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Strength and conditioning for combat sports athletes
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CHAPTER 2
Developing anaerobic power and capacity for combat sports athletes

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Abstract
This chapter describes the physiological responses associated with anaerobic power and capacity of combat sports athletes from different modalities (judo, Brazilian jiu-jitsu, wrestling, Olympic boxing, karate, and Muay Thai) during specific situations. Next, the most used evaluation methods for the control and monitoring of these variables are presented. Finally, based on longitudinal studies that evaluated the effects of anaerobic power and capacity training of combat sports athletes, the main training approaches are presented.

Keywords: Martial arts; combat sports; physical fitness; HIIT; high-intensity intermittent exercise.

1. Introduction

Combat sports are classified as intermittent activities, during which there are periods of high-intensity interspersed with short periods of recovery and it can be observed in diverse modalities such as judo [1], Brazilian jiu-jitsu [2], wrestling [3], taekwondo [4], karate [5] and Olympic boxing [6]. For example, combat sports as judo, Brazilian jiu-jitsu, and wrestling effort-pause ratio is between 2:1 or 3:1 [3,7-9], while in taekwondo, karate the interval periods are longer, with an effort-pause ratio of 1:6 to 1:9 [10-12]. Furthermore, mixed martial arts (MMA) shows an intermediate effort-pause, between 1:2 and 1:3 [13]. Thus, the development of training strategies and methods of assessing athlete's physical performance should be based on the request of different energy systems, which are difficult to quantify but can be inferred when considering each modality effort-pause ratio.

During physical activity, the immediate source of energy for muscle contraction comes from the hydrolysis of Adenosine Triphosphate (ATP) that is dependent on the duration and intensity of exercise [14]. The anaerobic energy system is divided into alactic and lactic components, referring to the processes involved in the splitting of the stored phosphagens, ATP and phosphocreatine (PCr), and the nonaerobic breakdown of carbohydrate to lactic through anaerobic glycolysis. The aerobic energy system refers to the combustion of carbohydrates and fats in the presence of oxygen [14]. During a combat, oxidative metabolism is the main metabolic pathway to provide energy during the rest period between high-intensity actions – especially during referee interruptions, while the ability to maintain high-intensity actions is derived from PCr system and the anaerobic lactic system is activated during repetitive periods of high-intensity activities (grappling) [1,15].

Anaerobic fitness is subdivided into capacity and power, which are performance's determinants during intermittent activities, such as combat sports. Anaerobic capacity is defined as the total energy that can be transferred by anaerobic metabolism[16], while anaerobic power is defined as the maximal amount of energy that can be generated per unit of time [17]. In this sense, the use of methods capable of evaluating the capacity and power anaerobic of fighters is an important factor, considering the development of these variables during training sessions.

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Although there is no gold standard method for assessing anaerobic capacity [18], the most utilized methods are total work performed in standardized tests, as Wingate test, maximal of accumulated oxygen deficit (MAOD) [14] as well as some physiological responses to standardized tests or in specific situations, such as lactate concentration. On the other hand, the evaluation of the anaerobic power occurs through mechanical variables, for example, peak power during the Wingate test [17].

Thus, this chapter describes the physiological responses associated with the anaerobic capacity and power of fighters (judo, Brazilian jiu-jitsu, wrestling, Olympic boxing, karate, and Muay Thai) during specific situations. After that, the most commonly used evaluation methods for the control and monitoring of these variables are presented. Finally, based on longitudinal studies that evaluated the effects of strategy training based on anaerobic capacity and power of fighters, will be presented training strategies with the objective of developing these capacities.

2. Anaerobic responses in combat sports

2.1 Lactate concentration during combat simulation

Lactate concentration is utilized to estimate to assess anaerobic glycolytic energy contribution during exercise. Thus, lactate concentration will be categorized as low < 3 $mmol{\cdot}L^{-1}$, moderate > 6 $mmol{\cdot}L^{-1}$, high >10 $mmol{\cdot}L^{-1}$ and very high >14 $mmol{\cdot}L^{-1}$ [19]. Thus, several studies have analyzed the lactate concentration during a combat simulation in karate athletes [10,20-22], taekwondo [23-26], Muay Thai [27,28], and boxing [6] it shows the importance of glycolytic metabolism in these modalities (Figure 1).

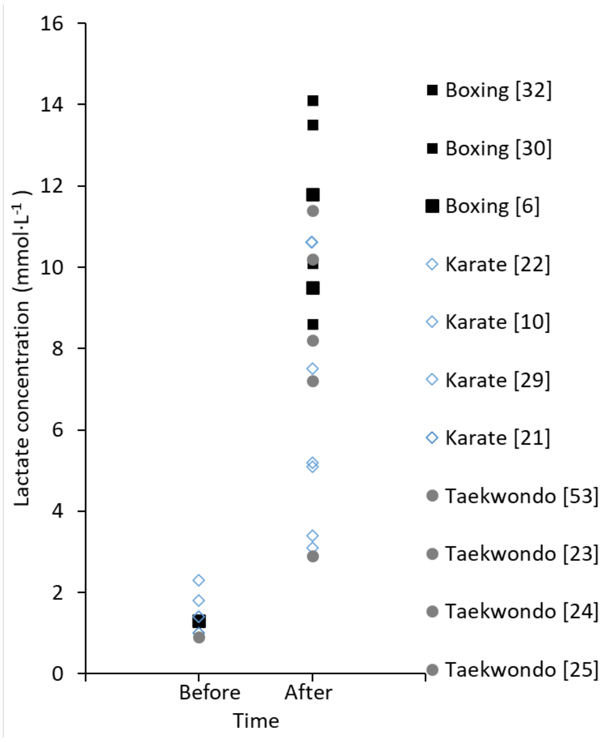


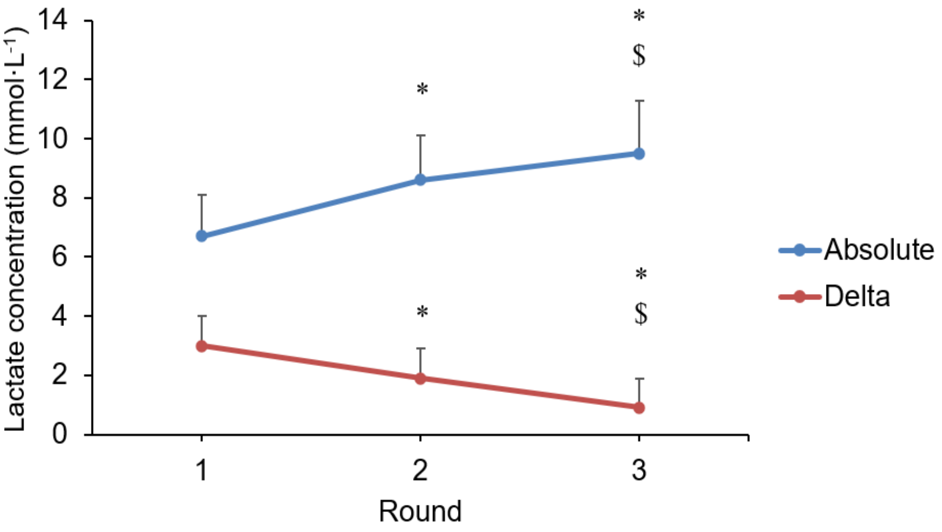
Figure 1: Lactate concentration before and after striking combat simulation.

Note: Some studies only reported the values after the combat simulation

After a karate kumite combat simulation, there is great variability in lactate concentrations, with values between 3.4 ± 1.0 $mmol{\cdot}L^{-1}$ [10] and 10.6 ± 4.8 $mmol{\cdot}L^{-1}$ [22]. Therefore, these studies indicate a moderate to high glycolytic demand during karate combat simulations. For example, in karate competitions, the duration of combat is different between genders: 4 minutes for men and 3 minutes for women. In this sense, Doria et al. [22] analyzed the lactate concentration after a combat simulation between men and women. Only 6 karate athletes were evaluated, 3 men and 3 women, after a combat simulation. The results showed that peak lactate concentration after the combat was 10.6 ± 4.8 $mmol{\cdot}L^{-1}$ for women and 7.5 ± 2.4 $mmol{\cdot}L^{-1}$ for men, but there was no significant difference between genders for peak lactate concentration. In another hand, Iide et al. [10] measured the lactate concentration during simulated karate sparring with different duration, 2 and 3 minutes. Twelve karate athletes participated in the study. Lactate concentration was significantly higher after 3-minute combat (3.4 ± 1 mmol·L^{-1}) when compared to 2-minute combat (3.1 ± 1 mmol·L^{-1}). Thus, during karate simulation, glycolytic responses are dependent on combat duration. Furthermore, Roschel et al. [29] showed no difference in lactate concentration between the winner (5.1 ± 1.2 mmol·L^{-1}) and defeated (5.2 ± 2.2 mmol·L^{-1}) after a karate combat simulation with 3 minutes of duration. Similarly, Chaabène et al. [21] showed no significant difference in lactate concentration after a karate combat simulation between the winner (11.2 ± 1.5 mmol·L^{-1}). Thus, studies showed a high to moderate glycolytic demand during karate combat simulation, but glycolytic demand is not determinant to the success or failure of athletes during combat.

