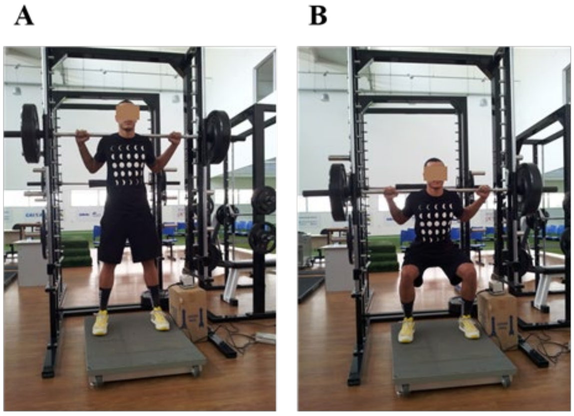


Figure 13: Strength platform and linear position transducer being used while performing the squat exercise.

The fourth method is to use an accelerometer. The accelerometer produces a voltage equal to the acceleration it suffers [69]. Modern equipment is small and light. However, it is noteworthy that the methods described above have some limitations, such as the inability to measure the muscle power of complex actions. These methods can be used mainly during linear movements.

Another way to measure the muscle power in athletes and practitioners of combat sports is through tests involving some variations of the vertical, horizontal and drop jumps, which are widely used among athletes involved with striking combat sports such as boxing [30], karate [70,71] and taekwondo [72]. These tests are also used among grappling combat sports such as judo [73] and jiu-jitsu [52]. In Figure 14 (A – C) and 15 (A – D), the vertical jump and the jump on the contact mat can be observed.

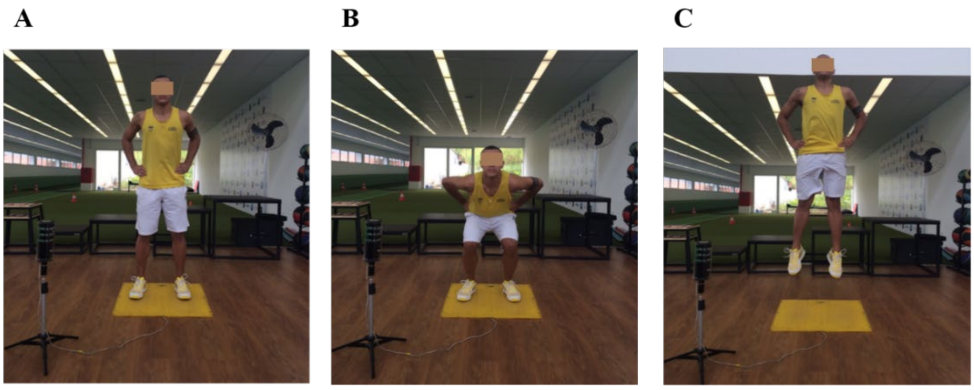


Figure 14: Execution of the vertical jump with countermovement (A-C).

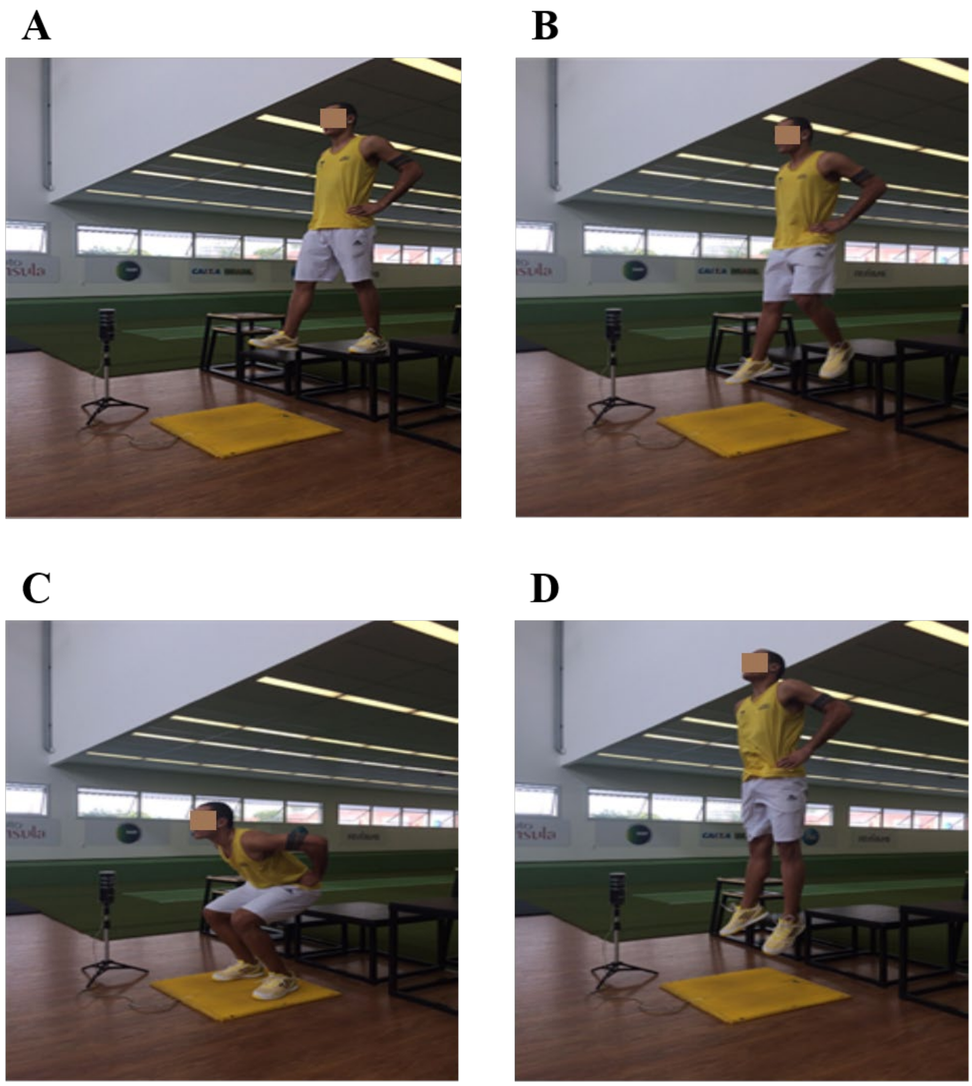


Figure 15: Performing the drop jump to determine the optimal height (A-C).

4.3. Striking and grappling combat sports measurements

In striking combat sports, muscle power is measured during tests in which the athlete performs a single blow, and the punch is the main technique used, measured by a force platform and the accelerometer. These tests have differentiated athletes according to the competitive level (elite, intermediate and beginner) [58] and performance during a match (winners and losers) [74].

Smith et al. [58] measured performance during two punches, jab and straight, by boxers of different competitive levels (elite, intermediate and novice). As expected, the elite group athletes performed better than the intermediate group athletes, who in turn presented superior performance to the novice athletes (Jab – elite: 2847 ± 225 N; intermediate: 2283 ± 126 N; novice: 1604 ± 97 N; straight – elite: 4800 ± 227 N; intermediate: 3722 ± 133 N; novice: 2381 ± 116 N). The performance during the direct punch was higher than the jab for all groups tested.

Loturco et al. [75] analyzed the relationship between impact during fixed distance jab, self-selected distance jab, fixed distance cross and self-selected cross punches with the muscle power and maximal isometric force and found positive relationships varying from 0.67 to 0.85. Muscle power and maximal isometric force variables included the CMJ height, mean propulsive power during jump squat and bench throw, maximum isometric force and rate of force development during squat and bench press. Therefore, muscle power and maximal isometric force are variables that when improved are likely to positive affect punch impact, which is a key element in boxing performance. Thus, these variables can be used during training monitoring and during strength and conditioning training sessions.

Dunn et al. [76] reported positive relationships between boxing punch force, punch impulse and punch force at 5ms and lower-body strength characteristics, but not with lower-body rate of force development or upper-body strength and power variables in male amateur boxers. Specifically, peak punch force for was positively correlated with CMJ force (r = 0.683) and isometric midthigh pull force (r = 0.680), suggesting that maximal strength development is related to punching performance. Moreover, they found significant differences between boxers with the highest and lowest punch forces for isometric midthigh pull force and rate of force development percentage, CMJ force and power, with higher values for those boxers who had the highest punch forces.

Another test used to evaluate boxers is the frequency speed of punch (FSP) [77]. The FSP consists of three steps. In the first one the speed of a single blow, the jab, is measured. In the second step, punches are executed during 5s. Finally, in the third step, the athlete hits for 15s. The FSP presented good reproducibility for the three steps (r = 0.84 and 0.95). However, the FSP did not differentiate athletes by their competitive level during the application of a single punch, but when the application of punches during 5s and 15s were executed there was a statistical difference between competitive levels (amateurs vs athletes - 5s: 25 rep vs 31 rep; 15s: 79 rep vs 89 rep). This difference may not have existed in the first study because there were no elite athletes among the groups [77].

To investigate the acceleration during a punch (*giaku-tsuki*), international level karate athletes were studied [71]. The athletes performed the punch in four different conditions: 1) fixed distance, aiming to generate the highest velocity; 2) fixed distance, aiming to generate the greatest impact; 3) self-selected distance, aiming to generate the highest speed; and 4) self-selected distance, aiming to generate the greatest impact. Male athletes performed better than female athletes. There was a statistical difference in the acceleration of the punch, with the superiority of condition 4 over condition 1, for athletes of both sexes.

Other tests performed with non-specific gestures are used to measure muscle power among karate athletes [71,74]. The squat and the propulsive bench press, using the load related to the athlete's body mass [71] and also percentages of 1RM [74]. Loturco et al. [71] analyzed whether there was a correlation between body mass and the acceleration of the *giaku-tsuki* punch technique between bench press and squat exercises performed with propulsion between winner and loser athletes [74]. In this condition, it was reported a higher muscle power by the winning athletes during the exercise of the bench press exercise and squat in comparison to the defeated athletes (peak muscle power – 30% bench press: 253 W ± 9 W vs. 206 W ± 6 W; 30% squat: 299 W ± 6 W vs. 270 W ± 23 W). Roschel et al. [74] investigated whether the intensity of the exercise could differentiate the level of the athletes. The authors reported that the exercise performed with a more intense load (60% 1RM) did not differentiate the winning and defeated athletes in terms of muscle power generation in squat and bench press exercises [74]. This test performed with lighter loads (30% of 1RM) seems to differentiate high-performance karate athletes (winners and losers).

For grappling combat sports, the optimal load has been determined for the bench press throw [21] and for the prone bench pull [22]. Silva et al. [21] determined the bench press throw peak power for advanced and non-advanced BJJ athletes and reported that groups did not differ concerning power achieved with 30% (advanced: 972 ± 166 W; non-advanced: 890 ± 146 W), 40% (advanced: 1015 ± 197 W; non-advanced: 931 ± 156 W), 50% (advanced: 1032 ± 173 W; non-advanced: 906 ± 126 W), and 60% of 1RM (advanced: 901 ± 176 W; non-advanced: 885 ± 135 W). When both groups were considered together the values achieved with 60% of 1RM were lower than those achieved with 40% and 50% of 1RM, but did not differ from those with 30% of 1RM. Additionally, for the advanced group, the values achieved with 60% of 1RM were lower than those with 40% and 50% of 1RM, but these differences were not found for the non-advanced group. Moreover, when groups were considered isolated or whole, the optimal load was approximately 42% of 1RM.

Tavares et al. [22] compared these same percentages of 1RM, but using the prone bench pull exercise and indicated that mean power mean velocity, mean propulsive power and mean propulsive velocity were lower during 30% and 60% of 1RM compared with 50% and 60% of 1RM, whereas mean propulsive power with 50% of 1RM resulted in higher values than 40% of 1RM (Table 1). The polynomial adjustment indicated that the optimal load for all power and velocity-related variables was 45%.

Table 1: Percentage of one-repetition maximum (1RM), absolute load, mean power (MP), mean velocity (MV), mean propulsive power (MPP) and mean propulsive velocity (MPV) during the prone bench pull executed by Brazilian jiu-jitsu athletes (adapted from Tavares et al. [22]).

Intensity	Load (kg)	MP (W)	MV (m/s)	MPP (W)	MPV (m/s)
30% 1RM	26.6 ± 7.9	950.2 ± 177.2[a]	0.95 ± 0.05[a]	1037.7 ± 130.3[a]	0.97 ± 0.04[a]
40% 1RM	35.7 ± 10.6	2289.5 ± 163.8	1.11 ± 0.07	1350.6 ± 123.2	1.21 ± 0.07
50% 1RM	44.6 ± 13.2	1135.5 ± 151.93	1.12 ± 0.06	1472.1 ± 133.9[b]	1.27 ± 0.06
60% 1RM	53.6 ± 15.9	930.7 ± 88.5[a]	0.88 ± 0.08[a]	1110.2 ± 80.7[a]	0.89 ± 0.08[a]

[a]Lower values than 40% 1RM and 50% 1RM ($p < 0.05$); [b]Greater values than 40% 1RM ($p < 0.05$).

4.4. Application throughout the competitive season

According to Kiss and Böhme [66], the evaluation of sports training should be performed before, during and after the sports training phases, with the following purposes:

a) At the beginning of the season: it has the function of diagnosing the condition of the athlete and the elaboration of goals to be achieved. This evaluation is called diagnostic.

b) During the season: it has the function of monitoring the training process and reaching the proposed objectives. If necessary, the objectives should be reformulated. This assessment is called formative.

c) At the end of the season or a specific phase: it has the function of attesting the effectiveness and the achievement of the objectives proposed for the training process. This assessment is called summative.

Performing initial performance tests after conducting a needs analysis to achieve high performance contribute to the completion of the planning and the tests applied throughout the season provide feedback for the planning and implementation of the training program as expected. The performance evaluations at the beginning, during and throughout the season are usually conducted in several modalities [78–80]. In combat sports it is no different, the performance tests are applied throughout the season to monitor the performance of the athlete [81], being intensified with the proximity of the competitions [82,83].

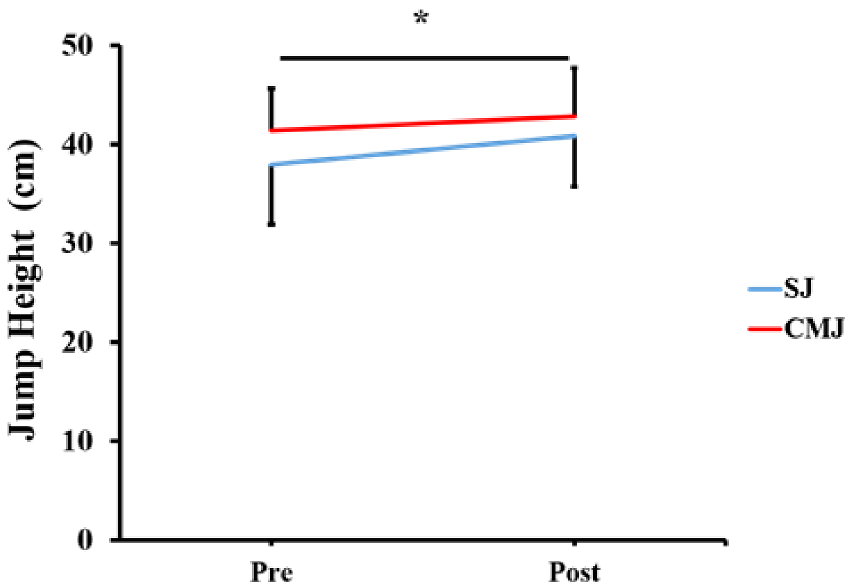
Taekwondo athletes had their muscle power tested weekly for a period of nine weeks prior to boarding for the 2008 Beijing Olympics [82]. The tests used for this purpose were vertical jump variations. This retrospective study showed that athletes improved muscle power during the pre-competition period. With weekly tests to measure the performance of athletes, there was a monitoring of the training program applied, allowing adjustments to the training routine in case the objectives were not reached. Another important point was the test used, the vertical jump, which was probably chosen for the easy attainment of the measure since it requires only the use of a contact mat and the accomplishment of a task usually known by athletes of different sports modalities.

Paralympic judo athletes had their muscle power assessed along a Paralympic cycle, including ParaPan American Games, World Championship and Paralympic Games [84]. The authors applied the SJ, CMJ, prone bench pull, jump squat and bench press in different moments from June 2013 to August 2016 to monitor the muscle power of these parathletes and identified that the best results were achieved close to the Paralympic Games.

5. Longitudinal studies on the manifestation of muscle power in combat sports athletes

To date, few longitudinal studies have been conducted to investigate the effect of training on combat sports athletes' muscle power manifestation. However, it seems that sports professionals should be aware of the variation of the training (periodization) and the choice and specificity of the exercises, only in this way the training can cause positive effects to the performance of the athletes [85]. Additionally, it seems that traditional strength training does not cause positive changes in the performance of the gesture performed during the match of athletes involved in the practice of striking combat sports [86]. In order to cause the desired adaptations, more specialized training is required in highly specialized athletes [4,5].

In the Ke-tien study [85], the objective was to describe the effect of 20 weeks of strength training and muscle power on taekwondo athletes' performance. The muscle strength and power training was divided into five phases, with the following objectives: 1) weeks 1-6: general physical conditioning (4 exercises, 25-40 repetitions, intensity between 25-45% of 1RM); 2) weeks 7-12: muscle hypertrophy (8 exercises, ~ 10 repetitions, intensity between 75-85% of 1RM); 3) weeks 13-16: maximum strength (7 exercises, 3-5 repetitions , intensity between 40% of 1RM to hang snatch, 45% of 1RM to power clean and hang clean and 95% of 1RM to another exercises); and 4) weeks 17-20: muscle power (6 exercises, 3-5 repetitions, intensity between 80-90% of 1RM). The training was conducted three times a week. The athletes performed the SJ and the jump with CMJ before and after 20 weeks of training. Athletes increased jump height after the training period, as can be seen in Figure 16. Athletes improved 7.1% and 3.3% in SJ and CMJ, respectively.



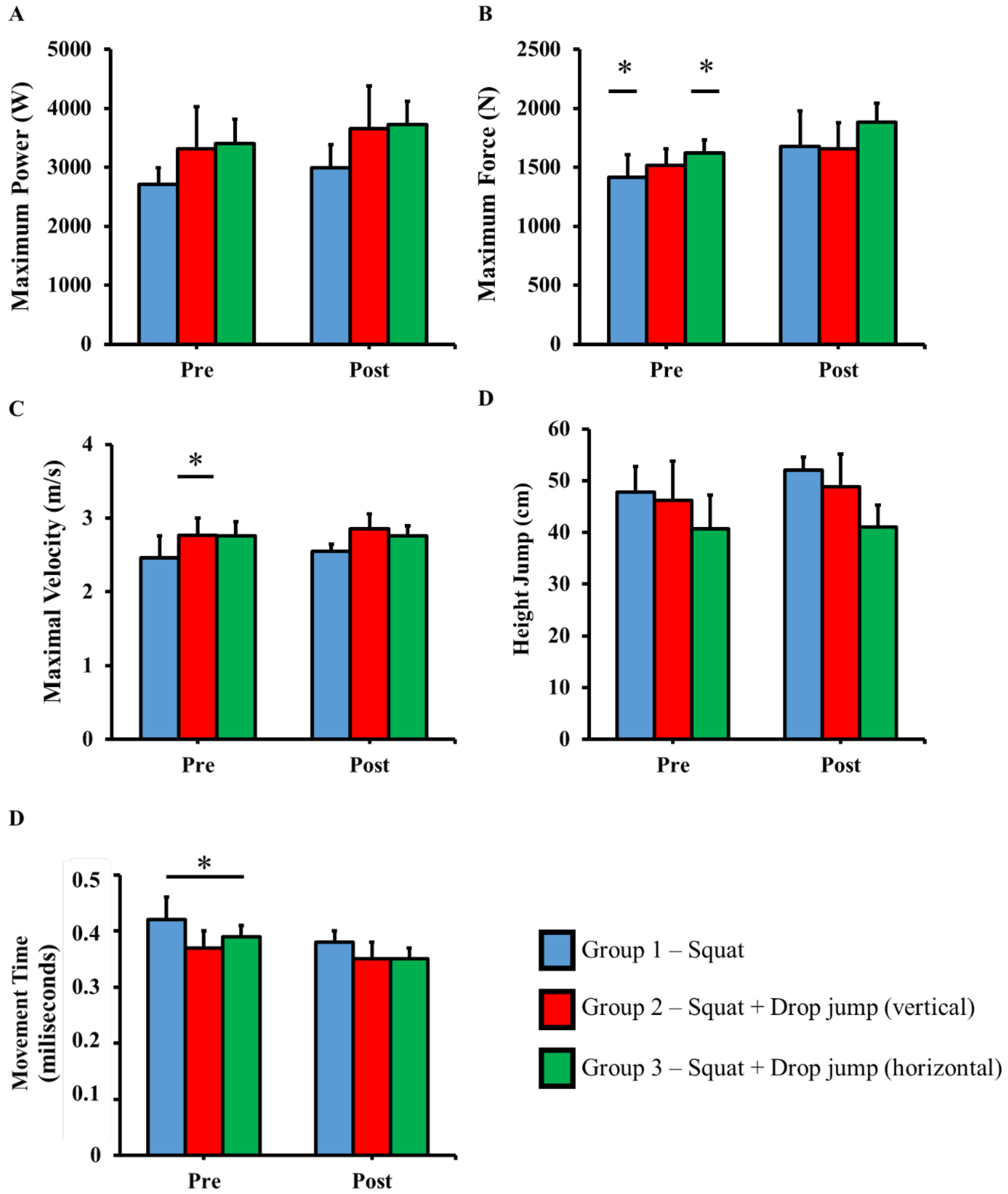
Note: * statistically significant difference (p <0.05) between the pre- and post-intervention moments in both tests.

Figure 16: Performance in muscle power test after 20 weeks of training (Adapted from Ke-tien [85]).

The study by Tsai et al. [87] aimed to compare the effect of three different training structures, performed over a period of 8 weeks, using taekwondo athletes. The groups trained as follows: 1) training using half squat exercise; 2) combination of vertical jump and half squat exercise, and 3) combination of horizontal jumping and half squat exercise. The volume and intensity used are shown in Table 2. Athletes who performed traditional strength training, using only the squat exercise, improved maximum strength (Figure 17 B). On the other hand, athletes who performed the training using variations of plyometric exercises improved the maximum power, maximum strength, speed and time of a blow (Figure 17 A, B, C, and E).

Table 2: Training protocol used by taekwondo athletes (Tsai et al. [87]).

Strength training (squat)			
Weeks	Intensity (%)	Repetitions	Rest interval (min)
1st -2nd	80	5	2
3rd -4th	85	4	2
5th -6th	90	3	2
7th -8th	95	2	2
Power training (drop jump)			
Weeks	Intensity (cm)	Repetitions	Rest interval (min)
1st -2nd	50	10	3
3rd -4th	57	10	3
5th -6th	64	10	3
7th -8th	71	10	3



Note: * difference between pre- and post-at the same points ($p < 0.05$).

Figure 17: Pre and post-training performance of taekwondo athletes (Adapted from Tsai et al. [87]).

The study by Voigt and Klaussen [88] investigated the effect of three strength training routines on the muscle power of the punch performed by karate athletes. The duration of the training was 20 weeks. The karate's group 1 (G1) underwent strength training for 16 weeks with heavy loads combined with training with light loads in the punching bag, followed by four weeks of intensive training in the punching bag. The karate's group 2 (G2) underwent training in the punching bag combined with punch exercises and intensification of training between the eighth and the sixteenth weeks. Group 3 (G3) was formed by non-karate athletes who performed sixteen weeks of strength training, followed by seven weeks without strength training. The results were as follows: all groups presented performance improvement for dynamic force, between 14% and 53%. G1 showed an increase in hand (10.1%) and shoulder speed (34.7%) during the first sixteen weeks of strength training. G2 presented an increase in the angular velocity of the shoulder until the sixteenth week (34.7%). G3 did not show any increase in angular velocity of the hand and shoulder but showed an improvement in the angular velocity of the elbow during the initial sixteen weeks (12.8%). Between the sixteenth and twentieth weeks, the G1 reduced the maximum shoulder velocity, without significant change in muscle strength. During this period the karate athletes discontinued strength training with high loads and kept only the training in the punching bag. Strength training with high loads carried out isolated did not influence the speed of specific movement of karate athletes. On the other hand, specific punch training was effective in increasing punch velocity and better utilizing the stretching-shortening cycle of the shoulder flexor and elbow extensors muscles. Finally, the results indicated that strength training is able to improve movement speed only when combined with specific punch training.

In the study by Seo et al. [89] the effect of 8 weeks of physical training on the performance of taekwondo athletes was investigated. Athletes performed strength, muscle power, and metabolic training during the 8 weeks. When the results of the pre- and post-tests were compared, there was a variation of 0.2% for male athletes and 2.2% for female athletes (values in delta percentage). However, there was no statistical difference between the pre- and post-training moments. The mean value of the horizontal jump is shown in Figure 18. Probably, the result achieved in this study should be associated with the lack of specificity of the training performed.

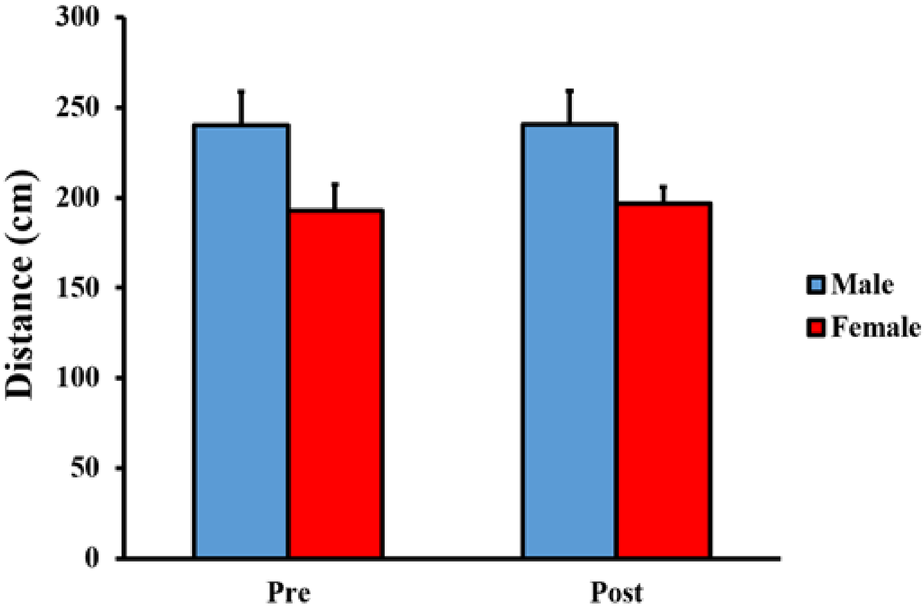


Figure 18: Performance in the horizontal jump pre- and post-20 weeks of training (Adapted from Seo et al. [89]).

Training programs for strength and muscle power using conventional gestures alter the performance of untrained or non-athletes [90]. However, more specific power training is needed to improve the performance of elite athletes [90]. Among taekwondo athletes, Jakubiak and Saunders [28] had the objective of investigating the effect of a specific training technique (*Bandal-Tchagui*), against the resistance of an elastic band, on the development of muscle power. Twelve taekwondo athletes were divided into two groups with six athletes in each group. The athletes performed the training three times per week for four weeks. The taekwondo training sessions were not interrupted. The training was composed by three sets of six repetitions with 1-min rest interval between sets. The number of sets and the strength provided by elastic increased progressively. Each week an exercise set was added, and the elastic tube was lengthened by 30 cm. This elongation of the elastic tube linearly increases the resistance against movement. There was a statistical difference in the experimental group. The athletes who performed the training improved the semicircular kick speed (*Bandal-Tchagui*) after the training period in comparison to the movement performed before the training period, whereas the athletes in the control group had a non-significant variation of 0.1%. The velocity of the *bandal tchagui* was improved in five of the six athletes in the experimental group (between 5% and 17%), but increased in only one athlete in the control group (6%). One-point worth emphasizing is that the resistance imposed by the elastic band cannot be so high as to be detrimental to the movement pattern of the technique that will be performed. Thus, an additional overload, caused by the elastic band, will only be beneficial if the technique pattern is not changed.

The study by Olsen and Hopkins [29] aimed to investigate the effects of training conducted with ballistic action attempts on kicking performance. The dependent variables used were: frontal kick, lateral kick and a blow with the palm of the hand. The study participants were divided into two groups, the experimental group (n = 13) and the control group (n = 9). The experimental group underwent strength training during the first 8 weeks, three times per week, two sets in the first week and three sets between the second and eighth weeks. Subsequently, the athletes of the experimental group performed strength training and ballistic training between the tenth and ninth weeks. Conventional strength training was performed twice per week. Ballistic training was performed three times per week, with a volume of four sets of ten repetitions during weeks ten and eleven, increasing to five sets of ten repetitions between weeks twelve and nine, in addition to practicing combat sports-specific training. The control group underwent combat sports-specific training during the first nine weeks, followed by additional front kick training three times a week. During weeks 10 and 11, four sets of ten repetitions per leg were performed. During the weeks twelve to nineteen, five sets of ten repetitions per leg were performed. The experimental group, which performed the conventional strength training, obtained a 12% improvement in the force generated during the frontal kick, in comparison to the control group. Ballistic training and conventional force training reduced lateral kick strength by 15% but increased movement speed by 11-21%. Ballistic training was more efficient at improving the performance of more experienced athletes. Thus, attempting to perform ballistic movements during training may be the best strategy for skilled athletes in combat sports where the strength and speed of movement execution are critical variables for performance.

Franchini et al. [91] aimed to determine the most efficient strength training method for judo athletes. Thirteen athletes participated in the study and were divided into two groups. Three strength training sessions were conducted for eight weeks, as shown in Table 3. Athletes performed a test battery before and after the training period. The measure of muscle power used was the horizontal jump. The first group, composed of six athletes performed the linear periodization, the second group, composed of seven athletes performed the non-linear undulating periodization. After the training period, there was no statistical difference between the groups nor between the pre- and post-moments for muscle power (Figure 19).