A typical boxing competition contains 3 x 2-minute rounds, in novice boxers, 4 x 2-minute rounds in intermediate boxers, and 3 x 3 or 4 x 2-minute rounds in open-class boxers by agreement of the coaches and boxers [6]. In amateur boxing, after combat of 3 x 2-minute rounds with 1 minute of recovery between each round, the glycolytic demand is moderate to high with lactate concentration between 9.5 ± 1.8 mmol·L^{-1} [30] to 11.8 ± 1.6 mmol·L^{-1} [6] with female amateur boxers showing values around (10.1 ± 2.1 mmol·L^{-1}) in relation to men [31]. In this sense, Smith et al. [31] analyzed the lactate concentration after a boxing combat simulation with different combat duration. During 3 x 2 minutes combats with 1 minute of recovery, lactate concentration after combat was 8.6 ± 3.0 mmol·L^{-1}. On the other hand, during 3 x 3 minutes with 1 minute of recovery, there was an increase in lactate concentration after the combat simulation (9.5 ± 3.0 mmol·L^{-1}). Although the studies did not demonstrate differences between genders in glycolytic demand during boxing combat, the duration of the rounds contributes positively to the increase in lactate concentration.

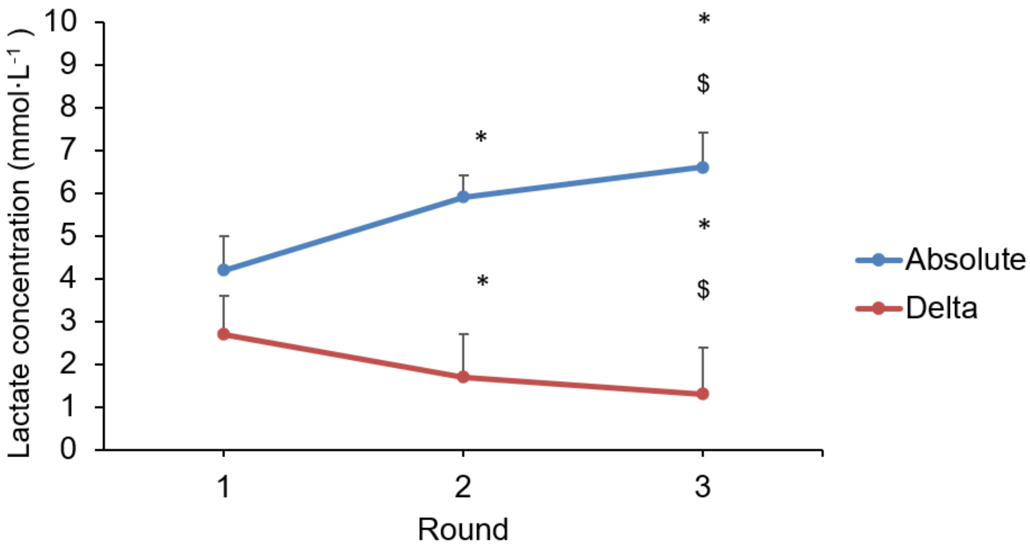
Although studies have shown an increase in absolute values of lactate concentration, throughout the rounds, this does not imply an increase in the glycolytic contribution. In this sense, the authors express the lactate concentration based on delta values, using the difference between peak lactate after each round and lactate concentration at the beginning of the round, when combat sports are divided by rounds. Thus, although there is an increase in lactate concentration, this does not indicate an increase in anaerobic contribution, however, there is a decrease in the glycolytic contribution with the course of the combat. For example, Davis et al. [30] analyzed the lactate concentration throughout the round in a boxing combat simulation, 3 x 2 minutes with 1 minute of recovery between each round. The results showed an increase in lactate concentration with the course of the rounds. However, when delta values were calculated, there was an increase in lactate concentration during the combat simulation. In this way, during boxing combat, the lactate concentration, when analyzed by absolute values, increases based on the number and the duration of rounds, although when values are expressed based on the delta, blood lactate decreases during the combat (Figure 2), indicating that the glycolytic contribution decreases throughout the rounds.



* Different from round 1; $ Different from round 2. All data are presented as mean ± standard deviation.

Figure 2: Lactate concentration during boxing combat simulation. (Adapted from Davis et al. [30]).

In relation to taekwondo combat simulation, Butios and Tasika [24] showed a lactate concentration of 2.9 ± 2.1 mmol·L^{-1} after combat of 3 x 3 minute with 1 minute of recovery between rounds. Furthermore, Campos et al. [25] analyzed the blood lactate concentration during a combat simulation of 3 x 2 minutes with 1 minute of recovery between rounds. The results showed that lactate concentration increased throughout the rounds. However, when lactate concentration was expressed based on delta values, there was a decrease in lactate concentration, indicating a decrease in glycolytic contribution during the combat (Figure 3). Similarly, as demonstrated by Davis et al. [30] with amateur boxing, although the absolute concentration of lactate increases during the combat when analyzed based on the delta, the glycolytic contribution decreases with the number of rounds.



* Different from round 2; $ Different from round 3. All data are presented as mean ± standard deviation.

Figure 3: Lactate concentration during taekwondo combat simulation. (Adapted from Campos et al. [25]).

Ouergui et al. [33] analyzed the effect of combat simulation of kickboxing on the anaerobic capacity of kickboxers. Therefore, 18 kickboxers were evaluated during combat simulation composed of 3 x 2 minutes with 1 minute of recovery between each round. Lactate concentration was measured before and after each round. Furthermore, the upper-body Wingate test was applied after the combat to evaluate the anaerobic capacity, through peak and mean power and fatigue index (%). There was a significant increase in blood lactate throughout the rounds (14.9 ± 0.7 mmol·L^{-1} after the third round), indicating very high participation of glycolytic metabolism during the kickboxing combat simulation. Furthermore, combat simulation was able to decrease the upper-body anaerobic capacity of kickboxers (Table 1). These results demonstrated that there are high glycolytic demand and high request from upper limbs during a kickboxing match.

Table 1: Peak power (PP), mean power (MP), and fatigue index (FI) before and after a kickboxing combat simulation.

	Before	**After**
MP (W.kg^{-1})	4.5 ± 0.5*	4.1 ± 0.5
PP (W.kg^{-1})	5.8 ± 0.6*	5.2 ± 0.6
FI (%)	50 ± 10*	40 ± 10

Data are reported as mean ± standard deviation. * Significant difference ($p < 0,05$) in relation to values after the combat simulation.

Posteriorly, Ouergui et al. [34] investigated whether there was any difference on lactate concentration and anaerobic capacity between kickboxers who win or lose. Twenty athletes of regional and national levels participated in the study and were submitted to a combat simulation comprised by three 2-min rounds with intervals of 1 minute between them. Lactate concentration and upper-body Wingate test performance were measured before and immediately after the combat. The results showed a very high glycolytic (14.0 ± 1.8 mmol·L^{-1}), without significant differences between winners (14.4 ± 1.7 mmol·L^{-1}) and losers (14.0 ± 2.0 mmol·L^{-1}). Furthermore, upper-body Wingate test performance was significantly lower after the combat, but it did not differ between winners and losers (Table 2). Thus, this suggests a similar anaerobic demand for both winning and losers kickboxers, whereas the decrease in peak power could be explained by the great anaerobic upper-body solicitation during the combat, which impaired subsequent performance in the Wingate test.

Table 2: Peak power (PP) and mean power (MP) before and after kickboxing competition in relation to combat outcome.

	Winners	**Losers**	**Overall**
PP (W.kg^{-1})			
Before	6.0 ± 1.2	5.1 ± 1.0	5.6 ± 1.2
After	4.0 ± 1.0*	3.4 ± 0.9*	3.7 ± 1.0*
Δ	2.1 ± 0.9	1.7 ± 0.6	1.9 ± 0.8
MP (W.kg^{-1})			
Before	3.6 ± 0.9	3.5 ± 0.9	3.6 ± 0.9
After	2.1 ± 0.5*	1.9 ± 0.6*	1.9 ± 0.6*
Δ	1.6 ± 1.0	1.6 ± 0.7	1.6 ± 0.8

Data are presented as mean ± standard deviation. * Different from before ($P < 0.001$). Abbreviation: Δ, difference between before and after combat.

Several studies analyzed the lactate concentration during combat simulation of Brazilian Jiu-Jitsu [35-38], judo [39-42], and wrestling [3,43-45]. These studies showed that glycolytic metabolism is important in these modalities. During Brazilian Jiu-Jitsu combat the glycolytic demand is moderate. For example, Andreato et al. [35] reported high values of lactate concentration (11.9 ± 5 mmol·L^{-1}) after a combat simulation of 7 minutes.

For example, Andreato et al. [36] analyzed the lactate responses in Brazilian jiu-jitsu athletes during combats of varied duration. For this, 10 athletes were submitted to combat simulations lasting 2-min, 5-min, 8-min, and 10-min. The sequence of combats was counterbalanced, and athletes had a 60-min recovery between each combat simulation. The lactate concentration was measured before and immediately after each combat of different duration. The absolute values of lactate concentration were significantly higher after combat with 2-min (6.2 ± 1.2 mmol·L^{-1}), 5-min (7.4 ± 1.9 mmol·L^{-1}), 8-min (8.1 ± 2.3 mmol·L^{-1}), and 10-min (10.1 ± 1.4 mmol·L^{-1}) duration in relation to baseline values (1.1 ± 0.3 mmol·L^{-1}). However, when the absolute values were reported, the lactate after the combat with 10-min (8.7 ± 1.6 mmol·L^{-1}) was significantly higher when compared to 2-min (5.4 ± 1.2 mmol·L^{-1}) and 5-min (6.4 ± 1.8 mmol·L^{-1}) combats. These results corroborate with the literature that demonstrated a moderate to high glycolytic activation during Brazilian jiu-jitsu combats. Moreover, this dynamic is influenced by time, i.e., the longer the combat duration, the higher the glycolytic demand. On the other hand, when lactate concentration was normalized by the effort time, the dynamic was different, a greater variation in lactate concentration was observed in shorter matches, 2-min (2.7 ± 0.6 mmol·L^{-1}) and 5-min (1.3 ± 0.4 mmol·L^{-1}), when compared to 8-min (0.9 ± 0.3 mmol·L^{-1}) and 10-min (0.9 ± 0.3 mmol·L^{-1}) combats. Thus, the higher activation in the longer combats may reflect a cumulative effect during combat. In other words, the lactate production rate during combat was greater than the removal rate, especially in the initial minutes.