Table 3: Periodization of strength training used in the study by Franchini et al. [91].

	Linear			**Non-Linear (undulating)**		
	1st week	2nd week		1st week	2nd week	
Monday	3-5 RM	3-5 RM		3-5 RM	Power Exercises	
Wednesday	3-5 RM	3-5 RM		Power Exercises	15-20 RM	
Friday	3-5 RM	3-5 RM		15-20 RM	3-5 RM	
	3rd week	4th week	5th week	3rd week	4th week	5th week
Monday	Power Exercises	Power Exercises	Power Exercises	3-5 RM	15-20 RM	Power Exercises
Wednesday	Power Exercises	Power Exercises	Power Exercises	Power Exercises	3-5 RM	15-20 RM
Friday	Power Exercises	Power Exercises	Power Exercises	15-20 RM	Power Exercises	Power Exercises
	6th week	7th week	8th week	6th week	7th week	8th week
Monday	15-20 RM	15-20 RM	15-20 RM	Power Exercises	15-20 RM	15-20 RM
Wednesday	15-20 RM	15-20 RM	15-20 RM	15-20 RM	Power Exercises	3-5 RM
Friday	15-20 RM	15-20 RM	15-20 RM	3-5 RM	15-20 RM	Power Exercises

Note: RM: Repetition Maximum

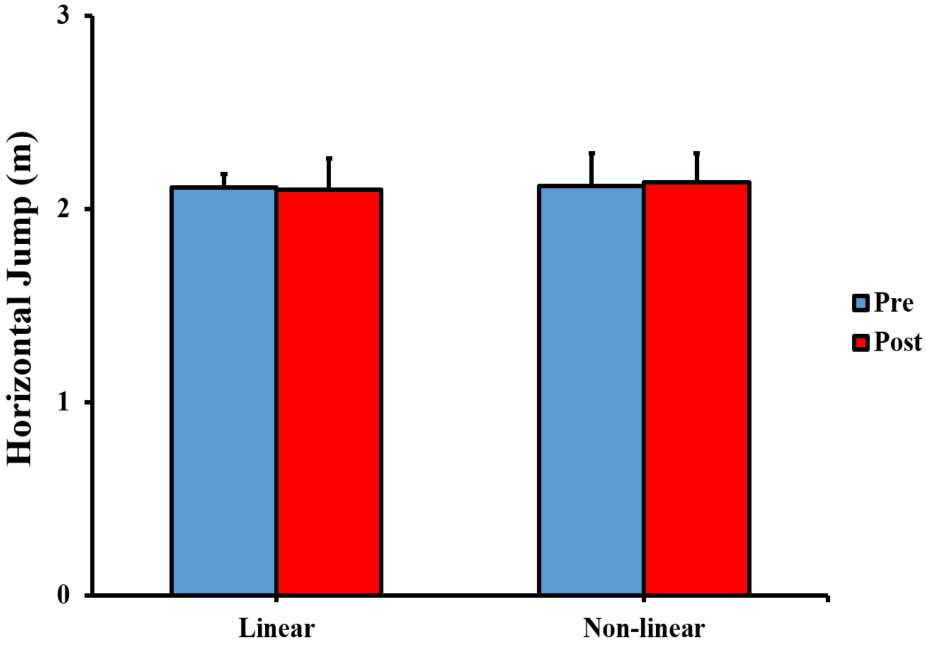


Figure 19: Performance in the horizontal jump before and after eight weeks of strength training with different load distributions (Adapted from Franchini et al. [91]).

Marques et al. [92] 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 similar to the transmutation phase, but the volume was reduced and judo technical actions were the main focus of the training phase. The authors tested the athletes concerning muscle power (CMJ and SJ), judo-specific test (SJFT) and maximal strength (row exercise 1RM). For the muscle power variables assessed there were no effects of competitive level, training phase or interaction. Although lower-body muscle power is relevant for judo performance, the fact that both CMJ and SJ are shorter than the duration of a judo throwing technique (approximately 1.14s) and are executed with no load, are aspects that have been used to suggest that the typical judo training adaptation could not be detected by these tests [93].

Kostikiadis et al. [94] compared the effects of a 4-week low-volume strength and conditioning training program based on circuit training with a regular conditioning training program. Strength and conditioning training were performed three times per week every 2 days (Monday, Wednesday, Friday), whereas in the intermediate three days (Tuesday, Thursday, Saturday), all athletes followed the same MMA training, focused on technical skills, striking and grappling. The strength training group executed strength and power exercises (i.e., squat, bench press and deadlift at 80-95% of 1RM followed by 3 CMJ jumps, 2-kg medicine ball throws, and jump shrugs with 45% of the deadlift load after each set, respectively, with 1 min rest between the three repetitions of each power exercise), and 10 min after they performed a rowing aerobic high-intensity interval training (details not provided here due to the goals of the present chapter) in the first and third sessions of the week. The second session in each week was directed to improve muscle power and speed (i.e., loaded jump squats in a Smith machine, with 4-min intervals, during which they performed drop jumps using individual optimal drop height, with 12s intervals; 4 sets of 8 reps of a 4-kg medicine jab punch throws. After 1.5 min of rest between sets, they performed 8 plyometric push-ups, with 12s between repetitions; then, the athletes performed 5 x 10m weighted sled maximum sprints with 4-min intervals, using loads to allow for a fatigue index lower than 10%, and 5 x 10 m unloaded sprints with 4-min intervals; then, a sprint interval training, involving 6 x 40 m shuttle sprints with change of direction each 10 m and 20s intervals between sets). The other group followed their regular strength and conditioning training routine plus the following training sessions: First and third sessions –

circuit workout using squat, military press and kettlebell swings, followed by 20 min of rope skipping at 70-80% predicted maximum heart rate; Second session – circuit training (5 rounds) using kettlebell swings, clean and press, sumo deadlifts high pull, executing the maximum number of repetitions in 1 min with 1 min between exercises. Then, they executed 20 min of rope skipping. After the 4-week training significant improvements were found for the strength training group but not for the regular strength training group. Concerning muscle power, the strength training group improve the SJ power (pre: 1195 ± 122.5 W; post: 1230 ± 6 W), right (pre: 10.5 ± 0.9 m/s; post: 11.6 ± 0.8 m/s) and left arm medicine ball throw velocity (pre: 9.8 ± 0.6 m/s; post: 10.3 ± 0.9 m/s), 10 m sprint time (pre: 1.95 ± 0.06 s; post: 1.88 ± 0.05 s), and 2-m 75 kg dummy take down (pre: 0.96 ± 0.1 s; post: 0.74 ± 0.01 s). Moreover, these post-training values were better than those presented by the regular training group. Therefore, low-volume high-intensity training was more appropriate to improve muscle power performance of MMA athletes.

6. Means and methods for the development of muscle power in combat sports athletes

A training session aimed at the muscle power development can be described by the acute variables of the program, as follow description.

6.1. Exercise choice

The choice of exercises that will compose the training sessions involves many decisions, from the equipment to be used to the type of muscle action [95]. The number of joint angles and possible exercises to be performed are almost infinite. Additionally, we know that when a muscle is not activated, it will not undergo any type of adaptation and, consequently, will not contribute to a better performance. For this reason, the choice of exercises should be a careful analysis of the athlete's needs in face of the requirements of the modality practiced [95].

In combat sports, complex movements are often performed, which includes jumps and twists [27,60,96,97]. In the application of some techniques, usually, each member is performing a different action, sometimes in different directions. For this reason, the exercises to be used in the training session should stress the muscles that are activated during the match, preferably at specific joint angles and muscle actions. Thus, to choose the exercises, an analysis is necessary, initially responding to some questions that affect the elaboration of the program. These questions are [98]:

1. What are the metabolic demands?
2. What are the biomechanical demands?
3. What are the main injury sites for a specific combat sport and the athlete's injuries history?

Among the main exercises used for the development of muscle power are the traditional, ballistic, plyometric and Olympic weightlifting style and its variations [4], as exemplified in Table 4.

Table 4: The main exercises used for muscle power training routines.

Exercises for muscle power development	Weightlifting derivatives	Ballistic exercises
Snatch	Power snatch	Bench Press
Clean and Jerk	Power clean	Pull
	Clean	Squat
	Snatch pull	
	Hang clean	
	Jerk	

6.2. Traditional resistance training exercises

The most commonly used strength exercises in a training program are the back squat and bench press. These exercises are relevant in the early stages of the training program or for athletes who have low levels of strength [4]. However, it has been suggested that as soon as muscle strength and power levels increase, the effectiveness of this exercise decreases [4].

During training with traditional strength exercises, there is a deceleration in the final phase of the movement [99,100]. For example, during bench press exercise, the duration of the deceleration phase represented 14% of the total time with 104% of 1RM, 23% with 100% of 1RM and 52% with 80% of 1RM [99]. When the bench press exercise was performed in an explosive manner with 45% of 1RM, the deceleration phase lasted 40% of the total movement [100]. This fact is contrary to what happens during the application of a combat sport technique, when the movement is accelerated at the final phase, and often the athlete projects to complete the execution of the technique. The deceleration phase of the movement is explained by the reduction of the activation of the agonist musculature and the increase of the activation of the antagonist muscles [100]. As a result of the deceleration of movement in the final phase and the lack of specificity with the gestures of the combat sports, the transfer can be impaired [4].

Although the traditional exercises for strength and power training are important, it will be necessary to perform other, more specific, mechanic stimuli so that muscle power continues to be developed [4].

6.3. Ballistic exercises

The problem of the deceleration phase is solved with the use of ballistic exercises. Many times, the ballistic exercises predict the projection of the implement or the body weight itself at the final phase of the movement, eliminating the deceleration. The main exercises used are squats and bench press. The intensity in which ballistic exercises are performed varies between 0-80% of 1RM obtained during exercises performed in a traditional way [4].

Previous studies have compared kinetics, kinematics, and neural activation of the bench press exercise performed in a traditional and ballistic manner [100]. Superior performance has been observed during ballistic exercise when compared to the same exercise performed in a traditional manner. In addition, mean muscle activation during the concentric phase for the pectoralis major, anterior deltoid, triceps brachii, and biceps brachii muscles were higher (19%, 34%, 44%, and 27% respectively) during the ballistic exercise in comparison to the traditional execution [100]. In addition, it was observed that eight-week jump squat exercises involving well-trained athletes (volleyball) resulted in improvement in vertical jump compared to the group that performed the training using the squat and leg press exercises during the same period [101]. Thus, it seems that the use of ballistic exercises helps the athlete in the muscle power production during the accomplishment of a specific gesture when compared to the traditional exercises.

6.4. Plyometric exercises

Plyometric exercises are characterized by rapid stretch-shorten cycle (SSC) muscle actions and used by athletes who need to perform explosive movements during the training routine [4]. The most used exercises during a plyometric training session are the deep jumps and some variations of jumps with horizontal and vertical component [102,103]. In addition, multiple jumps, single leg, and box exercises are performed to increase the overload imposed on the muscle and, consequently, the muscle power generated. The basic concept behind plyometric training is to absorb energy during the eccentric phase of movement and move to the concentric phase as quickly as possible, avoiding loss of energy as heat [9]. For example, superiority at jump height has been observed during CMJ as compared with SJ, starting from knee flexion at 90º [104]. This difference in performance has been attributed to the characteristic of each jump. While the SJ is purely concentric, in the CMJ an eccentric phase and a rapid transition to the concentric phase are performed. The reactive force index is influenced by the height of the jump and by the individual's training state, with athletes achieving the best performance.

Traditionally, plyometric exercises are performed with little or no external overload [102]. When some overload is used, usually medicine ball, the goal is to potentiate energy absorption during the eccentric phase of the stretching-shortening cycle [4,5,102,103]. Another resource used for the same purpose is to increase the height of the deep jump [4,5]. Table 5 shows different classifications to be used for the prescription of plyometric exercises.

Table 5: Classification of plyometric exercises (Adapted from Bompa [105]).

Exercise Type	Exercise Intensity	Number of sets and repetitions	Number of repetitions per session	Rest interval between sets
High reactivity jumps	Maximal	5-8 x 10-20	120-150	8-10min
Drop Jumps	Very High	5-15 x 5-15	75-100	5-7min
Multiple jumps	Sub-maximal	3-25 x 5-15	50-250	3-5min
Low reactivity jumps	Moderate	10-25 x 10-25	150-250	3-5min
Low impact, jumps in place, throwing implements	Low	10-30 x 10-15	50-300	2-3min

6.5. Olympic weightlifting exercises and its derivatives

Weightlifting exercises are the snatch and clean and jerk [106]. These exercises are used in training programs for athletes of various modalities [18,79,107]. Olympic weightlifting exercises and their derivatives are proposed as efficient for the development of muscle power [108]. These exercises are chosen by the great power generated during their execution [11,106]. This characteristic is a result of the acceleration generated during the entire propulsive phase of the movement [109,110]. Musculoskeletal changes are also attributed to the use of strength and power exercises, including Olympic weightlifting [4,5,106]. Among these changes are the modification of type IIx fibers to type IIA, increase in maximal strength and muscle hypertrophy, especially type II fibers. Type II fibers have a great capacity to generate muscle power and strength, superior to type I fibers [111–114]. The athletes involved in modalities in which the main characteristic is power, on average, 53% to 65% of type II fibers in the vastus lateralis muscle [115–122]. However, untrained subjects have the same percentage distribution of type II fibers, the difference is that in athletes the cross-sectional area of the muscle is larger [116,117,121,122]. This feature allows athletes to achieve superior performance in power tests and is desired by athletes of various sports, including combat sports. However, it is worth mentioning that there is no study performed with athletes of the combat sports. In fact, few studies have investigated the effectiveness of training for muscle power using Olympic weightlifting exercises.

It is not the purpose of this text to demonstrate the technique of movement of Olympic weightlifting exercises. The technical description of Olympic weightlifting exercises can easily be found in the specialized literature [106,123]. The main objective of this session is to present information that may be useful when planning and selecting the exercises that will be used by the combat sports athletes.

6.6. Complex exercises

Complex training is performed with the aim of stimulating adaptations for muscle strength and power in the same training session [124]. Complex training involves the combination of an exercise performed at high-intensity followed by an exercise performed with low overload, using biomechanically similar movements, in each set [125]. An example of a complex exercise in judo is to perform the squat exercise followed by the *seoi-nage* technique; another example applied to striking combat sports is the execution of bench press exercise followed by a punch technique.

In one of the first literature reviews on the subject, Ebben and Watts [126] made recommendations on the prescription of complex training. Subsequently, several studies have investigated the acute effect of complex training on performance. Among the manipulated variables are mainly the training intensity [16,127] and the interval between conditioning activity (e.g., strength exercise) and the conditioned activity (e.g., main activity) [127–135]. There is evidence that complex training can improve maximal strength and 20-m sprint speed when the complex training is applied for more than 4 weeks [136]. Therefore, complex training can provide positive benefits to key elements of power (i.e., maximal strength and speed), but no chronic study using combat sports athletes was found.