On the other hand, Da Silva et al. [37] investigated if lactate concentration after a simulation of Brazilian Jiu-Jitsu combat could be different for athletes with different competitive levels. Thus, 14 Brazilian Jiu-Jitsu athletes were divided into two groups: 7 advanced (brown and black belts) and 7 no-advanced (blue to purple belts). Combat simulation was composed of 10 minutes. The results showed a high glycolytic demand after the combat simulation (10.3 ± 2.6 mmol·L^{-1}). However, there was no significant difference between the two groups advanced and no-advanced (10.4 ± 3.6 mmol·L^{-1} and 10.2 ± 1.3 mmol·L^{-1}, respectively). Thus, the competitive level does not influence the glycolytic demand during Brazilian Jiu-Jitsu combat simulation.

In this sense, Franchini and da Silva [46] showed that glycolytic demand was not different after Brazilian jiu-jitsu when winning and losing athletes were compared. The peak lactate concentration after the combat was significantly higher (8.79 ± 2.34 mmol L−1) when compared to values before combat (2.19 ± 0.55 mmol·L−1). However, the lactate concentration of winners (7.83 ± 2.47 mmol·L−1) and losers (9.76 ± 1.90 mmol·L−1) was similar. Thus, our results confirm the notion that glycolytic activation does not seem to be decisive for victory/defeat in Brazilian jiu-jitsu athletes.

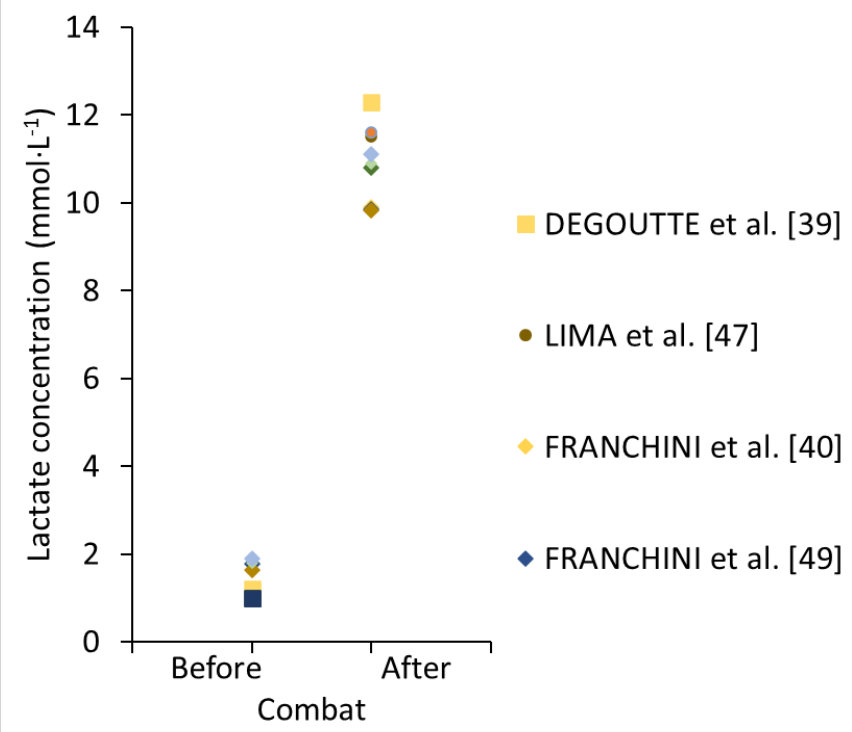
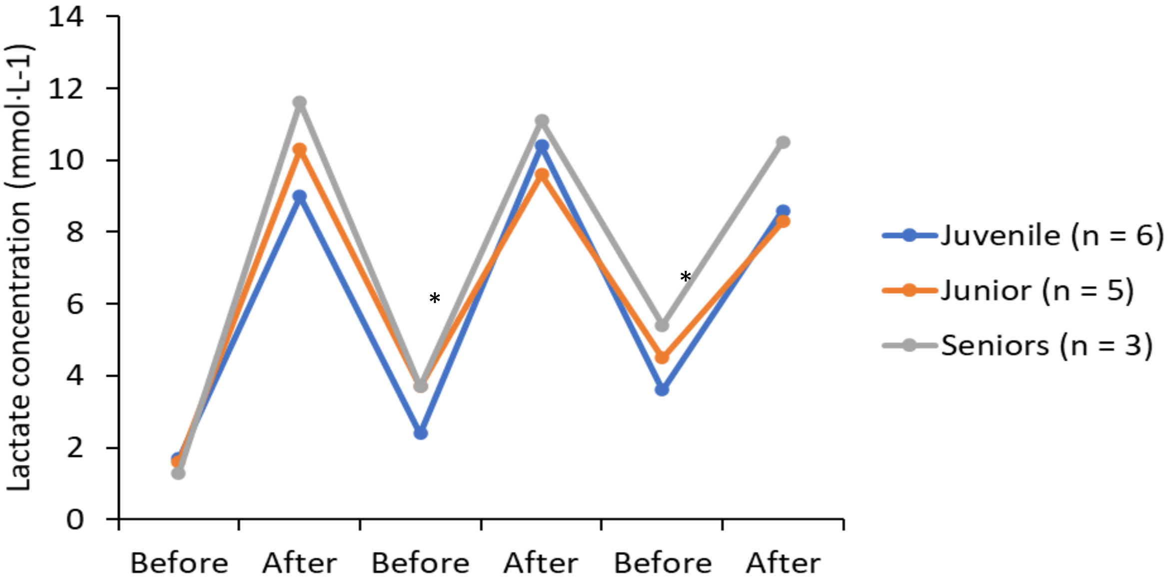


Figure 4: Lactate concentration before and after judo combat simulation.

The glycolytic demand is high (10 mmol·L-1) after a judo combat simulation (Figure 4). Degoutte et al. [39] reported a lactate concentration of 12.3 ± 0.8 mmol·L-1 when evaluated 2 minutes after a combat simulation of 5 minutes. On the other hand, Lima et al. [47] investigated if lactate concentration could be different after judo combat simulation with different duration: 1.5, 3, and 5 minutes. The results of the study showed that lactate concentration after the combat simulation did not present a significant difference between combats with different durations: 1.5 minutes (11.5 ± 0.76 mmol·L-1), 3 minutes (11.6 ± 1.8 mmol·L-1), and 5 minutes (11.6 ± 2.6 mmol·L-1). It suggests the glycolytic demand may occur in the initial stage of combat.

In judo competitions, the medalists perform 5-7 fights in a single day. In this sense, some studies analyzed lactate concentration during several judo combats. Franchini et al. [48] analyzed the lactate concentration after 3 judo combats of 4 minutes duration with a minimum interval of 20 minutes between each combat. For that, 15 judo athletes were evaluated and divided into 3 groups according to their category: 6 juvenile, 5 junior, and 4 seniors. The results showed that there was an increase in peak lactate concentration after each combat, but without differences between category and combats. On the other hand, lactate concentration after the first combat (1.6 ± 0.6 mmol·L-1) was significantly lower in relation to second (1.3 ± 1.9 mmol·L-1) and third (4.3 ± 2.2 mmol·L-1) combats (Figure 5). Thus, these results show that a 20 minutes period between each combat was not enough for the lactate concentration to return to resting levels.

Furthermore, Franchini et al. [49] analyzed the lactate concentration after two 5-min combat simulations with 15 minutes of recovery between them. The peak lactate concentration after the first combat was significantly higher (12.6 ± 5 mmol·L-1) when compared to the second combat (11.62 ± 4.79 mmol·L-1). It indicates a lower glycolytic demand as combat is repeated. In a series of studies [50-52] analyzed the lactate concentration during four 5-min judo combat simulations, interspersed with 15 minutes of passive recovery between each combat. The results showed that the lactate concentration was significantly lower after the fourth combat (12.6 ± 3.5 mmol·L-1) when compared to values after the first combat (14.6 ± 4.0 mmol·L^{-1}), without difference between other combats [51], whereas Bonitch-Góngora et al. [52] reported an increase in lactate concentration after each combat, with higher significantly values after the first (18.1 ± 4.4 mmol·L^{-1}) and the second combat (16.9 ± 3.5 mmol·L^{-1}) in relation to the third (15.2 ± 4.4 mmol·L^{-1}) and fourth combats (14.5 ± 3.5 mmol·L^{-1}). Recently, Bonitch-Góngora et al. [50] reported a progressive decrease in lactate along with the judo combats: after the first (17.8 ± 4.3 mmol·L^{-1}), second (16.6 ± 3.5 mmol·L^{-1}, third (15.6 ± 4.8 mmol·L^{-1}) and fourth (14.2 ± 3.7 mmol·L^{-1}) combats. Taken together, these studies indicate decreased glycolytic activation when successive combats are performed.



* Different from before first combat.

Figure 5: Lactate concentration before and after combat simulation in juvenile, junior, and seniors' athletes. (Adapted from Franchini et al. [48]).