Complex training has been used among athletes practicing striking [16] and grappling combat sports [15]. In the study performed with taekwondo athletes, the complex training was superior to the others in improving the performance during the accomplishment of the task using specific gestures of the modality, the frequency speed of kick test (FSKT) [16]. However, although there was an improvement in performance during FSKT, there was no improvement in performance during CMJ. This result was attributed to the lack of CMJ specificity for the modality. However, another study using a combination of low- (1 x 3 rep) versus high-volume (3 x 3 rep) and low- (50% of 1RM) versus high-intensity (90% of 1RM) strength conditioning activities did not find any improvement in the CMJ or FSKT performance when 10-min rest intervals were used [137].

Aandahl et al. [138] submitted 16 striking combat sport athletes to a 10-min warm-up followed either by 10 kicks using an elastic band (30 N resistance in the initial and 60 N in the final kick phases) or not, and after 5-8 min tested their roundhouse kick performance. Foot kicking velocity increased 3.3% when the elastic band was used, which was explained by the increased muscle activity in the vastus medialis (35.2%) and rectus femoris (43.9%) in this condition. These results that the use of elastic band in combat sport-specific conditioning activity can also improve kick performance.

The study carried out with judo athletes aimed to investigate the effect of different strength and power exercises on performance during a specific judo test [15]. The specific test was the Special Judo Fitness Test (SJFT). This test is divided into three periods: (A) 15 s, (B) 30 s, and (C) 30 s, with 10 s interval between periods. It was observed an increase in performance in the first period after performing 10 sets of three jumps with 30-s intervals between sets and 3-min interval before executing the SJFT (6.4 ± 0.5 throws) compared to the control condition (5.7 ± 0.5 throws). The best test index (13.58 ± 0.72) occurred after performing the complex exercise, being lower than the index obtained after the plyometric exercise (14.51 ± 0.54); lower index represents a better performance in this test. However, it is worth noting that the test index is also influenced by the heart rate after the test, which may have been more determinant for the final test result than the number of throws performed.

Lum [139] compared a regular judo-specific warm-up, a lower-body conditioning activity (3 x 5 standing broad jump) and a lower- and upper-body conditioning activity (2 x 5 standing broad jump plus 2 x 5 elastic band pull simulating the *kuzushi* phase of a judo throwing technique) on the high pull test performance and on the SJFT performance. The interval between these procedures and the high pull test was 5-min long, and between this test and the SJFT a 2-min interval was given. RPE was lower after the two conditioning activities compared with the traditional warm-up. The results indicated that the combined lower- and upper-body conditioning activity improved the high pull test power compared with the traditional warm-up, whereas both conditioning activities resulted in higher number of throws (lower-body: 5.3 ± 0.6 rep; lower- and upper-body: 5.3 ± 0.5 rep) in the set A of SJFT compared with the traditional warm-up (4.9 ± 0.5 rep). This study confirmed that the use of complex training can improve acute judo-specific performance.

Boxers, karate and to a lesser degree taekwondo athlete (because they use few punches, ~ 2% [140]), can benefit from the use of complex exercises for the upper limbs. An example of a complex exercise for the upper limbs is to perform the bench press exercise first, followed by push-ups. Another example is the bench press, followed by specific punching actions.

Some indications for the prescription of complex training aimed at the acute improvement of performance are presented in the literature [55,141]. These studies indicate the most appropriate situation to achieve an acute improvement in performance (Table 6).

Table 6: Characteristics needed for the prescription of complex training aiming at the acute improvement of acute performance (Based on Gouvêa et al. [141], Wilson et al. [55]).

Variable	Better performance
Training status	Athletes
Muscle action performed	Dynamic for lower limbs
Exercise intensity	Moderate (60-84% of 1RM)
Volume	Multiple sets
Rest interval between stimuli	3-10 min

The use of strength and power exercises may benefit the athletes when performing the specific gesture [23,28]. In combat sports, the ability to perform force quickly is often more important than reaching maximum force. In striking combat sports such as boxing, karate, and taekwondo the techniques are applied quickly, as can be seen in Table 7 and, if the athlete is trained to perform powerful movements, he/she may win the combat.

Table 7: Characteristics of different blows according to the combat sport.

Reference	Action	Linear velocity (m/s)	Duration (s)
Karate			
Diacu [142]	Junzuki	5.7 – 9.8	-
	Otoshiuke	10 – 14	-
	Shutouke	10 – 14	-
	Mae-geri	9.9 – 14.4	-
	Yoko-geri	9.9 – 14.4	-
	Mawashi-geri	9.5 – 11.0	-
	Ushiro-geri	10.6 – 12.0	-
Chiu and Shiang [143]	Reverse punch (Gyaku Zuki)	14.7	-
	Straight punch (Oi Zuki)	10.6	-
Gianino [144]	Reverse punch (Gyaku Zuki)	13.0	-
	Straight punch (Oi Zuki)	10.0	-
Daniel and LiviuRazvan [145]	Reverse punch (Gyaku Zuki)	8.2	-
	Kizame Zuki	6.8	-
Cesari and Bertucco [146]	Tate Zuki	Athletes: 7.8	-
		Novices: 6.5	-
Smith 1983	Straight punch (direct)	vmean 11.5	-
Taekwondo			
Pearson [147]	Semicircle Kick	14.6	-
Pieter and Pieter [148]	Semicircle Kick	15.9	-
Serina and Lieu [149]	Semicircle Kick	15.5	-
Conkel et al. (31)	Semicircle Kick	13.4	-
Svoboda et al. [150]	Straight punch (direct)	vmax 8.4	-
		vmean 8.0	-
Boxe			
Walilko et al. [151]	Straight punch (direct)	Vmáx: 13.4	-
		Vmean: 9.1	-
Tong-Iam et al. [152]	Straight punch (direct)	Vmáx: 6.6	-
		Vmean: 6.3	-
House and Cowan [153]	Straight punch (direct)	vmax 8.1	-
		vmean 7.0	-
Cheraghi et al. [154]	Straight punch (direct)	vmax 9.4	-
		vmean 7.8	-
Bingul et al. [155]	Straight punch (direct)	vmean 5.3	-
Kimm and Thiel [156]	Straight punch (direct)	vmean 8.1	-
Atha et al. [157]	Straight punch (direct)	vmax 8.9	-
Kung fu			
Neto et al. [158]	Palm strike	vmax 5.8	-
		vmean 5.5	-
Judo			
Blais, Trilles, Lacouture [159]	Morote-seoı-nage	-	1.14
	Imbalance (Kuzushi)	-	0.56
	Prepation (Tsukuri)	-	0.42
	Execution (Kake)	-	0.16

6.7. Exercise order

Among the variables that are reported in this chapter, the order of exercises is certainly the less studied. For many years the recommendation on the order of the exercises was to perform the exercises intended for the large muscle groups before the exercises for smaller muscle groups [13,160,161]. Another recommendation is that multi-joint exercises should be performed before mono-articular ones [160,161]. This recommendation was made because when a smaller muscle group, considered secondary in some movements, or a mono-articular exercise is performed before, there is a possibility that the training may be less effective for the primary muscle due to the reduced ability to maintain performance during the sets executed at the end of the session [13,162]. However, few studies have investigated these recommendations with the use of protocols involving exercises for muscle power development [162,163].

Another recommendation based on the practical experience of the training relates to the performance of exercises in a priority way, that is, if the training for muscle power is the main objective of the training session, it must be performed first. This design allows the athlete to perform the training aimed at muscle power without fatigue, which could hinder the development of maximum power. On the other hand, in some moments it may be interesting for the combat sports athletes to train power in a situation of fatigue, since many times, several actions are carried out during the same match and several matches in a day of competition [46–49,52].

Another situation in which the exercise should be performed at the beginning of the training session is when it is being improved or even learned [13]. This situation will allow the athlete to perform the movement without limitations caused by muscle fatigue.

Finally, training for muscle power involves performing multi-joint exercises in an explosive manner, which will be best performed if they are performed at the beginning of the training session [4,5]. Inappropriate sequencing of the training session aiming at muscle power may compromise the athlete's performance and shorten the training session [164]. An example of the contents that can be worked on in the same training session is presented in Table 8.

Table 8: Contents to be combined in the same training session (Based on Haff and Haff, [164]).

Primary purpose	Secondary purpose
Muscle Power	Endurance
Muscle Power	Velocity
Muscle Power	Agility
Muscle Power	Maximal strength
Technical training	Muscle power

Usually, the exercises used to train athletes' muscle power are multi-articular because they resemble what happens during sports practice. In addition, these movements generate a high speed of execution and require inter- and intra-muscle coordination [11].

6.8. Exercise intensity

The load to be used during training intended for muscle power development is another point of discussion. In general, athletes begin to perform exercises with more intense loads and as training progresses, they use lighter loads and less training volume [160,161,165]. This strategy aims to create the necessary conditions for the manifestation of the best performance during the competition. Muscle power is highly dependent on the athlete's ability to develop a high amount of force, and this is evident from studies that show a strong positive correlation ($r = 0.77$ to 0.94) between peak power and maximum strength [166].

Training for muscle power at high loads is based on the principle of size. This principle is based on the size or caliber of the motoneuron, it is said that the fibers innervated by low-caliber neurons are activated earlier than the high-caliber neurons [167]. Additionally, on the lack of specificity regarding the speed of execution of the movement, it has been said that athletes should have the intention of performing the movement quickly, even if this does not happen [29,168,169]. Exercise performed in this way can improve muscle power [29]. However, the results are still controversial in the literature [29,168,169]. This difference can perhaps be attributed to the characteristics of the movements used in the studies. Punches and kicks are complex, multi-articular movements [29] and require greater motor coordination than the mono-articular movements of plantar back flexion, which was the movement used in the study in which there was an improvement in muscle power in these training conditions [168].

Training using lighter loads or intensity is based on the specificity principle, assuming that athletes can obtain better results if they train with loads with which they generate the greatest muscle power. In this sense, winning karate athletes differ from defeated athletes by generating higher muscle power with lighter loads (30% of 1RM), but not with the use of slightly higher loads (60% of 1RM) [74].

An aspect that should be considered when choosing the intensity used, in addition to the phase of the periodization in which the athlete is, is that if the strength component is prioritized the improvement will occur in the portion of the force in the force-velocity curve. If the velocity is prioritized, the improvement will occur at the portion of velocity in the force-velocity curve. And finally, we can suggest that the use of the optimal load to improve the portion of maximal power in the force-velocity curve. This load improves maximum strength too, but to a lesser degree compared with percentages closer to the maximal loads [59,170].

Another strategy suggested for the development of muscle power is the training with mixed intensity stimulus [4,11,171]. If we imagine that the use of high loads will further affect the portion of the force and that lower loads will affect the speed portion of the force-velocity curve more, we may suggest that training with mixed loads over a period will also be beneficial for the development of power muscular. Harris et al. [172] compared loads that maximized force (80% of 1RM), loads that maximized muscle power generation (30% of peak isometric force), and the combination of both for lower limbs training. After twelve weeks of training, the group that utilized loads that maximized muscle strength did not improve performance during the vertical jump (cm), average vertical jump power (W), peak vertical jump power (W), or standing long jump (m). However, for training loads that maximized muscle power generation and the group that used combined loads, the peak vertical jump power (W) (2.5% and 2.6%, respectively) and vertical jump (2.3 cm and 1.8 cm, respectively) were improved.

In any case, it is necessary to use exercises with different characteristics throughout the competitive season. This is because muscle power is dependent on the integration between force and velocity. In this way, the athlete can improve his performance if there is an improvement in one or both of these characteristics. At the beginning of the season, the athlete can benefit from the use of exercises that generate higher muscle power with higher loads, such as the power clean and the hang power clean, and later use the exercises that generate greater muscle power with intermediate loads or as in the case of squat and jumping exercises respectively. Or even work with a greater range of intensity in a given exercise. For example, perform the squat exercise with intensity between 40% and 70% of 1RM (percentage in which the highest power is generated in that exercise).

An alternative is to work simultaneously with different exercises at different percentages of 1RM. For example, in Table 9 it is suggested to perform exercises with different characteristics and intensities, which will emphasize different portions of the force-velocity curve.

Table 9: Example of exercises performed with different intensities and the emphasis given in the force-velocity curve (Adapted from Haff and Nimphius [170]).

Exercise	Series x Reps	Load (% de 1RM)	Emphasis
Power clean	3 x 5	75-85	Strength
Back Squat	3 x 5	80-85	Strength
Jump Squat	3 x 5	0-30	Velocity
Drop Jump	3 x 5	0	Velocity

Finally, it is expected that athletes will be able to transfer the achieved performance and generate the greatest muscle power during the performance of a specific gesture. The explanation for expecting this effect is that if during planning the two portions of the force-velocity curve are stimulated both will be improved [101,172–179]. Another practical application is that specific movement has a specific coordination and therefore should be introduced in strength-training to improve power in sport-specific actions.

6.9. Repetitions, number of sets, intensity and rest interval between sets and exercises

The production of muscle power is associated with the quality with which each repetition is performed [180]. Traditionally, it is recommended to perform 3 to 6 sets and 1 to 8 repetitions of a given exercise in training sessions designed to develop muscle power [17,18,160,161].

Initially, the effect of the number of sets, repetitions and the way in which they can be performed aiming the development of muscle power will be approached. In general, the sets are a group of repetitions, carried out without interruption, that is, without rest. In turn, repetition is defined as the execution of a complete movement, concentric and eccentric phases, of an exercise. To date, all studies conducted with combat sports athletes have used this configuration of repetitions and sets for the development of acute [15,16] and chronic muscle power [28,91]. It has been observed that increasing the number of repetitions results in higher concentrations of blood lactate [181] (Figure 20). Increased blood lactate is associated with the increase of the hydrogen ions (H+), which is indicated as one of the causes of fatigue [182–184]. However, it does not seem to affect the manifestation of muscle power during the match [36,46,48,49,52]. But the temporal structure seems to be important so that powerful techniques can be carried out for a longer time, as it will be necessary to recover or to avoid the depletion of the energy supplies to continue the task so that the gesture is executed in perfect conditions and with power.

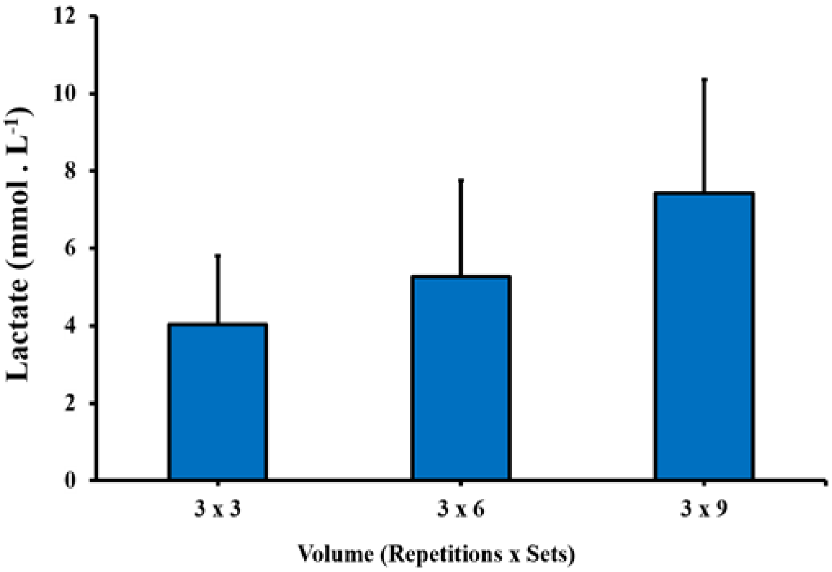


Figure 20: Accumulation of lactate in the power clean exercise according to the volume (Adapted from Date et al. [181]).