Karninčić et al. [45] investigated the influence of competitive level on lactate concentration during Greco-Roman wrestling combat simulation. 20 wrestlers were divided into 10 from the national team and 10 from a club team. The combat was composed of 3 rounds of 2 minutes intercepted by 30 seconds between each round. There was a high glycolytic demand after the combat, but lactate concentration after the combat was no significant differences between elite (12.55 ± 1.8 mmol·L^{-1}) nonelite (13.23 ± 1.47 mmol·L^{-1}).

After that, Karninčić et al. [44] investigated the influence of weight category on lactate concentration after wrestling combat. 60 youth wrestlers were divided into three weight groups: 20 lightweight, 20 middleweight, and 20 heavyweights. The wrestling combat was composed of 3 rounds of 2 minutes with 30 seconds of rest between each round. Lactate concentration increased significantly after the combat, but there were no significant differences in the lactate concentration between lightweight (11.7 ± 3.1 mmol·L^{-1}), middleweight (10.8 ± 2.5 mmol·L^{-1}), and heavyweight (10.8 ± 2.1 mmol·L^{-1}).

Furthermore, Karninčić et al. [43] analyzed the influence of the age categories in the lactate concentration of wrestlers. The study was conducted on a sample of 30 young wrestlers. The sample was divided into three age categories: 10 boys (12.7 ± 0.5 years, 10 cadets (15.6 ± 0.5 years), and 10 juniors (18.2 ± 1.1 years). The combat was composed of 3 rounds of 2 minutes with 30 seconds of rest between each round. The results showed a high glycolytic demand in all categories after the combat. There was no significant difference in the lactate concentration after the combat between juniors (11.2 ± 1.3 mmol·L^{-1}) and cadets (12.0 ± 2.5 mmol·L^{-1}). However, the lactate concentration was significantly lower for boys (9.1 ± 1.6 mmol·L^{-1}) when compared to juniors and cadets. The authors justified these results may be caused by maturational factors or the type of training of athletes. The juvenile athletes were in the process of learning wrestling techniques; thus, the developments of the motor and functional abilities are not of primary interest.

2.2 Lactate concentration after competition simulation

Several studies have been investigated the lactate responses after a competition simulation during karate [20,21,50,51] and taekwondo [17,51-53] combats (Figure 6). Beneke et al. [20] analyzed the lactate concentration during a karate competition simulation, composed of 4 combats. Delta values demonstrated a reduction in the lactate concentration after the first (5.9 ± 1.6 mmol·L^{-1}), second (5.0 ± 1.2 mmol·L^{-1}), third (3.3 ± 1.2 mmol·L^{-1}), and fourth (2.2 ± 1.5 mmol·L^{-1}) combats. Furthermore, the values after the third and fourth combats were significantly lower when compared to the first and second combats. These results suggest that after the third combat the glycolytic contribution was reduced and a possible increase in the oxidative contribution.

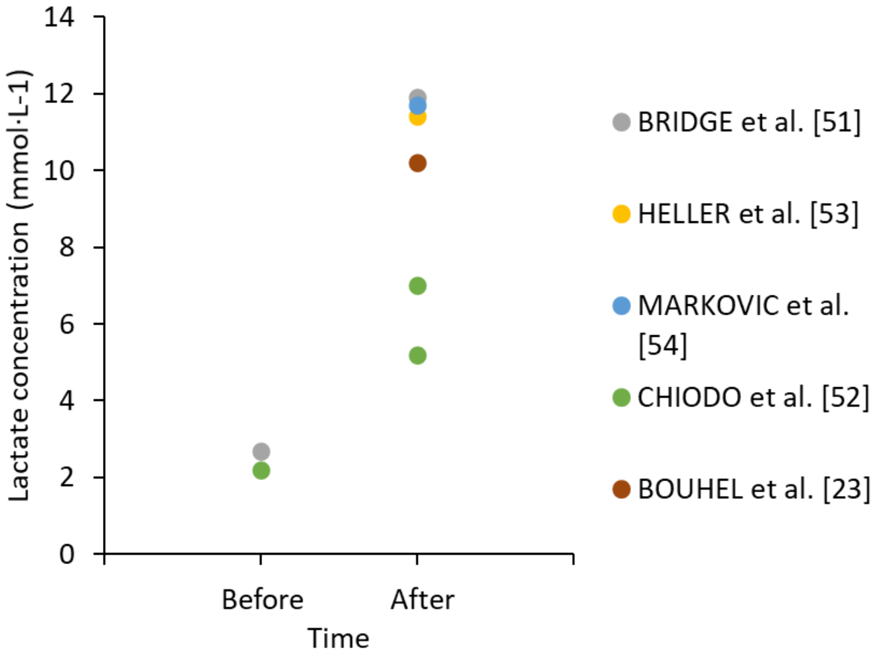


Figure 6: Lactate concentration before and after taekwondo combat simulation.

Tabben et al. [50] analyzed the lactate concentration before and after the international karate Kumite competition (International Karate Dutch Open, Rotterdam 2010). Seven karate athletes (3 women and 4 male) were evaluated. The duration of combat was 3 minutes for men and 2 minutes for women. The lactate concentration was measured before the first combat and immediately after each combat. There was a significant increase in the lactate concentration after each combat, but there was no significant difference between the combat and the genders (Figure 7). Furthermore, the values reported by Tabeen et al. [50] were higher than reported during a karate combat simulation [20]. This difference can be caused by the methodological reasons between these two studies, combat simulation [20] and competition simulation [50]. In this sense, the glycolytic demand is higher during international competitions in relation to combat simulation.

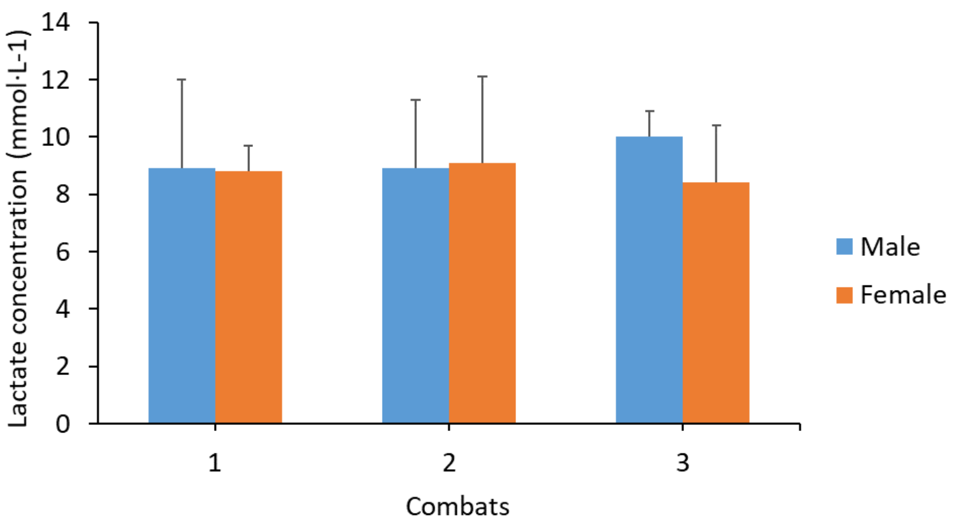


Figure 7: Lactate concentration during international karate Kumite competition. (Adapted from Tabben et al. [50]).

Moreover, Chaabène et al. [21] compared the lactate concentration during official and simulated karate combat. 10 high-level karate athletes participated in this study. The combats were composed in 3 minutes. The lactate concentration was measured before and 3 minutes post-combat. The results showed a higher lactate concentration after official combat when compared to combat simulation (Figure 8). These results showed that official combats demand a higher glycolytic participant in relation to combat simulation, probably because of greater intensity during the official combat.

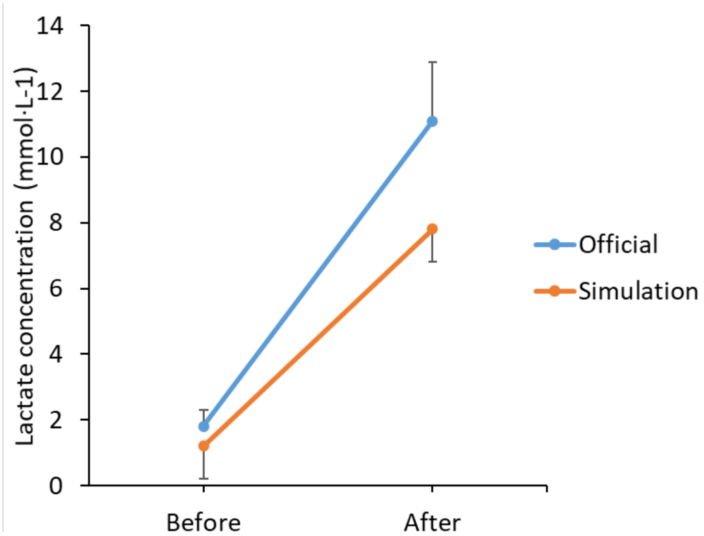


Figure 8: Lactate concentration before and after official and simulated karate combat. (Adapted from Chaabène et al. [21]).