Some recent studies have suggested that the use of new methods for performing repetitions within the same sets may alter the performance of athletes wishing to develop muscle power [180,185–187]. Based on some scientific evidence, it is possible to suggest that the performance of sets with inter-repetition intervals and sets with clustered repetitions could benefit athletes who practice sports in which the ability to perform movements with muscle power is important [180,188], as is the case of combat sports. The effect of introducing pause between repetitions between equated sessions regarding volume, intensity and total rest was investigated in judo athletes [189]. Two groups were compared, one which trained up to set failure and another with no failure. The set failure group executed 3 sets to failure of parallel back squat with 4 repetitions at maximum load, and a rest of 3 min between the sets. The no set failure group performed the same but total resting time was distributed among individual repetitions. The authors reported that the no set failure group showed an 18.94% (~17.98) higher average mean propulsive velocity during the session (0.42 ± 0.04 vs. 0.35 ± 0.08 m.s-1), lower blood lactate concentration after session (maximum average value 1.52 ± 0.77 vs. 3.95 ± 1.82 mmol/L-1) and higher mean propulsive velocity with load corresponding to maximum propulsive power (mean propulsive velocity immediately after session 0.64 ± 0.09 vs. 0.59 ± 0.12 m.s-1) compared with the set failure group [189]. Therefore, the distribution of rest interval between repetitions can change the performance of judo athletes using same total rest interval and equated volume.

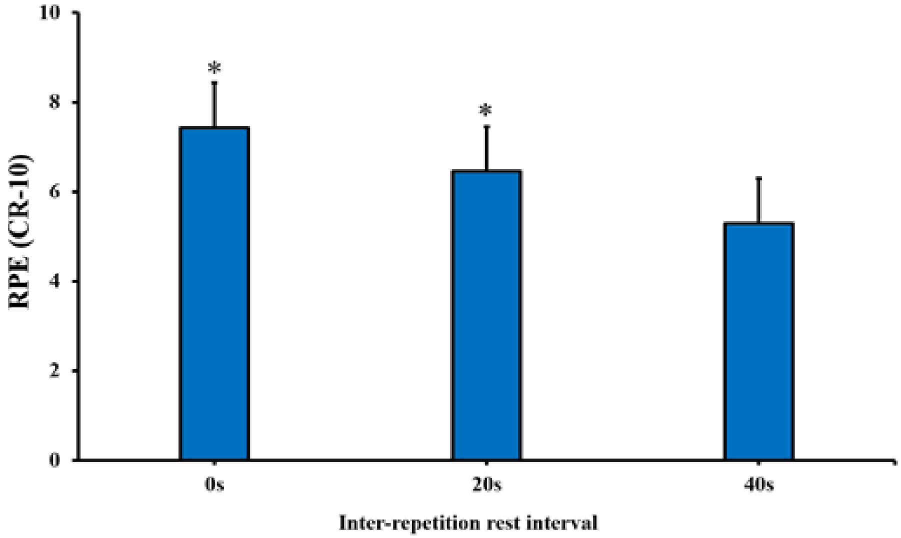


Figure 21: Rating of perceived exertion after the traditional sets and inter-repetition interval (Adapted from Hardee et al. [188]).

As the ability to generate muscle power goes down rapidly after performing few repetitions, something between 5-9 repetitions [180,190], it is likely that performing sets with inter-repetition interval and cluster will generate less muscle fatigue. In addition, the reduction of phosphocreatine (PCr) stores is less pronounced during the inter-repetition and cluster sets when compared to the traditional sets. In addition, it is possible that the intervals used between each repetition or between each cluster allow some recovery of the PCr stores and, consequently, an increase in performance related to the generation of strength and muscle power. In Figure 22, 23 and 24 we can compare a theoretical model of what can happen with the generation of muscle power after the execution of the traditional and cluster sets [185]. Unlike the traditional sets, the cluster-type sets provide some time intervals between the repetitions or grouped repetitions, usually something between 5s and 45s [186,187]. For example, the athlete performs 6 repetitions with 60% of 1RM with the 20s of interval every two repetitions, as shown in Equation 1. We can use the same example by changing the intensity and using percentages of body mass for the prescription, according to the information presented in Equation 2. This type of training may be adequate in some moments of the physical preparation process of the athletes when performing the exercise with reduced fatigue is desirable [180,186,187]. It has been mentioned that exercises using cluster sets generate less fatigue by allowing some muscle metabolic recovery. This process can result in training sessions with the accomplishment of technically more appropriate gestures when compared to the exercises performed in a fatigued condition.

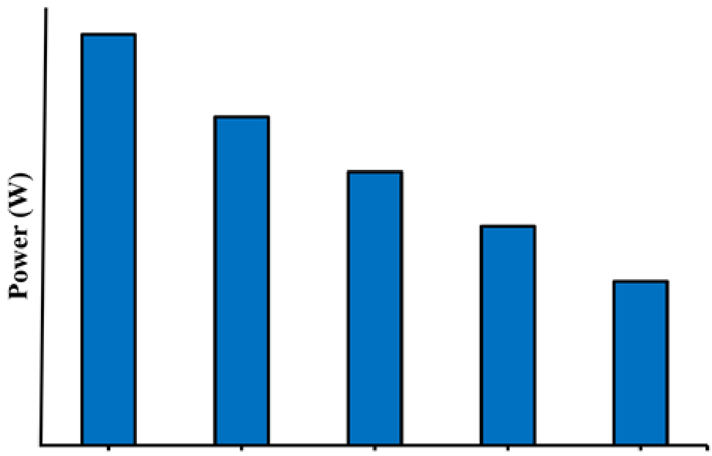


Figure 22: Theoretical model of muscle power generated during traditional sets (Adapted from Haff et al. [185]).

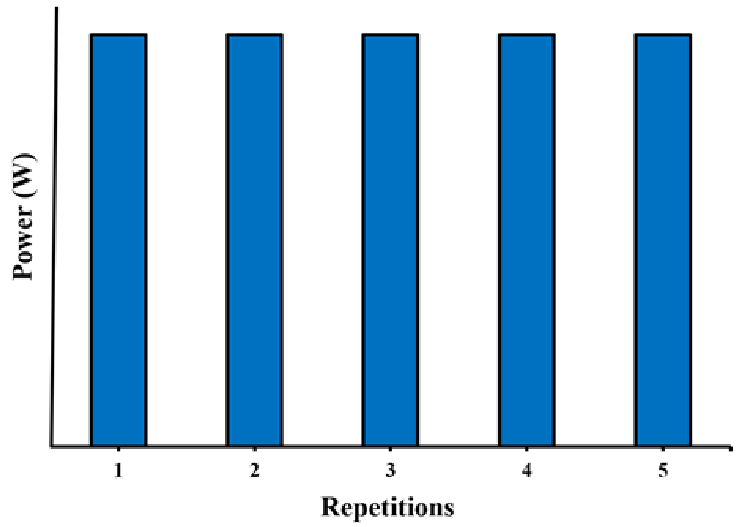


Figure 23: Theoretical model of muscle power generated during cluster sets (Adapted from Haff et al. [185]).

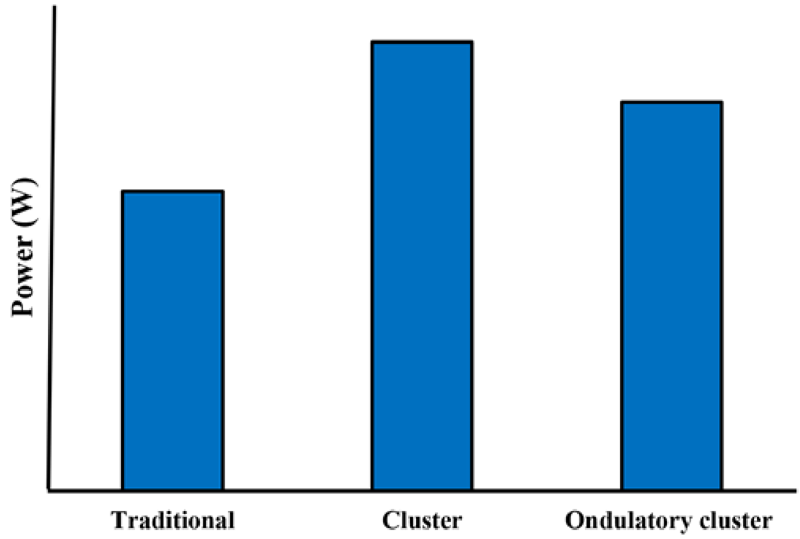


Figure 24: Theoretical model of muscle power generated during traditional, cluster and undulating cluster sets (Adapted from Haff et al. [185]).

$$\frac{\text{6 repetitions}}{\text{2 repetitions by cluster}} = \frac{60\%}{2}\ 20s\ \frac{60\%}{2}\ 20s\ \frac{60\%}{2}$$

Equation (1). Example of training prescription using cluster type sets and percentages of one-repetition maximum (1RM).

$$\frac{\text{6 repetitions}}{\text{2 repetitions by cluster}} = \frac{BM\ \%}{2}\ 20s\ \frac{BM\ \%}{2}\ 20s\ \frac{BM\ \%}{2}$$

Equation (2). Example of training prescription using cluster type sets and percentages of the athlete's body mass.

In addition, cluster-type sets can help reduce another problem. Athletes who are divided by weight categories, as in the case of combat sports, generally expect to improve their performance by performing muscle power training. However, in most cases these athletes do not wish to gain weight, resulting from strength training. A large variety can be created when using cluster sets, however, in addition to the standard cluster sets, previously presented, there are other variations denominated as undulatory, increasing and decreasing pyramids. These variations can be applied during the training sessions, with the intention of attending to the oscillations that may occur during a combat.

One possibility of manipulation of the cluster type sets is the undulating sets. In this model, the variation of the load between two or more intensities is foreseen. An example of cluster sets is exemplified in Equation 3.

$$\text{Undulating cluster sets} = \frac{\text{4 repetitions}}{\text{1 repetitions by cluster}} = \frac{30\%}{1}\ 30s\ \frac{40\%}{1}\ 30s\ \frac{30\%}{1}\ 30s\ \frac{40\%}{1}$$

Equation (3). Undulating cluster sets.

The pyramidal cluster sets are performed with an increase in intensity to an apex, stipulated according to the objectives of the training session, followed by a reduction until returning to the load initially used. An example of a pyramidal cluster sets can be seen in Equation 4.

$$\text{Pyramid cluster sets} = \frac{\text{6 repetitions}}{\text{2 repetitions by cluster}} = \frac{35\%}{2}\ 35s\ \frac{40\%}{2}\ 35s\ \frac{35\%}{2}$$

Equation (4). Pyramid cluster sets.

In the ascending model the load increases with each cluster, reaching the highest load at the end of the sets, that is, the last cluster set. An example of ascending cluster sets can be seen in Equation 5.

$$\text{Ascending cluster sets} = \frac{\text{6 repetitions}}{\text{2 repetitions by cluster}} = \frac{35\%}{2}\ 35s\ \frac{40\%}{2}\ 35s\ \frac{45\%}{2}$$

Equation (5). Ascending cluster sets.

The descending load model starts with the highest load and is reduced to each cluster within a set. A descending cluster sets model can be observed in Equation 6.

$$\text{Descending cluster sets} = \frac{\text{6 repetitions}}{\text{2 repetitions by cluster}} = \frac{45\%}{2}\ 35s\ \frac{40\%}{2}\ 35s\ \frac{35\%}{2}$$

Equation (6). Descending cluster sets.

The complex spherical cluster model is presented in the following figure. In this model, the intensity and number of repetitions in each cluster are predicted, as shown in Equation 7.

$$\text{Complex undulating cluster sets} = \frac{\text{6 repetitions}}{\text{2 and 1 repetitions by cluster}} = 6/2 + 1$$

$$\frac{45\%}{2}\ 35s\ \frac{60\%}{1}\ 35s\ \frac{45\%}{2}\ 35s\ \frac{60\%}{1}$$

Equation (7). Complex undulating cluster sets.

The interval applied between the repetitions during the execution of cluster sets varies according to the purpose of the training session and the phase of the periodization in which the athletes are. For example, shorter intervals between one cluster set and another may be more indicated when the purpose of the training session or period is to work the strength-endurance or under the greatest fatigue condition. When the goal is the development of muscle power, longer intervals (30s to 45s) between one cluster set and another may be more appropriate. In Table 10 we can observe inter-repetition interval suggestions during the realization of cluster sets according to the objective. It is worth mentioning that the figures presented in the table are only suggestions, understanding that a great variety of combinations is possible.

Table10: Inter-repetition interval suggestion according to the training objective (Adapted from Haff [186]).

Interval between-repetitions	Purpose
5-15s	Strength and muscle power endurance
15-30s	Development of muscle power
30-45s	Maximal muscle power

In a recent study, Moreno et al. [180] had the objective to investigate the effect of the use of cluster type sets compared with the traditional sets. Sets with a total volume of 20 repetitions of a plyometric exercise were performed, applying the recovery interval in different ways regarding the interval duration and clustering the repetitions, as presented in Equation 8. They demonstrated power maintenance, take-off velocity (TOV) and jump height with the accomplishment of the cluster set 2 followed by a rest interval of 10s. Therefore, this may be a good strategy when the goal is to develop muscle power with the use of plyometric exercises.

2 sets x 10 repetitions / 90s of rest interval between sets

$$\frac{\text{20 repetitions}}{\text{5 repetitions by cluster}} = \frac{BM}{5}\ 30s\ \frac{BM}{5}\ 30s\ \frac{BM}{5}\ 30s\ \frac{BM}{5}$$

$$\frac{\text{20 repetitions}}{\text{2 repetitions by cluster}} = \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}\ 10s\ \frac{BM}{2}$$

Equation (8). Experimental design used by Moreno et al. [180].

Although we are not aware of any studies that have used cluster-type sets to develop muscle strength and power in the training of athletes involved with combat sports, this form of training could be used during sessions, aiming at the development of muscle power and technical quality of execution of the movement [2,191]. In general, it seems that the use of cluster sets is more adequate when the development of muscle power is the main objective. Traditional sets are preferable if the goal is to generate greater muscle hypertrophy or higher levels of maximum strength.

6.10 Rest interval between sets

The execution of multiple sets has been demonstrated to be superior to the execution of a single set for the strength and power development [192,193]. However, the execution of multiple series depends on the athlete's ability to perform the movement with good quality, in a consecutive way. The ability to sustain the execution of multiple sets is dependent on the time interval applied between the sets. The duration of the recovery interval between the sets allows recovery of the energy systems (e.g., adenosine triphosphate [ATP] and PCr), allowing recovery for the production of muscle strength [194,195].

The recovery interval applied between sets depends on the purpose of the training. In general, intervals between 2-8 minutes between sets are recommended when the training session aims to train muscle power [160,161,196,197]. However, it is worth noting that in addition to the training objective, other factors should influence the coach's decision on the interval to be applied.

7. Final considerations

In this chapter, suggestions were presented for the development of training aimed at developing muscle power for combat sports athletes. In this sense, several means and methods were approached in order to extend the possibilities of application, as well as the specificity of the training session. For highly trained athletes it is important to consider the specificity of the modality so that the athlete improves muscle power in a specific gesture. Among the means and training methods presented, it seems that those involving ballistic, elastic and complex gestures cause positive changes by using technical gestures with the same pattern of movement. However, the development and possibility of transfer of muscle power should be further investigated in the future.

Conflict of interest

None declare.

References

[1] Franchini E, Del Vecchio FB. Preparação física para atletas de judô. Phorte; 2008.
[2] Turner A. Training for power: principles and practice. Prof Strength Cond 2009;14:20–32.
[3] ACSM. Power development in athletes: considerations for coaches – a consensus panel statement 2001.
[4] Cormie P, McGuigan MR, Newton RU. Developing Maximal Neuromuscular Power. Sport Med 2011;41:125–46. https://doi.org/10.2165/11538500-000000000-00000.
[5] Cormie P, McGuigan MR, Newton RU. Developing Maximal Neuromuscular Power. Sport Med 2011;41:17–38. https://doi.org/10.2165/11537690-000000000-00000.
[6] Cormie P, McBride JM, McCaulley GO. Power-Time, Force-Time, and Velocity-Time Curve Analysis of the Countermovement Jump: Impact of Training. J Strength Cond Res 2009;23:177–86. https://doi.org/10.1519/JSC.0b013e3181889324.
[7] Cormie P, McGuigan MR, Newton RU. Influence of strength on magnitude and mechanisms of adaptation to power training. Med Sci Sports Exerc 2010;42:1566–81. https://doi.org/10.1249/MSS.0b013e3181cf818d.
[8] Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, Schilling B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. J Strength Cond Res 2003;17:140–7. https://doi.org/10.1519/1533-4287(2003)017<0140:pamsrd>2.0.co;2.
[9] Ugrinowitsch C, Barbanti VJ. The stretch shortening cycle and the vertical jumping ability. Rev Paul Educ Física 1998;12:85. https://doi.org/10.11606/issn.2594-5904.rpef.1998.139535.
[10] Kraemer WJ, Newton RU. Training for muscular power. Phys Med Rehabil Clin N Am 2000;11:341–68, vii.
[11] Newton RU, Kraemer WJ. Developing explosive muscular power: implications for a mixed methods training strategy. Strength Cond J 1994;16:20–31.
[12] Fry AC, Newton RU. Uma breve história do treinamento de força, princípios básicos e conceitos. In: Kraemer WJ, Häkkinen K, editors. Treinamento força para o esporte. 1st ed., Porto Alegre: Artmed; 2004, p. 15–32.
[13] Fleck SJ, Kraemer WJ. Designing Resistance Training Programs. 4th ed. Champaign, IL: Human Kinetics; 2014.
[14] Kraemer WJ, Fleck SJ. Optimizing strength training: designing nonlinear periodization workouts. 1st ed. Champaign, IL: Human Kinetics; 2007.
[15] Miarka B, Del Vecchio FB, Franchini E. Acute effects and postactivation potentiation in the Special Judo Fitness Test. J Strength Cond Res 2011;25:427–31. https://doi.org/10.1519/JSC.0b013e3181bf43ff.
[16] Santos JF da S, Valenzuela TH, Franchini E. Can different conditioning activities and rest intervals affect the acute performance of taekwondo turning kick? J Strength Cond Res 2015;29:1640–7. https://doi.org/10.1519/JSC.0000000000000808.
[17] Bird SP, Tarpenning KM, Marino FE. Designing Resistance Training Programmes to Enhance Muscular Fitness. Sport Med 2005;35:841–51. https://doi.org/10.2165/00007256-200535100-00002.
[18] Stone MH, O'Bryant H, Garhammer J. A hypothetical model for strength training. J Sports Med Phys Fitness 1981;21:342–51.
[19] Cormie P, McCaulley GO, McBride JM. Power versus strength-power jump squat training: influence on the load-power relationship. Med Sci Sports Exerc 2007;39:996–1003. https://doi.org/10.1097/mss.0b013e3180408e0c.

[20] Kawamori N, Crum AJ, Blumert PA, Kulik JR, Childers JT, Wood JA, et al. Influence of different relative intensities on power output during the hang power clean: identification of the optimal load. J Strength Cond Res 2005;19:698–708. https://doi.org/10.1519/16044.1.

[21] da Silva BVC, Simim MA de M, Marocolo M, Franchini E, da Mota GR. Optimal load for the peak power and maximal strength of the upper body in Brazilian Jiu-Jitsu athletes. J Strength Cond Res 2015;29:1616–21. https://doi.org/10.1519/JSC.0000000000000799.

[22] Tavares LD, Zanchetta F, Lasevicius T, Anorato A, de Souza EO, Laurentino GC, et al. Optimal load for the muscle power profile of prone bench pull in Brazilian Jiu-Jitsu athletes. Sport Sci Health 2018;14:143–9. https://doi.org/10.1007/s11332-017-0418-x.

[23] McGuigan MR, Wright GA, Fleck SJ. Strength training for athletes: does it really help sports performance? Int J Sports Physiol Perform 2012;7:2–5. https://doi.org/10.1123/ijspp.7.1.2.

[24] Leichtweis MF, Antunez BF, Xavier BEB, Del Vecchio FB. Effects of different training protocols on time to execution taekwondo kick. Arq Ciências Do Esporte 2013;1:37–45.

[25] Villani R, Petrillo D De, Distaso M. Influence of four different methods of training on the specific rapidity of taekwondo. B. Abstr. 12th Annu. Congr. Eur. Coll. Sport Sci., Jyväskylä, Finland: 2007, p. 458–9.

[26] Villani R, Ruggieri F, Tomasso A, Distaso M. Increase of the specific rapidity in the Tae-Kwon-Do through a contrast method. B. Abstr. 10th Annu. Congr. Eur. Coll. Sport Sci., Belgrade, Serbia: 2005, p. 419–20.

[27] Blais L, Trilles F. The progress achieved by judokas after strength training with a judo-specific machine. J Sports Sci Med 2006;5:132–5.

[28] Jakubiak N, Saunders DH. The feasibility and efficacy of elastic resistance training for improving the velocity of the Olympic Taekwondo turning kick. J Strength Cond Res 2008;22:1194–7. https://doi.org/10.1519/JSC.0b013e31816d4f66.

[29] Olsen PD, Hopkins WG. The effect of attempted ballistic training on the force and speed of movements. J Strength Cond Res 2003;17:291–8. https://doi.org/10.1519/1533-4287(2003)017<0291:teoabt>2.0.co;2.

[30] Ebben WP, Blackard DO. Developing a strength-power program for amateur boxing. Strength Cond J 1997;19:42–51.

[31] Iide K, Imamura H, Yoshimura Y, Yamashita A, Miyahara K, Miyamoto N, et al. Physiological responses of simulated karate sparring matches in young men and boys. J Strength Cond Res 2008;22:839–44. https://doi.org/10.1519/JSC.0b013e31816a5af6.

[32] Matsushigue KA, Hartmann K, Franchini E. Taekwondo: Physiological responses and match analysis. J Strength Cond Res 2009;23:1112–7. https://doi.org/10.1519/JSC.0b013e3181a3c597.

[33] Santos VGF, Franchini E, Lima-Silva AE. Relationship between attack and skipping in Taekwondo contests. J Strength Cond Res 2011;25:1743–51. https://doi.org/10.1519/JSC.0b013e3181ddfb0f.

[34] Campos FAD, Bertuzzi R, Dourado AC, Santos VGF, Franchini E. Energy demands in taekwondo athletes during combat simulation. Eur J Appl Physiol 2012;112:1221–8. https://doi.org/10.1007/s00421-011-2071-4.

[35] Morin J-B, Jiménez-Reyes P, Brughelli M, Samozino P. When Jump Height is not a Good Indicator of Lower Limb Maximal Power Output: Theoretical Demonstration, Experimental Evidence and Practical Solutions. Sport Med 2019;49:999–1006. https://doi.org/10.1007/s40279-019-01073-1.

[36] Chiodo S, Tessitore A, Cortis C, Lupo C, Ammendolia A, Iona T, et al. Effects of Official Taekwondo Competitions on All-Out Performances of Elite Athletes. J Strength Cond Res 2011;25:334–9. https://doi.org/10.1519/JSC.0b013e3182027288.

[37] Chaabène H, Mkaouer B, Franchini E, Souissi N, Selmi MA, Nagra Y, et al. Physiological Responses and Performance Analysis Difference between Official and Simulated Karate Combat Conditions. Asian J Sports Med 2014;5:21–9.

[38] Loturco I, Nakamura FY, Lopes-Silva JP, Silva-Santos JF, Pereira LA, Franchini E. Physical and physiological traits of a double world karate champion and responses to a simulated kumite bout: A case study. Int J Sports Sci Coach 2017;12:138–47. https://doi.org/10.1177/1747954116684395.

[39] Cuenca-Fernández F, Smith IC, Jordan MJ, MacIntosh BR, López-Contreras G, Arellano R, et al. Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. Appl Physiol Nutr Metab 2017;42:1122–5. https://doi.org/10.1139/apnm-2017-0217.
[40] Prieske O, Behrens M, Chaabene H, Granacher U, Maffiuletti NA. Time to Differentiate Postactivation "Potentiation" from "Performance Enhancement" in the Strength and Conditioning Community. Sport Med 2020;50:1559–65. https://doi.org/10.1007/s40279-020-01300-0.
[41] Ouergui I, Davis P, Houcine N, Marzouki H, Zaouali M, Franchini E, et al. Hormonal, Physiological, and Physical Performance During Simulated Kickboxing Combat: Differences Between Winners and Losers. Int J Sports Physiol Perform 2016;11:425–31. https://doi.org/10.1123/ijspp.2015-0052.
[42] Del Vecchio FB, Bianchi S, Hirata SM, Chacon-Mikahi MPT. Análise morfo-funcional de praticantes de Brazilian jiu-jitsu e estudo da temporalidade e da quantificação das ações motoras na modalidade. Mov e Percepção 2007;7:263–81.
[43] Marcon G, Franchini E, Jardim JR, Barros Neto TL. Structural Analysis of Action and Time in Sports: Judo. J Quant Anal Sport 2010;6. https://doi.org/10.2202/1559-0410.1226.
[44] Miarka B, Julio UF, Del Vecchio FB, Calmet M, Franchini E. Técnica y táctica en judo: una revisión. Rev Artes Marciales Asiáticas 2010;5:91–112. https://doi.org/10.18002/rama.v5i1.139.
[45] Nilsson J, Csergö S, Gullstrand L, Tveit P, Refsnes PE. Work-time profile, blood lactate concentration and rating of perceived exertion in the 1998 Greco-Roman Wrestling World Championship. J Sports Sci 2002;20:939–45. https://doi.org/10.1080/026404102320761822.
[46] Barbas I, Fatouros IG, Douroudos II, Chatzinikolaou A, Michailidis Y, Draganidis D, et al. Physiological and performance adaptations of elite Greco-Roman wrestlers during a one-day tournament. Eur J Appl Physiol 2011;111:1421–36. https://doi.org/10.1007/s00421-010-1761-7.
[47] Kraemer WJ, Fry AC, Rubin MR, Triplett-McBride T, Gordon SE, Koziris LP, et al. Physiological and performance responses to tournament wrestling. Med Sci Sports Exerc 2001;33:1367–78. https://doi.org/10.1097/00005768-200108000-00019.
[48] Bonitch-Domínguez J, Bonitch-Góngora J, Padial P, Feriche B. Changes in peak leg power induced by successive judo bouts and their relationship to lactate production. J Sports Sci 2010;28:1527–34. https://doi.org/10.1080/02640414.2010.512641.
[49] da Silva BVC, Ide BN, de Moura Simim MA, Marocolo M, da Mota GR. Neuromuscular responses to simulated brazilian jiu-jitsu fights. J Hum Kinet 2014;44:249–57. https://doi.org/10.2478/hukin-2014-0130.
[50] del Vecchio FB, Hirata SM, Franchini E. A Review of Time-Motion Analysis and Combat Development in Mixed Martial Arts Matches at Regional Level Tournaments. Percept Mot Skills 2011;112:639–48. https://doi.org/10.2466/05.25.PMS.112.2.639-648.
[51] Detanico D, Pupo JD, Franchini E, dos Santos SG. Effects of Successive Judo Matches on Fatigue and Muscle Damage Markers. J Strength Cond Res 2015;29:1010–6. https://doi.org/10.1519/JSC.0000000000000746.
[52] Andreato L V., Julio UF, Gonçalves Panissa VL, Del Conti Esteves J V., Hardt F, Franzói de Moraes SM, et al. Brazilian Jiu-Jitsu Simulated Competition Part II. J Strength Cond Res 2015;29:2015–25. https://doi.org/10.1519/JSC.0000000000000819.
[53] Andreato LV, Esteves JVDC, Julio UF, Panissa VLG, Hardt F, Moraes SMF de, et al. Physical performance, time-motion, technical-tactical analyses, and perceptual responses in brazilian jiu-jitsu matches of varied duration. Kinesiology 2017;49:30–40.
[54] Julio UF, Gonçalves Panissa VL, Agostinho MF, Cury RL, Esteves JV, Franchini E. Time-course of time-motion, physiological, perceived exertion and neuromuscular responses during simulated judo matches. Int J Perform Anal Sport 2018;18:582–94. https://doi.org/10.1080/24748668.2018.1507479.
[55] Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SMC, et al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. J Strength Cond Res 2013;27:854–9. https://doi.org/10.1519/JSC.0b013e31825c2bdb.