During taekwondo competitions, Heller et al. [53] demonstrated a lactate concentration of 3.34 mmol·L^{-1} after a simulation of competition, composed of one combat of 2 rounds of 2 minutes with 1 minute of recovery between each round. On the other hand, Bridge et al. [51] analyzed the lactate concentration during a simulation of competition, 3 rounds of 2 minutes with 30 seconds of the interval between each round. The results showed an increase in the lactate concentration after the first (7.5 ± 1.6 mmol·L^{-1}), second (10.4 ± 2.4 mmol·L^{-1}), and third (11.9 ± 2.1 mmol·L^{-1}) rounds. However, after the second and third rounds, the lactate concentration was significantly lower than compared with values after the first round. In another study, Matsushighe et al. [17] compared the relationship between lactate concentration and competitive success. The results showed an increase in the lactate concentration after the competition simulation, but there was no significant difference after the combat between winners (7.8 ± mmol·L^{-1}) and defeated (7.2 ± 3.4 mmol·L^{-1}). Furthermore, Markovic et al. [54] measured the lactate concentration after competitive taekwondo combat performed by elite women. The results showed an increase in the lactate concentration 3 minutes after the competition simulation (11.7 ± 1.8 mmol·L^{-1}). Moreover, Chiodo et al. [52] analyzed if gender could influence the lactate concentration after a taekwondo competition simulation. The results showed an increase in the lactate concentration after the combat, but there were no significant differences between gender (Figure 9).

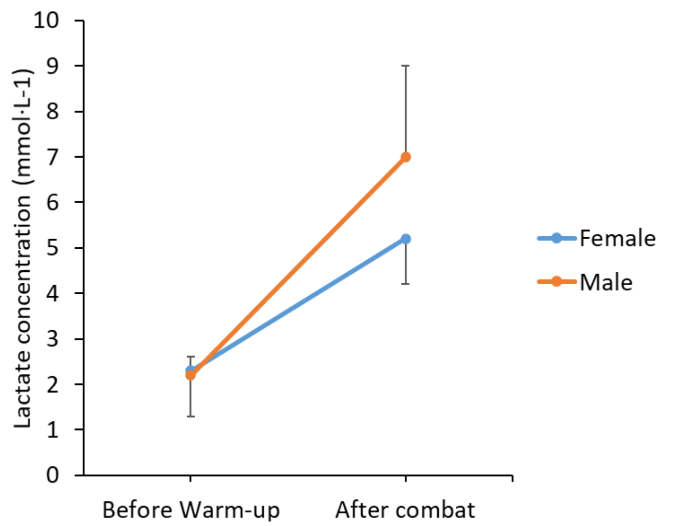


Figure 9: Lactate concentration before and after taekwondo combat simulation. (Adapted from Chiodo et al. [52]).

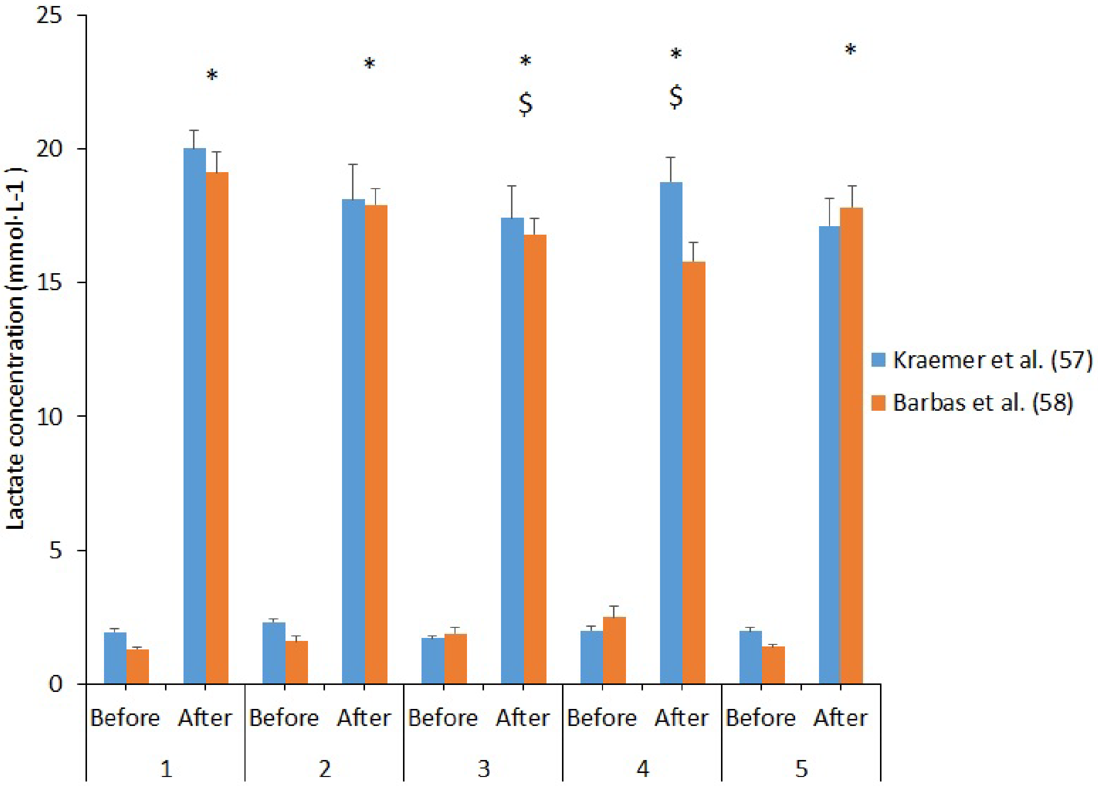
Several studies have analyzed the lactate concentration during judo [42,55,56] and wrestling [57,58] competition simulations. Furthermore, some studies analyzed the lactate concentration during official competition of wrestling [3] and Brazilian Jiu-Jitsu [7,35,36]. For example, Andreato et al. [35] analyzed the lactate concentration after a regional competition of Brazilian Jiu-Jitsu. 35 male Brazilian Jiu-Jitsu athletes graded from white to brown belt participated in the study. The lactate concentration was measured before and after the combat. The results showed a moderate glycolytic demand, with values of 10.1 ± 8 mmol·L^{-1} after the regional competition. Furthermore, Andreato et al. [36] evaluated 12 Brazilian Jiu-Jitsu athletes' blue belt, which participated in a regional competition of Brazilian Jiu-Jitsu. The lactate concentration was measured before and after the combat. Although the lactate showed a moderate glycolytic demand (6.2 ± 2.3 mmol·L^{-1}), these values were lower than reported by Andreato et al. [35]. A possible explanation for differences between studies may be caused by the different graduation of the athletes, Andreato et al. [35] analyzed athletes more graduated in comparison to athletes analyzed by Andreato et al. [36].

Franchini et al. [55] described the glycolytic demand during a simulated judo competition. For this, ten judo athletes were submitted to a simulated competition (four matches separated by 15-min intervals). The lactate concentration was measured before and after each combat. The results showed that lactate concentration was significantly higher after combats when compared to values before combats. Furthermore, lactate concentration before the third combat was significantly higher compared to before the first combat, while lactate concentration after the second combat was significantly higher in relation to values after the third and fourth combats. Thus, the glycolytic demand decreased as the athlete performs consecutive combats during a typical competition day.

Recently, Franchini et al. [56] investigated the effects of different fatigue levels on glycolytic demand during judo combats. For this, 12 judo athletes completed three 4-minute combats interspersed by 15-min passive recovery against the same opponents in three different conditions: after warm-up (control condition), after a regular training session (TS) (totaling 90 minutes), and after a high-intensity interval exercise (HIIE) session (2 blocks of 10 sets of 20-second all-out *uchi-komi*, with 10-seconds interval between sets and 5-minutes interval between blocks). Lactate concentration was measured before and after each match. Furthermore, delta lactate was calculated as lactate peak minus lactate before the combat. The results showed that peak lactate was significantly higher in the HIIE compared with the TS, with higher values after combat 1 in HIIE (9.51 ± 2.79 mmol·L^{-1}) compared to post-combat 1 in the TS condition (5.68 ± 1.56 mmol·L^{-1}). The delta values were significantly higher in the control condition in relation to the HIIE condition, with higher values for combat 1 of the control condition (6.00 ± 2.05 mmol·L^{-1}) compared with combats 2 (3.60 ± 1.71 mmol·L^{-1}) and 3 (2.07 ± 1.87 mmol·L^{-1}) of the same condition. Furthermore, delta values of blood lactate for the combat 1 (0.07 ± 1.71 mmol·L^{-1}) in the HIIE was lower than combats 2 (2.75 ± 1.64 mmol·L^{-1}) and 3 in the same condition (3.23 ± 1.51 mmol·L^{-1}) and combat 1 in the TS condition (2.62 ± 1.22 mmol·L^{-1}).

Wrestling events are organized in a tournament format thereby requiring athletes to compete in multiple matches for hours of a few consecutive days. In this sense, Kraemer et al. [57] and Barbas et al. [58] analyzed the lactate concentration during freestyle and Greco-Roman wrestling competitions, respectively. Kraemer et al. [57] investigated the lactate concentration responses to consecutive two days of wrestling in a tournament format after a typical period of cut weight. Therefore, athletes had to reduce their body weight during the week before the competition. The 2 days wrestling tournament consisted of five freestyle matches (three matches on day 1 and two matches on day 2. Each match was a 5-min Olympic freestyle match. Before and after each match athletes performed a vertical jump to evaluate the lower body power. The results showed a very high lactate concentration during the competition (Figure 10). However, the lower body power was significantly reduced after the fourth combat (4,318.4 ± 344.1 W) when compared to values before the first, second, and third combats (4,758.5 ± 361.5 W, 4,869.1 ± 278.1 W, and 5,052.7 ± 344.1 W, respectively).

Similarly, Barbas et al. [58] analyzed the lactate concentration of well-trained wrestlers to a simulated one-day tournament of Greco-Roman wrestling following a typical weight loss regimen. For this, athletes reduced approximately 6% of the body during the week that preceded the competition. The tournament consisted of five matches scheduled according to the official regulation of the International Wrestling Federation (FILA). Each match was composed by three 2-min rounds, 30-s breaks between rounds. The second match was performed 80-90 minutes after the first, the third 60-70 minutes after the second, the fourth 30-40 minutes after the third, and the fifth 5-6 hours after the fourth. The results showed a very high glycolytic demand after each combat during the competition. However, after the third and fourth combats, the lactate concentration was significantly reduced when compared to values after the first combat (Figure 10). Furthermore, the vertical jump was reduced before and after each combat. However, the vertical jump before the fourth combat (34.9 ± 2.3 cm) was significantly lower when compared to values before the first combat (41.7 ± 1.9 cm). Thus, the reduction in the lactate concentration and concomitant reduction in the vertical jump demonstrates that 30-40 minutes of recovery between combats are insufficient to recover the performance.



* Significantly higher when compared to before combat in Greco-Roman and Freestyle Wrestling.
$ Significantly lower when compared to after second combat in Greco-Roman and Freestyle Wrestling.

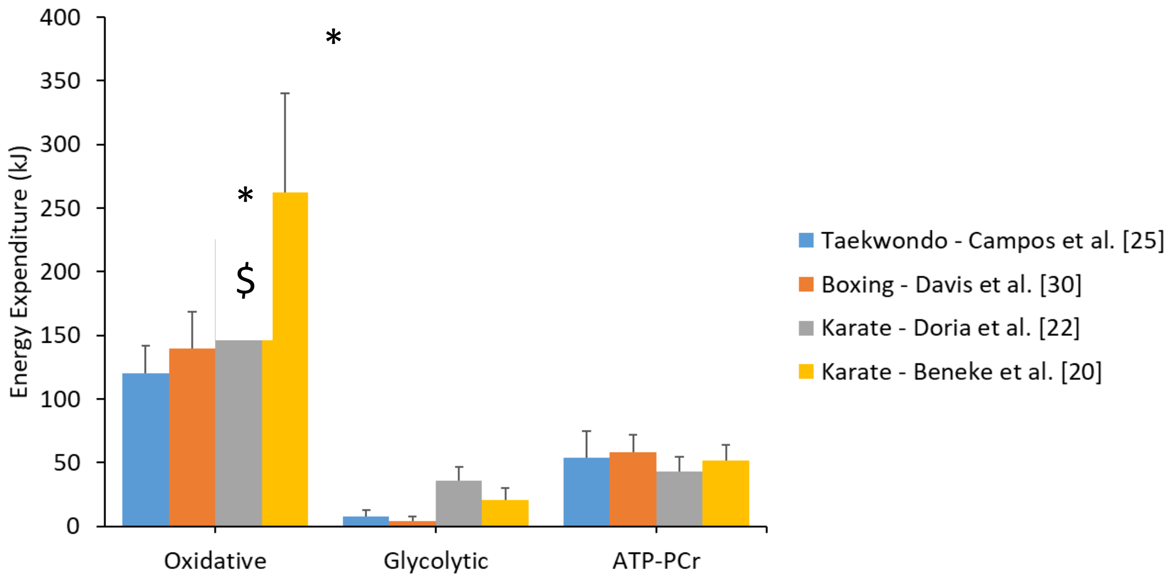
Figure 10: Lactate concentration during Greco-Roman and freestyle Wrestling, respectively (Adapted from Barbas et al. [58] and Kraemer et al. [57]).

Moreover, Del Vecchio et al. [13] analyzed the lactate concentration during an official competition, the 2005 Jiu-Jitsu World Cup. The results showed a high glycolytic demand (10.2 ± 1.5 mmol·L^{-1}) 2 minutes after the combat. Additionally, Nilsson et al. [3] analyzed the lactate concentration after the 1998 Greco-Roman wrestling World Championship. The results showed a very high glycolytic demand (14.8 ± 2.8 mmol·L^{-1}) after the competition. Furthermore, when lactate concentration was analyzed based on combat duration, there was a significant difference between combats of long duration (442 ± 56s; 15.7 ± 2.4 mmol·L^{-1} than in those of short duration (175 ± 51s; 13.6 ± 2.8 mmol·L^{-1}).

2.3 Energy systems contribution

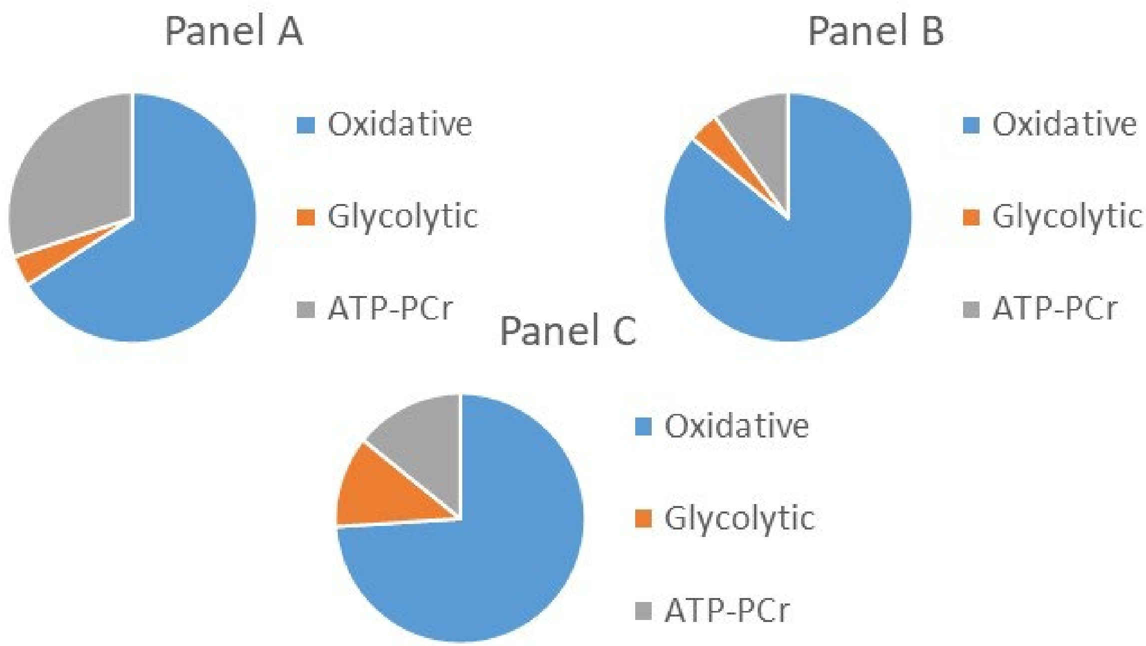
In general, combat sports are classified as high-intensity intermittent activities during which glycolytic metabolism is determinant [1]. In this sense, several studies have been evaluated the energy system contribution during combat of karate [20,22], taekwondo [25], and boxing [30], through the method in which is possible to separate the contribution of glycolytic and ATP-PCr metabolism. However, Crisafulli et al. [28] quantified the aerobic and anaerobic contribution during a combat simulation of Muay Thai. In relation to judo combat, one study analyzed the energy system contribution during a combat simulation [59] and specific exercise training, as *nage-komi* [60] and *uchi-komi* [61].

When analyzed the energy predominance during combat, aerobic metabolism is the predominant absolute source of energy, following by anaerobic ATP-PCr and glycolytic metabolism, but without significant difference between the absolute contribution of ATP-PCr and glycolytic metabolism. (Figure 11). Similarly, the contribution relative to total work done (%) is predominantly aerobic, following by ATP-PCr and glycolytic metabolisms, but without significant differences between ATP-PCr and glycolytic contributions during combat simulation of taekwondo, boxing, and karate (Figure 13).



* Significantly higher in relation to glycolytic contribution. $ Significantly higher in relation to ATP-PCr contribution.

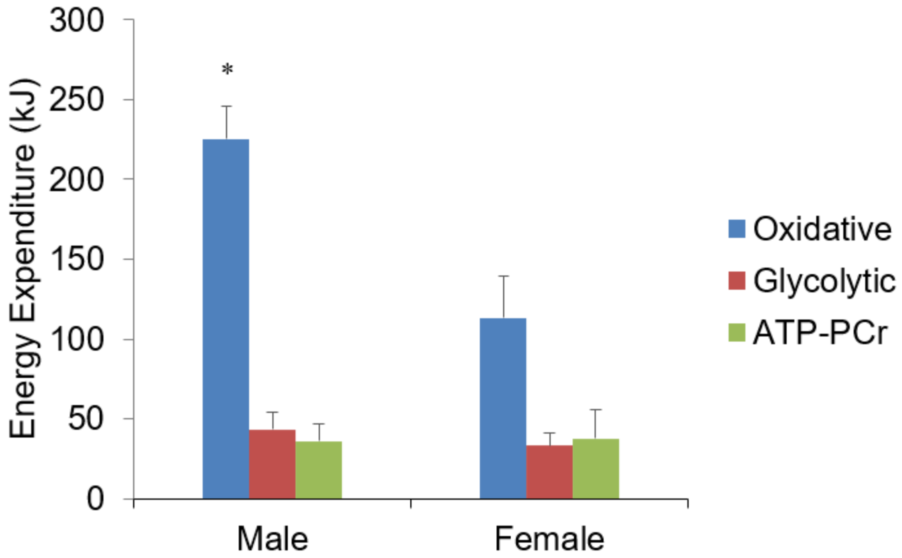
Figure 11: Oxidative, Glycolytic, and ATP-PCr energy sources taekwondo, boxing, and karate combat simulations. Absolute contribution (kJ).



Taekwondo (Panel A, adapted from Campos et al. [25]), Boxing (Panel B, adapted from Davis et al. [30]) and Karate (Panel C, adapted from Doria et al. [22]).

Figure 12: Relative energy contribution (%) during combat simulation.