[56] Detanico D, Dal Pupo J, Franchini E, Fukuda DH, Dos Santos SG. Effects of traditional judo training session on muscle damage symptoms. J Sports Med Phys Fitness 2017;57:872–8. https://doi.org/10.23736/S0022-4707.16.06320-9.
[57] James LP, Beckman EM, Kelly VG, Haff GG. The Neuromuscular Qualities of Higher- and Lower-Level Mixed-Martial-Arts Competitors. Int J Sports Physiol Perform 2017;12:612–20. https://doi.org/10.1123/ijspp.2016-0373.
[58] Smith MS, Dyson RJ, Hale T, Janaway L. Development of a boxing dynamometer and its punch force discrimination efficacy. J Sports Sci 2000;18:445–50. https://doi.org/10.1080/02640410050074377.
[59] Turner A, Baker E, Miller S. Increasing the Impact Force of the Rear Hand Punch. Strength Cond J 2011;33:2–9. https://doi.org/10.1519/SSC.0b013e318232fdcb.
[60] Blais L, Trilles F. Analyse mécanique comparative d'une même projection de judo : Seoi Nage, réalisée par cinq experts de la Fédération Française de Judo. Sci Mot 2004:49–68. https://doi.org/10.3917/sm.051.0049.
[61] Iteya M, Yanagisawa H, Watanabe R, Kimura M, Deguchi T, Kaneko K, et al. Characteristics of hikite power in elite women judo players. Bull Assoc Sci Stud Judo 2005:578–64.
[62] Zaggelidis G, Lazaridis SN, Malkogiorgos A, Mavrovouniotis F. Differences in vertical jumping performance between untrained males and advanced Greek judokas. Arch Budo 2012;8:85–90. https://doi.org/10.12659/AOB.882775.
[63] Helm N, Prieske O, Muehlbauer T, Krüger T, Chaabene H, Granacher U. Validation of A New Judo-Specific Ergometer System in Male Elite and Sub-Elite Athletes. J Sports Sci Med 2018;17:465–74.
[64] Franchini E, Artioli GG, Brito CJ. Judo combat: time-motion analysis and physiology. Int J Perform Anal Sport 2013;13:624–41. https://doi.org/10.1080/24748668.2013.11868676.
[65] Duzgun I, Baltaci G, Colakoglu F, Tunay VB, Ozer D. The effects of jump-rope training on shoulder isokinetic strength in adolescent volleyball players. J Sport Rehabil 2010;19:184–99. https://doi.org/10.1123/jsr.19.2.184.
[66] Kiss M, Böhme M. Avaliação de treinamento esportivo. In: Kiss MAPDM, editor. Esporte e Exerc. avaliação e prescrição. 1st ed., São Paulo: Roca; 2003, p. 3–20.
[67] Dugan EL, Doyle TLA, Humphries B, Hasson CJ, Newton RU. Determining the optimal load for jump squats: a review of methods and calculations. J Strength Cond Res 2004;18:668–74. https://doi.org/10.1519/1533-4287(2004)18<668:DTOLFJ>2.0.CO;2.
[68] Hori N, Newton RU, Nosaka K, McGuigan MR. Comparison of Different Methods of Determining Power Output in Weightlifting Exercises. Strength Cond J 2006;28:34–40. https://doi.org/10.1519/00126548-200604000-00006.
[69] Harman H. The measurement of human machanical power. In: Maud PJ, Foster C, Maud P, editors. Physiol. Assess. Hum. Fit. 2nd ed., Champaign, IL: Human Kinetics; 2005, p. 93–118.
[70] Chaabène H, Hachana Y, Franchini E, Mkaouer B, Chamari K. Physical and physiological profile of elite karate athletes. Sports Med 2012;42:829–43. https://doi.org/10.1007/BF03262297.
[71] Loturco I, Artioli GG, Kobal R, Gil S, Franchini E. Predicting punching acceleration from selected strength and power variables in elite karate athletes: a multiple regression analysis. J Strength Cond Res 2014;28:1826–32. https://doi.org/10.1519/JSC.0000000000000329.
[72] Bridge CA, Ferreira da Silva Santos J, Chaabène H, Pieter W, Franchini E. Physical and Physiological Profiles of Taekwondo Athletes. Sport Med 2014;44:713–33. https://doi.org/10.1007/s40279-014-0159-9.
[73] Franchini E, Del Vecchio FB, Matsushigue KA, Artioli GG. Physiological Profiles of Elite Judo Athletes. Sport Med 2011;41:147–66. https://doi.org/10.2165/11538580-000000000-00000.
[74] Roschel H, Batista M, Monteiro R, Bertuzzi RC, Barroso R, Loturco I, et al. Association between neuromuscular tests and kumite performance on the brazilian karate national team. J Sports Sci Med 2009;8:20–4.
[75] Loturco I, Nakamura FY, Artioli GG, Kobal R, Kitamura K, Cal Abad CC, et al. Strength and Power Qualities Are Highly Associated With Punching Impact in Elite Amateur Boxers. J Strength Cond Res 2016;30:109–16. https://doi.org/10.1519/JSC.0000000000001075.
[76] Dunn EC, Humberstone CE, Franchini E, Iredale KF, Blazevich AJ. Relationships Between Punch Impact Force and Upper- and Lower-Body Muscular Strength and Power in Highly Trained Amateur Boxers. J Strength Cond Res 2020. https://doi.org/10.1519/JSC.0000000000003585.

[77] Villani R, Tomasso A, Tucciarone G, Distaso M. Elaboration of a specific test for the evaluation of frequency speed of punches in boxe, 2006.
[78] Ebben WP, Blackard DO. Strength and conditioning practices of National Football League strength and conditioning coaches. J Strength Cond Res 2001;15:48–58.
[79] Ebben WP, Carroll RM, Simenz CJ. Strength and conditioning practices of National Hockey League strength and conditioning coaches. J Strength Cond Res 2004;18:889–97. https://doi.org/10.1519/14133.1.
[80] Simenz CJ, Dugan CA, Ebben WP. Strength and conditioning practices of National Basketball Association strength and conditioning coaches. J Strength Cond Res 2005;19:495–504. https://doi.org/10.1519/15264.1.
[81] Agostinho MF, Philippe AG, Marcolino GS, Pereira ER, Busso T, Candau RB, et al. Perceived Training Intensity and Performance Changes Quantification in Judo. J Strength Cond Res 2015;29:1570–7. https://doi.org/10.1519/JSC.0000000000000777.
[82] Ball N, Nolan E, Wheeler K. Anthropometrical, Physiological, and Tracked Power Profiles of Elite Taekwondo Athletes 9 Weeks before the Olympic Competition Phase. J Strength Cond Res 2011;25:2752–63. https://doi.org/10.1519/JSC.0b013e31820d9f3f.
[83] Franchini E, Matsushigue KA, Kiss MAPD, Sterkowicz S. A case study of physiological and performance changes in female judo players preparing for the Pan-American Games. Rev Bras Ciência e Mov 2001;9:21–7.
[84] Loturco I, Pereira LA, Winckler C, Bragança JR, da Fonseca RA, Kobal R, et al. Performance Changes of Elite Paralympic Judo Athletes During a Paralympic Games Cycle: A Case Study with the Brazilian National Team. J Hum Kinet 2017;60:217–24. https://doi.org/10.1515/hukin-2017-0111.
[85] Ke-tien Y. Training periodization in lower limb performance and neuromuscular controlling in taekwondo athletes. Life Sci J 2012;9:850–7.
[86] Zacho M, Sorensen H, Bangsbo J, Andersen L. Changes in muscle MHC-composition and kicking performance after heavy resistance training in taekwondo athletes. In: Marconnet P, Gaulard J, Margarits I, Tessier F, editors. B. Abstr. First Anu. Congr. Front. Sport Sci., Nice, France: 1996.
[87] Tsai Y, Liu G, Chem C, Huang C. The effect of different plyometric-squat training on taekwondo power development in the lower extremity. 17 International Symposium on Biomechanics in Sports. 17 Int. Symp. Biomech. Sport., Perth, Australia: 1999, p. 413–6.
[88] Voigt M, Klausen K. Changes in muscle strength and speed of an unloaded movement after various training programmes. Eur J Appl Physiol Occup Physiol 1990;60:370–6. https://doi.org/10.1007/BF00713501.
[89] Seo M-W, Jung H-C, Song J-K, Kim H-B. Effect of 8 weeks of pre-season training on body composition, physical fitness, anaerobic capacity, and isokinetic muscle strength in male and female collegiate taekwondo athletes. J Exerc Rehabil 2015;11:101–7. https://doi.org/10.12965/jer.150196.
[90] Kraemer WJ, Häkkinen K. Strength Training for Sport. 1st ed. Wiley-Blackwell; 2002.
[91] Franchini E, Branco BM, Agostinho MF, Calmet M, Candau R. Influence of linear and undulating strength periodization on physical fitness, physiological, and performance responses to simulated judo matches. J Strength Cond Res 2015;29:358–67. https://doi.org/10.1519/JSC.0000000000000460.
[92] Marques L, Franchini E, Drago G, Aoki MS, Moreira A. Physiological and performance changes in national and international judo athletes during block periodization training. Biol Sport 2017;34:371–8. https://doi.org/10.5114/biolsport.2017.69825.
[93] Franchini E, Del Vecchio FB, Ferreira Julio U, Matheus L, Candau R. Specificity of performance adaptations to a periodized judo training program. Rev Andaluza Med Del Deport 2015;8:67–72. https://doi.org/10.1016/j.ramd.2013.11.001.
[94] Kostikiadis IN, Methenitis S, Tsoukos A, Veligekas P, Terzis G, Bogdanis GC. The Effect of Short-Term Sport-Specific Strength and Conditioning Training on Physical Fitness of Well-Trained Mixed Martial Arts Athletes. J Sports Sci Med 2018;17:348–58.
[95] Kraemer WJ. Developing a strength training workout. In: Kraemer WJ, Hakkinen K, editors. Strength Train. Sport. 1st ed., Blackwell Science; 2000, p. 37–54.
[96] Wąsik J. The structure of the roundhouse kick on the example of an European champion of taekwon-do. Arch Budo 2010;6:211–6.

[97] Wąsik J. Structure of movement of a turning technique used in the event of special techniques in taekwon-do ITF. Arch Budo 2009;5:111–5.
[98] Kraemer W, Comstock B, Clark J, Dunn-Lewis C. Athlete needs analysis. In: Hoffman JR, editor. NSCA's Guid. to Progr. Des. 1st ed., Champaign, IL: Human Kinetics; 2012, p. 1–21.
[99] Elliott BC, Wilson GJ, Kerr GK. A biomechanical analysis of the sticking region in the bench press. Med Sci Sports Exerc 1989;21:450–62.
[100] Newton RU, Kraemer WJ, Häkkinen K, Humphries BJ, Murphy AJ. Kinematics, Kinetics, and Muscle Activation during Explosive Upper Body Movements. J Appl Biomech 1996;12:31–43. https://doi.org/10.1123/jab.12.1.31.
[101] Newton RU, Kraemer WJ, Häkkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. Med Sci Sports Exerc 1999;31:323–30. https://doi.org/10.1097/00005768-199902000-00017.
[102] de Villarreal ES-S, Kellis E, Kraemer WJ, Izquierdo M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. J Strength Cond Res 2009;23:495–506. https://doi.org/10.1519/JSC.0b013e318196b7c6.
[103] Wathen D. Position statement: explosive/plyometric exercises. Natl Strength Cond Assoc J 1993:16.
[104] Bosco C, Viitasalo JT, Komi P V., Luhtanen P. Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. Acta Physiol Scand 1982;114:557–65. https://doi.org/10.1111/j.1748-1716.1982.tb07024.x.
[105] Bompa T. Treinamento de potência para o esporte. 1st ed. São Paulo: Phorte; 2004.
[106] Storey A, Smith HK. Unique aspects of competitive weightlifting: performance, training and physiology. Sports Med 2012;42:769–90. https://doi.org/10.1007/BF03262294.
[107] Ebben WP, Hintz MJ, Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. J Strength Cond Res 2005;19:538–46. https://doi.org/10.1519/R-15464.1.
[108] Haff G, Potteiger J. A brief review: explosive exercises and sports performance. Strength Cond J 2001;23:13–20.
[109] Garhammer J, Gregor R. Propulsion forces as a function of intensity for weightlifting and vertical jumping. J Appl Sport Sci Res 1992;6:129–34.
[110] Schilling BK, Stone MH, O'Bryant HS, Fry AC, Coglianese RH, Pierce KC. Snatch technique of collegiate national level weightlifters. J Strength Cond Res 2002;16:551–5.
[111] Bottinelli R, Pellegrino MA, Canepari M, Rossi R, Reggiani C. Specific contributions of various muscle fibre types to human muscle performance: an in vitro study. J Electromyogr Kinesiol 1999;9:87–95. https://doi.org/10.1016/S1050-6411(98)00040-6.
[112] Malisoux L, Francaux M, Nielens H, Theisen D. Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. J Appl Physiol 2006;100:771–9. https://doi.org/10.1152/japplphysiol.01027.2005.
[113] Thorstensson A, Grimby G, Karlsson J. Force-velocity relations and fiber composition in human knee extensor muscles. J Appl Physiol 1976;40:12–6. https://doi.org/10.1152/jappl.1976.40.1.12.
[114] Widrick JJ, Stelzer JE, Shoepe TC, Garner DP. Functional properties of human muscle fibers after short-term resistance exercise training. Am J Physiol Regul Integr Comp Physiol 2002;283:R408-16. https://doi.org/10.1152/ajpregu.00120.2002.
[115] Clarkson PM, Kroll W, McBride TC. Maximal isometric strength and fiber type composition in power and endurance athletes. Eur J Appl Physiol Occup Physiol 1980;44:35–42. https://doi.org/10.1007/BF00421761.
[116] Fry AC, Schilling BK, Staron RS, Hagerman FC, Hikida RS, Thrush JT. Muscle fiber characteristics and performance correlates of male Olympic-style weightlifters. J Strength Cond Res 2003;17:746–54. https://doi.org/10.1519/1533-4287(2003)017<0746:mfcapc>2.0.co;2.
[117] Gollnick PD, Armstrong RB, Saubert CW, Piehl K, Saltin B. Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. J Appl Physiol 1972;33:312–9. https://doi.org/10.1152/jappl.1972.33.3.312.
[118] Häkkinen K, Komi P V, Alén M, Kauhanen H. EMG, muscle fibre and force production characteristics during a 1 year training period in elite weight-lifters. Eur J Appl Physiol Occup Physiol 1987;56:419–27. https://doi.org/10.1007/BF00417769.