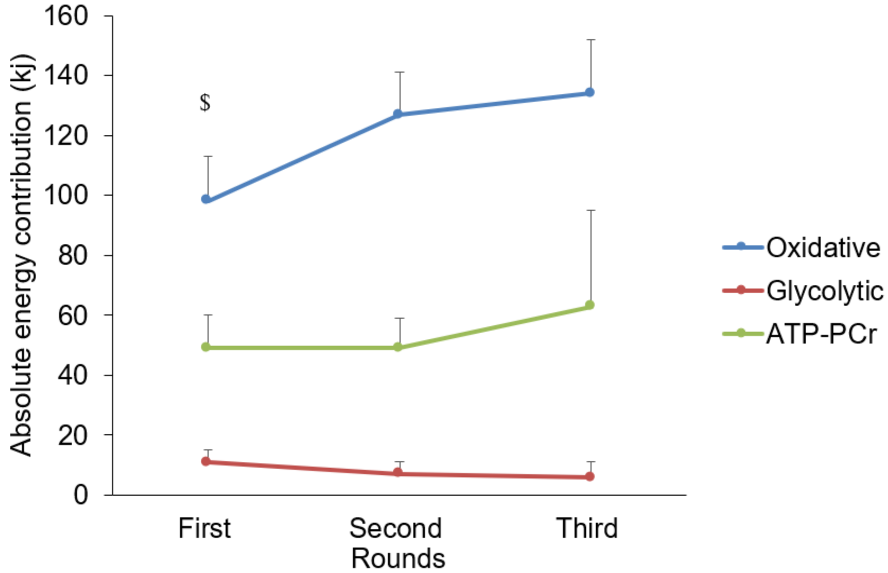
Doria et al. [22] analyzed the influence of gender on the energy system contribution during karate combat. The results demonstrated a predominance of the absolute aerobic metabolism during the combat simulation, with men presenting a higher aerobic metabolism in relation to women. Furthermore, there was no significant difference between men and women in relation to absolute glycolytic and ATP-PCr contributions (Figure 13). Similarly, the relative aerobic contribution related to total work done (%) was significantly higher in men when compared to women, following by ATP-PCr and glycolytic contribution, but without significant differences between genders.



* Significantly higher in relation to female.

Figure 13: Energy expenditure during karate combat simulation (Adapted from Doria et al. [22).

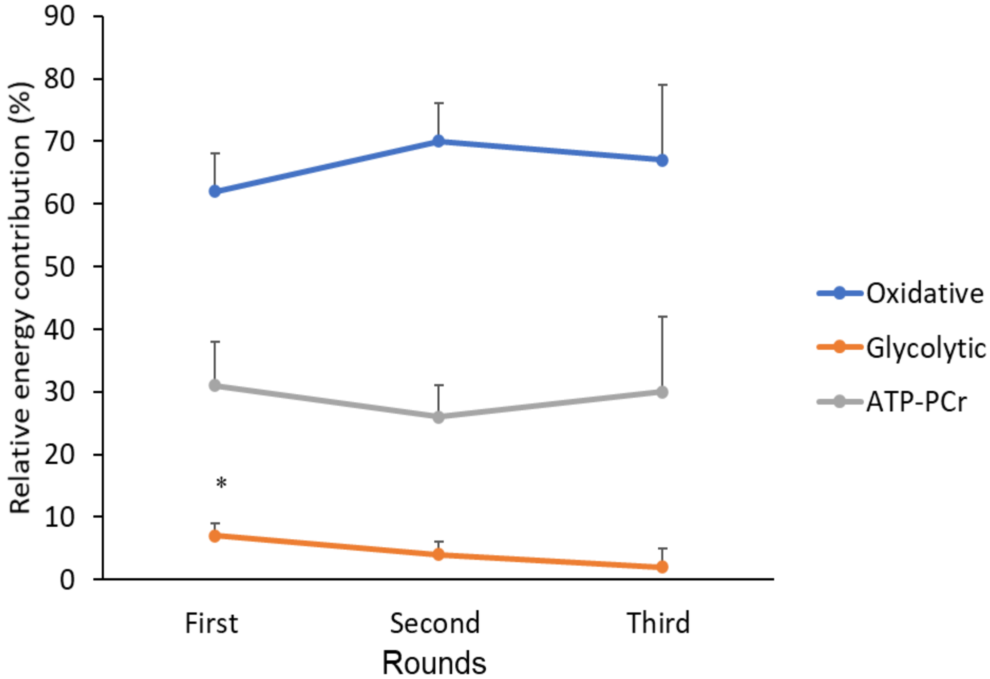
Aerobic metabolism is predominant during a combat simulation boxing (3 rounds of 2 minutes with 1 minute of recovery between each round). Davis et al. [30] demonstrated aerobic metabolism is predominant during a combat simulation, following the ATP-PCr and glycolytic metabolism (Figure 11). When values were expressed by the percentage of total work performed, the relative contribution of oxidative, ATP-PCr, and glycolytic metabolism was 77%, 19%, and 4%, respectively (Figure 12).



$ Significantly lower when compared to second and third rounds. All data are presented as mean ± standard deviation.

Figure 14: Absolute energy contribution (kJ) during taekwondo combat simulation. (Adapted from Campos et al. [25]).

Furthermore, Campos et al. [25] analyzed the energy system contribution during a combat simulation of taekwondo, 3 rounds of 2 minutes with 1 minute of recovery between each round. The results that absolute aerobic metabolism increased significantly over the rounds with lower values in the first round when compared to the second and third rounds. In relation to the glycolytic contribution, there was a decrease over the rounds, with significantly lower values after the first round in relation to the third round. However, there was no significant difference in the ATP-PCr contribution over the rounds (Figure 14). When analyzed the system contribution in relation to total work done, there were no significant differences in the aerobic and ATP-PCr contribution, but the glycolytic contribution decreased significantly over the rounds, with higher values in the first round when compared to the second and third (Figure 15).



* Significantly higher in relation to the third round. All data are presented as mean ± standard deviation.

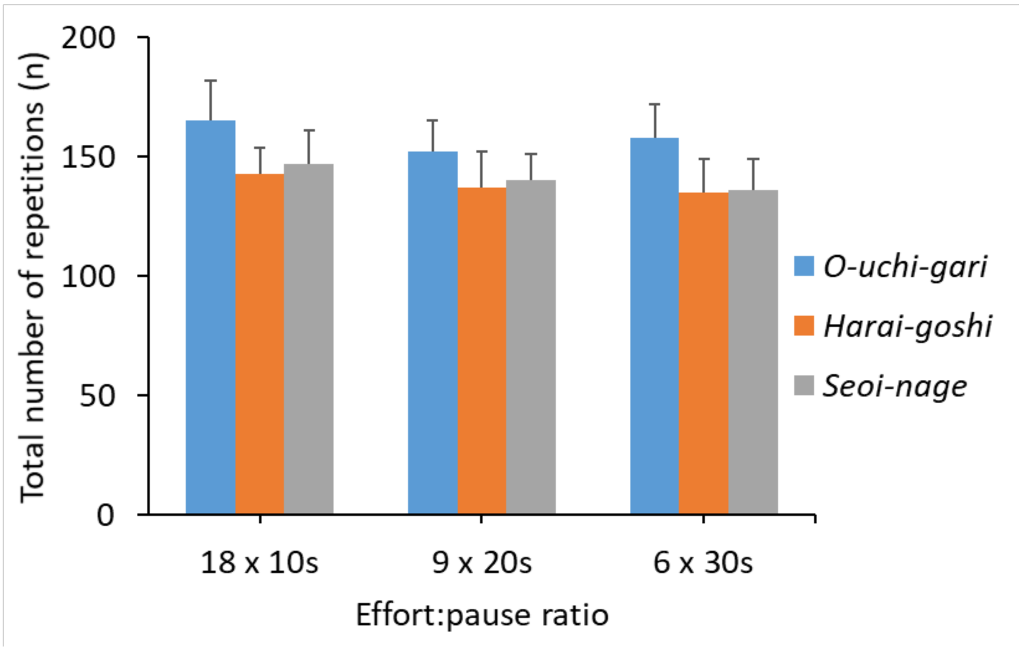
Figure 15: Relative energy contribution during taekwondo combat simulation. (Adapted from Campos et al. [25]).

Additionally, Crisafulli et al. [28] utilized another method to evaluate the energy demand during simulation combat of Muay Thai. Therefore, 10 athletes, 6 of the international level and 4 of the national level performed a combat simulation consisted of 3 rounds of 2 minutes, with 1 minute of recovery between each round. During the combat, the oxygen uptake and carbon dioxide production (CO2) were measured to obtain an index of anaerobic glycolysis, but this method is not possible to separate the anaerobic contribution into lactic and alactic. The results showed a linear increase with higher values of CO2 in the first and second rounds (307.3 ± 77.5 $mL.min^{-1}$ and 405.8 ± 95.5 $mL.min^{-1}$, respectively), but CO2 values decrease in the third round (195.7 ± 93.6). In this sense, these results demonstrated that glycolytic metabolism was predominant in the first round, while oxidative metabolism was predominant in the second and third rounds. However, the method utilized to calculated the energy anaerobic demand, through the CO2 production, does not allow to separate what was derived from lactic or alactic anaerobic metabolism.