[119] Häkkinen K, Pakarinen A, Alen M, Kauhanen H, Komi P V. Neuromuscular and hormonal adaptations in athletes to strength training in two years. J Appl Physiol 1988;65:2406–12. https://doi.org/10.1152/jappl.1988.65.6.2406.
[120] Prince FP, Hikida RS, Hagerman FC. Human muscle fiber types in power lifters, distance runners and untrained subjects. Pflugers Arch 1976;363:19–26. https://doi.org/10.1007/BF00587397.
[121] Tesch PA, Thorsson A, Essén-Gustavsson B. Enzyme activities of FT and ST muscle fibers in heavy-resistance trained athletes. J Appl Physiol 1989;67:83–7. https://doi.org/10.1152/jappl.1989.67.1.83.
[122] Tesch PA, Thorsson A, Kaiser P. Muscle capillary supply and fiber type characteristics in weight and power lifters. J Appl Physiol 1984;56:35–8. https://doi.org/10.1152/jappl.1984.56.1.35.
[123] Association NS& C. Exercise technique manual for resistance training. Third Edit. Champaign, IL: Human Kinetics; 2016.
[124] Carter J, Greenwood M. Complex Training Reexamined. Strength Cond J 2014;36:11–9. https://doi.org/10.1519/SSC.0000000000000036.
[125] Fleck S, Kontor K. Soviet strength and conditioning: complex training. Natl Strength Cond Assoc J 1986;8:66–72.
[126] Ebben W, Watts P. A review of combined weight training and plyometric training modes: Complex training. Strength Cond J 1998;20:18–27.
[127] Lowery RP, Duncan NM, Loenneke JP, Sikorski EM, Naimo MA, Brown LE, et al. The effects of potentiating stimuli intensity under varying rest periods on vertical jump performance and power. J Strength Cond Res 2012;26:3320–5. https://doi.org/10.1519/JSC.0b013e318270fc56.
[128] Comyns TM, Harrison AJ, Hennessy LK, Jensen RL. The Optimal Complex Training Rest Interval for Athletes from Anaerobic Sports. J Strength Cond Res 2006;20:471–6. https://doi.org/10.1519/18445.1.
[129] Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, Yang G-Z. The Acute Potentiating Effects of Back Squats on Athlete Performance. J Strength Cond Res 2011;25:3319–25. https://doi.org/10.1519/JSC.0b013e318215f560.
[130] Jensen R, Ebben W. Effects of complex training rest interval on vertical jump performance. J Strength Cond Res 2003;17:345–9.
[131] Jones P, Lees A. A biomechanical analysis of the acute effects of complex training using lower limb exercises. J Strength Cond Res 2003;17:694–700. https://doi.org/10.1519/1533-4287(2003)017<0694:abaota>2.0.co;2.
[132] Kilduff LP, Bevan HR, Kingsley MIC, Owen NJ, Bennett MA, Bunce PJ, et al. Postactivation potentiation in professional rugby players: optimal recovery. J Strength Cond Res 2007;21:1134–8. https://doi.org/10.1519/R-20996.1.
[133] Kilduff LP, Cunningham DJ, Owen NJ, West DJ, Bracken RM, Cook CJ. Effect of postactivation potentiation on swimming starts in international sprint swimmers. J Strength Cond Res 2011;25:2418–23. https://doi.org/10.1519/JSC.0b013e318201bf7a.
[134] Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MIC, Cunningham D. Influence of recovery time on post-activation potentiation in professional rugby players. J Sports Sci 2008;26:795–802. https://doi.org/10.1080/02640410701784517.
[135] McCann MR, Flanagan SP. The effects of exercise selection and rest interval on postactivation potentiation of vertical jump performance. J Strength Cond Res 2010;24:1285–91. https://doi.org/10.1519/JSC.0b013e3181d6867c.
[136] Bauer P, Uebellacker F, Mitter B, Aigner AJ, Hasenoehrl T, Ristl R, et al. Combining higher-load and lower-load resistance training exercises: A systematic review and meta-analysis of findings from complex training studies. J Sci Med Sport 2019;22:838–51. https://doi.org/10.1016/j.jsams.2019.01.006.
[137] da Silva Santos JF, Herrera-Valenzuela T, Ribeiro da Mota G, Franchini E. Influence of half-squat intensity and volume on the subsequent countermovement jump and frequency speed of kick test performance in taekwondo athletes. Kinesiology 2016;48:95–102. https://doi.org/10.26582/k.48.1.6.
[138] Aandahl HS, Von Heimburg E, Van den Tillaar R. Effect of Postactivation Potentiation Induced by Elastic Resistance on Kinematics and Performance in a Roundhouse Kick of Trained Martial

Arts Practitioners. J Strength Cond Res 2018;32:990–6. https://doi.org/10.1519/JSC.0000000000001947.
[139] Lum D. Effects of Various Warm-Up Protocol on Special Judo Fitness Test Performance. J Strength Cond Res 2019;33:459–65. https://doi.org/10.1519/JSC.0000000000001862.
[140] Kazemi M, Waalen J, Morgan C, White AR. A profile of olympic taekwondo competitors. J Sports Sci Med 2006;5:114–21.
[141] Gouvêa AL, Fernandes IA, César EP, Silva WAB, Gomes PSC. The effects of rest intervals on jumping performance: a meta-analysis on post-activation potentiation studies. J Sports Sci 2013;31:459–67. https://doi.org/10.1080/02640414.2012.738924.
[142] Diacu F. On the dynamics of karate. Martial Arts Math 2003:9–11.
[143] Chiu H, Shiang T. A new approach to evaluate karate punch techniques. Int. Soc. Biomech. Conf. Proc. Arch., Perth, Western Australia: 1999, p. 61–4.
[144] Gianino C. Physics of karate: kinematics analysis of karate techniques by a digital movie camera. Latin-American J. Phys. Educ., 2010, p. 32–4.
[145] Daniel TM, Răzvan-Liviu P. Correlation between Plantar Pressure and Striking Speed in Karate-do. Procedia - Soc Behav Sci 2014;117:357–60. https://doi.org/10.1016/j.sbspro.2014.02.227.
[146] Cesari P, Bertucco M. Coupling between punch efficacy and body stability for elite karate. J Sci Med Sport 2008;11:353–6. https://doi.org/10.1016/j.jsams.2007.05.007.
[147] Pearson JN. Kinematics and kinetics of the taekwon-do turning kick. University of Otago, 1997.
[148] Pieter F, Pieter W. Speed and force in selected taekwondo techniques. Biol Sport 1995;12:257–66.
[149] Serina ER, Lieu DK. Thoracic injury potential of basic competition taekwondo kicks. J Biomech 1991;24:951–60. https://doi.org/10.1016/0021-9290(91)90173-k.
[150] Svoboda M, Soukup J, Jelen K, Kubový P. Measurement of Force Impact Taekwondo Athletes, Assessing the Possibility of Injury of Human Head. Procedia Eng 2016;136:211–5. https://doi.org/10.1016/j.proeng.2016.01.199.
[151] Walilko TJ. Biomechanics of the head for Olympic boxer punches to the face. Br J Sports Med 2005;39:710–9. https://doi.org/10.1136/bjsm.2004.014126.
[152] Tong-Iam R, Rachanavy P, Lawsirirat C. Kinematic and kinetic analysis of throwing a straight punch: the role of trunk rotation in delivering a powerful straight punch. J Phys Educ Sport 2017:2538–43.
[153] House P, Cowan J. Predicting straight punch force of impact. Oklahoma Assoc Heal Phys Educ Recreat Danc 2015;53.
[154] Cheraghi M, Agha Alinejad H, Arshi AR, Shirzad E. Kinematics of straight right punch in boxing. Ann Appl Sport Sci 2014;2:39–50. https://doi.org/10.18869/acadpub.aassjournal.2.2.39.
[155] Bingul M, Bulgan C, Tore O, Aydin M, Bal E. The effects of impact forces and kinematics of two different stance at straight punch techniques in boxing. Arch Budo Sci Martial Arts Extrem Sport 2017;13:35–9.
[156] Kimm D, Thiel D V. Hand Speed Measurements in Boxing. Procedia Eng 2015;112:502–6. https://doi.org/10.1016/j.proeng.2015.07.232.
[157] Atha J, Yeadon MR, Sandover J, Parsons KC. The damaging punch. BMJ 1985;291:1756–7. https://doi.org/10.1136/bmj.291.6511.1756.
[158] Neto OP, Silva JH, Marzullo AC de M, Bolander RP, Bir CA. The effect of hand dominance on martial arts strikes. Hum Mov Sci 2012;31:824–33. https://doi.org/10.1016/j.humov.2011.07.016.
[159] Blais L, Trilles F, Lacouture P. Three-dimensional joint dynamics and energy expenditure during the execution of a judo throwing technique (Morote Seoï Nage). J Sports Sci 2007;25:1211–20. https://doi.org/10.1080/02640410600982204.
[160] Medicine AC of S. Progression Models in Resistance Training for Healthy Adults. Med Sci Sports Exerc 2002;34:364–80. https://doi.org/10.1097/00005768-200202000-00027.
[161] ACSM. Progression Models in Resistance Training for Healthy Adults. Med Sci Sport Exerc 2009;41:687–708. https://doi.org/10.1249/MSS.0b013e3181915670.
[162] Simão R, de Salles BF, Figueiredo T, Dias I, Willardson JM. Exercise Order in Resistance Training. Sport Med 2012;42:251–65. https://doi.org/10.2165/11597240-000000000-00000.

[163] Carpinelli RN, Otto RM, Winett RA. A critical analysis of the ACMS stand on resistance training: insufficient evidence to support recommended training protocols. J Exerc Physiol 2004;7:1–60.
[164] Haff G, Haff E. Training integration and periodization. In: Hoffman JR, editor. NSCA's Guid. to Progr. Des. 1st ed., Champaign, IL: Human Kinetics; 2012, p. 213–58.
[165] Bompa T, Cornacchia L. Treinamento de força consciente. São Paulo: Phorte; 2002.
[166] Asci A, Acikada C. Power production among different sports with similar maximum strength. J Strength Cond Res 2007;21:10–6.
[167] Hannerz J. Discharge properties of motor units in relation to recruitment order in voluntary contraction. Acta Physiol Scand 1974;91:374–85. https://doi.org/10.1111/j.1748-1716.1974.tb05692.x.
[168] Behm DG, Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. J Appl Physiol 1993;74:359–68. https://doi.org/10.1152/jappl.1993.74.1.359.
[169] Dinn NA, Behm DG. A comparison of ballistic-movement and ballistic-intent training on muscle strength and activation. Int J Sports Physiol Perform 2007;2:386–99. https://doi.org/10.1123/ijspp.2.4.386.
[170] Haff GG, Nimphius S. Training Principles for Power. Strength Cond J 2012;34:2–12. https://doi.org/10.1519/SSC.0b013e31826db467.
[171] Newton RU, Hakkinen K, Hakkinen A, McCormick M, Volek J, Kraemer WJ. Mixed-methods resistance training increases power and strength of young and older men. Med Sci Sports Exerc 2002;34:1367–75. https://doi.org/10.1097/00005768-200208000-00020.
[172] Harris G, Stone M, O'Bryant H, Proulx C, Johnson R. Short-term performance effects of high power, high force, or combined weight-training methods. J Strength Cond Res 2000;14:14–20.
[173] Adams K, O'Shea JP, O'Shea KL, Climstein M. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. J Od Appl Sport Sci Res 1992;6:36–41.
[174] Cormie P, McBride JM, McCaulley GO. Validation of Power Measurement Techniques in Dynamic Lower Body Resistance Exercises. J Appl Biomech 2007;23:103–18. https://doi.org/10.1123/jab.23.2.103.
[175] Kyröläinen H, Avela J, McBride JM, Koskinen S, Andersen JL, Sipilä S, et al. Effects of power training on muscle structure and neuromuscular performance. Scand J Med Sci Sports 2005;15:58–64. https://doi.org/10.1111/j.1600-0838.2004.00390.x.
[176] Lyttle A, Wilson G, Ostrowski K. Enhancing performance: maximal power versus combined weights and plyometrics training. J Strength Cond Res 1996;10:173–9.
[177] Newton RU, Dugan E. Application of strength diagnosis. Strength Cond J 2002;24:50–9. https://doi.org/10.1519/00126548-200210000-00014.
[178] Toji H, Kaneko M. Effect of multiple-load training on the force-velocity relationship. J Strength Cond Res 2004;18:792–5. https://doi.org/10.1519/13933.1.
[179] Toji H, Suei K, Kaneko M. Effects of combined training loads on relations among force, velocity, and power development. Can J Appl Physiol 1997;22:328–36. https://doi.org/10.1139/h97-021.
[180] Moreno SD, Brown LE, Coburn JW, Judelson DA. Effect of cluster sets on plyometric jump power. J Strength Cond Res 2014;28:2424–8. https://doi.org/10.1519/JSC.0000000000000585.
[181] Date AS, Simonson SR, Ransdell LB, Gao Y. Lactate Response to Different Volume Patterns of Power Clean. J Strength Cond Res 2013;27:604–10. https://doi.org/10.1519/JSC.0b013e31825d9bd9.
[182] Creamer J. Bioenergetics of exercise and training. In: Baechle T, Earle R, editors. Essenc. strength Train. Cond. 3th ed., Champaign, IL: Human Kinetics; 2008, p. 21–40.
[183] Herda TJ, Cramer JT. Bioenergetics of Exercise and Training. In: Haff GG, Triplett NT, editors. Essenc. strength Train. Cond. 4th ed., Champaign, IL: Human Kinetics; 2016, p. 43–63.
[184] Nakamaru Y, Schwartz A. The influence of hydrogen ion concentration on calcium binding and release by skeletal muscle sarcoplasmic reticulum. J Gen Physiol 1972;59:22–32. https://doi.org/10.1085/jgp.59.1.22.
[185] Haff GG, Whitley A, McCoy LB, O'Bryant HS, Kilgore JL, Haff EE, et al. Effects of different set configurations on barbell velocity and displacement during a clean pull. J Strength Cond Res 2003;17:95–103. https://doi.org/10.1519/1533-4287(2003)017<0095:eodsco>2.0.co;2.

[186] Haff G. Hot topics: cluster sets a novel method for introducing additional variation into a resistance training program part I n.d. www.nsca.com (accessed September 12, 2014).
[187] Haff G. Hot topics: cluster sets a novel method for introducing additional variation into a resistance training program part II n.d.:www.nsca.com.
[188] Hardee JP, Lawrence MM, Utter AC, Triplett NT, Zwetsloot KA, McBride JM. Effect of inter-repetition rest on ratings of perceived exertion during multiple sets of the power clean. Eur J Appl Physiol 2012;112:3141–7. https://doi.org/10.1007/s00421-011-2300-x.
[189] Iglesias-Soler E, Carballeira E, Sánchez-Otero T, Mayo X, Jiménez A, Chapman ML. Acute effects of distribution of rest between repetitions. Int J Sports Med 2012;33:351–8. https://doi.org/10.1055/s-0031-1299699.
[190] Izquierdo M, González-Badillo JJ, Häkkinen K, Ibáñez J, Kraemer WJ, Altadill A, et al. Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions. Int J Sports Med 2006;27:718–24. https://doi.org/10.1055/s-2005-872825.
[191] Turner AN. Strength and Conditioning for Muay Thai Athletes. Strength Cond J 2009;31:78–92. https://doi.org/10.1519/SSC.0b013e3181b99603.
[192] Carpinelli RN, Otto RM. Strength training. Single versus multiple sets. Sports Med 1998;26:73–84. https://doi.org/10.2165/00007256-199826020-00002.
[193] Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. J Strength Cond Res 2010;24:1150–9. https://doi.org/10.1519/JSC.0b013e3181d4d436.
[194] McMahon S, Jenkins D. Factors affecting the rate of phosphocreatine resynthesis following intense exercise. Sports Med 2002;32:761–84. https://doi.org/10.2165/00007256-200232120-00002.
[195] Sahlin K. Metabolic factors in fatigue. Sports Med 1992;13:99–107. https://doi.org/10.2165/00007256-199213020-00005.
[196] Beachler T, Earle R, Wathen D. Resistance training. In: Beachler T, Earle R, editors. Essentials strength Train. Cond. 3rd ed., Champaign, IL: Human Kinetics; 2008, p. 381–412.
[197] Sheppard JM, Triplett NT. Program design for resistance training. In: Haff G, NT T, editors. Essentials Strength Train. Cond. 4th ed., Champaign, IL: Human Kinetics; 2016, p. 439–69.