Franchini et al. [60] analyzed the energy system contribution in three different judo techniques: *o-uchi-gari*, *morote-seoi-nage* and *harai-goshi*. Twelve black belt judo athletes participated in this study. Each athlete was submitted to a 5-minute protocol for each technique, with a 40-60 minutes interval. During each session, the athlete applied the technique, throwing an opponent on time at each 15s. This pattern was based on the mean time between throwing attempts during the competition and on the total match duration, respectively. The absolute ATP-PCr contribution was significantly higher during *seoi-nage* (42.2 ± 2 kJ) and *harai-goshi* (43.2 ± 2 kJ) when compared to *o-uchi-gari* (31.2 ± 2 kJ). Similarly, the relative ATP-PCr contribution was significantly higher during *seoi-nage* (16.3 ± 2.8 %) and *harai-goshi* (16.1 ± 2.7 %) when compared to *o-uchi-gari*

(16.1 ± 2.7%). The absolute oxidative contribution was significantly higher during *seoi-nage* (223 ± 66 kJ) when compared to *o-uchi-gari* (196 ± 74 kJ). No difference was observed in the relative oxidative contribution among techniques. There was also no difference in both relative and absolute glycolytic contribution among techniques. However, total energy expenditure is higher during *seoi-nage* (273 ± 86 kJ) in relation to *o-uchi-gari* (237 ± 99 kJ).

Understanding the physiological responses to the most common judo training modalities may help to improve the prescription and monitoring of training programs. In this sense, Franchini et al. [61] analyzed the physiological response and performance with different judo techniques and time-structured *uchi-komi* (technique entrance) protocols. Ten judo athletes which were submitted to nine all-out *uchi-komi* sessions. Three techniques (*o-uchi-gari*, *seoi-nage*, and *harai-goshi*) and 3 different time structures (18 x 10 seconds/10 seconds of the interval, 9 x 20 seconds/20 seconds of interval and 6 x 30 seconds/30 seconds of the interval). The authors evaluated the performance through the number of throwing performed. There was no significant difference in time structure for the number of technique repetitions (Figure 16). This result suggests that when a 1:1 effort-pause ration and all-out effort are used, judo athletes can perform the same number of repetitions during *uchi-komi*.



All data are presented as mean ± standard deviation.

Figure 16: Number of repetitions during *uchi-komi* using 3 different techniques and 3 times structures (Adapted from Franchini et al. [61]).

Furthermore, there was no significant difference for time structure or technique on the absolute energy expenditure. However, *o-uchi-gari* resulted in a lower total energy expenditure per repetition when compared to *seoi-nage* (Table 3). This result may be a consequence of the movement pattern, especially because of the requirement for trunk rotation and knee flexion during *seoi-nage*, which increase the length of time required to perform a single repetition. Thus, the use of *uchi-komi* as a training stimulus may be a better training stimulus because it is specific to the sport.

Table 3: Absolute (kJ) and relative (%) energy expenditure during uchi-komi session using different technique structures (Values expressed as mean ± standard deviation); Adapted from Franchini et al. [61]).

	O-uchi-gari			***Harai-goshi***			***Seoi-nage***		
	18 x 10s	9 x 20s	6 x 30s	18 x 10s	9 x 20s	6 x 30s	18 x 10s	9 x 20s	6 x 30s
Total (kJ)	32.4 ± 49.3	316.6 ± 50.7	348.3 ± 31.7	314.6 ± 34.7	314.2 ± 4.5	329.1 ± 0.1	340.9 ± 33.3	334.9 ± 9.6	343.4 ± 2.8
Total (%)	2.01 ± 0.42*	2.10 ± 0.40*	2.22 ± 0.29*	2.21 ± 0.26	2.31 ± 0.52	2.45 ± 0.24	2.34 ± 0.28	2.40 ± 0.27	2.53 ± 0.43

* Significant lower ($p < 0.05$) in relation to *seoi-nage.*

To characterized the metabolic demand of judo combat, Julio et al. [59] estimated the contribution of 3 energy systems of simulated judo combat. For this, 12 male judo athletes performed 5 combats with different durations (1, 2, 3, 4, and 5 minutes). The method utilized to estimate the energy expenditure during the matches was the same utilized by previous studies [19,21,24]. The results showed that absolute oxidative contribution (70%) was significantly higher when compared to glycolytic (8%) and ATP-PCr absolute contribution (21%). Furthermore, absolute ATP-PCr contribution was significantly higher when compared to glycolytic metabolism. Similarly, the relative oxidative contribution (70%) was significantly higher when compared to relative glycolytic (8%) and ATP-PCr (21%) contributions, whereas relative ATP-PCr contribution was significantly higher in relation to relative glycolytic contribution. These results suggest that oxidative metabolism is predominant to supply the energy cost of judo matches, followed by ATP-PCr and glycolytic contributions. This predominance was observed from the first minute to last minute of combat when compared to the anaerobic systems. In relation to ATP-PCr and glycolytic contributions, the ATP-PCr contribution was higher than the glycolytic from the third minute. However, the ATP-PCr contribution system was reduced as the match duration increased. In other words, during judo combat simulations there is an increase in the oxidative contribution (from 50% to 81%) with a concomitant reduction in the contribution of the ATP-PCr system (from 40% to 12%), while the glycolytic contribution remains relatively constant (between 6% and 10%). These results suggest that oxidative metabolism is predominant, but it is important to emphasize that actions that generate scores and, thus, determine the outcome of the match (i.e. mainly the throwing-technique attacks) require a high rate of energy over a very short period, suggesting they are highly dependent on the ATP-PCr pathway. Furthermore, the glycolytic demand is important during the gripping dispute.

3. Longitudinal studies

Franchini et al. [40] monitored the final phase of preparation of judokas which participated in the 1999 Pan American Games. The athletes were evaluated two and one months before the competition. After the test evaluation, the focus of the training was capacity and power anaerobic during a specific situation of training, along with the technical-tactic training. there was no significant improvement in performance when evaluated through two bouts of upper and lower-body Wingate test and the total number of throws. However, the lactate concentration after the second bout of the Wingate test was lower during the period closer to competition, indicating that athletes performed the same performance with lower glycolytic demand. During the specific training (randori and Special Judo Fitness Test), the lactate concentration was the same in both periods. Although the performance did not change during the specific and no-specific test, the last was performed with a lower glycolytic demand after the training period.

Franchini et al. [62] investigated the effect of three different high-intensity intermittent training (HIIT) during four weeks on the anaerobic performance of 35 judo athletes. Participants were allocated to three groups: 9 athletes in the lower-body HIIT group, 9 athletes in the upper-body HIIT group, 9 athletes in the *uchi-komi* group, and 8 athletes in the control group. The lower-body group performed the HIIT using a lower-body cycle ergometer. These stimuli consisted of two sets of the 20s with 10s interval between sets and 5-min between blocks. Each effort was an all-out bout using 4.5% and 3% of body mass as resistance for the lower-body and upper-body groups, respectively. The upper-body group underwent the same protocol used by the lower-body group, except that the ergometer used was an upper-body bicycle and the load used was 3% of body mass. The specific group was submitted to two blocks of 10 sets of the 20s of the *uchi-komi* (technique entrance) throwing the partner at the end of each set, with 10s intervals between sets and a 5 min interval between blocks. Similar to the other groups, the athletes in this group were also asked to perform every set in an all-out mode. In all groups, the training session lasted for a total of 22 min 40s and athletes performed four lower-body and upper-body Wingate tests before and after four weeks of training. All tests were separated by a 3-min recovery period. Furthermore, blood lactate was measured before each test, 1, 3, and 5-min after the fourth bout. The results showed that the *uchi-komi* group showed a higher upper-body (+16.7%) and lower-body (+8.5%) peak power after the training when compared to before training and the lower-body group increased the mean power (+14.2%) in the fourth lower-body Wingate test. However, there was no significant difference between upper-body HIIT and lower-body HIIT. Thus, different HIIT protocols resulted in upper-body non-specific anaerobic performance improvement in judo athletes.

Additionally, Franchini et al. [63] investigated the effect of low-volume HIIT on performance responses during judo-specific tests. The groups and training protocols were the same as reported in Franchini et al. [63]. Athletes performed a Special Judo Fitness test before and after four weeks of training. The results showed that the upper-body group increased the number of throws after the training (27 ± 2 reps) when compared to values before (25 ± 2 reps), while the lower-body group decreased the HR immediately after the SJFT following four weeks of training (174 ± 9 bpm) when compared to the period before training (181±9 bpm). Furthermore, the *uchi-komi* group reduced the SJFT index after the training (12.07 ± 1.36 beats.min^{-1}.throw^{-1}) when compared to before training (12.84 ± 1.47 beats.min^{-1}.throw^{-1}). Furthermore, the lower-body group decreased the standing sequences number after the training (10 ± 3 times) in comparison to values before training (13 ± 2). Thus, these results showed that all training modes were able to improve judo-specific performance, but each group adapted differently.

Marques et al. [64] investigated the judo-specific performance of state/national level and international judo athletes submitted to block periodization. The sample included 21 elite judo athletes, 11 (5 males and 6 females) were included in the state-national group, and ten (6 males and 4 females) were included in the international group. Block periodization was composed of 13-week training and was divided as follows: five weeks of the accumulation training phase (ACP), followed by a 5-week transmutation phase (TP) and 3-week realization phase (RP). The main physical content developed during the ACP included strength exercises, which were mainly performed using weight training exercises, and conditioning workouts aimed at developing judo-specific strength. During the ACP the technical preparation was mainly throughout *uchi-komi* and *nage-komi* exercises. The main physical training during TP was to develop muscle power. The physical training content included explosive weight training, jumps, and throws, while technical and conditioning workouts were performed according to judo-specific activities, such as *uchi-komi*, and randori. During RP training, the training content for both strength and conditioning, and technical workouts were similar to those developed during TP, but the training volume was substantially reduced and the specific judo technical actions became the main focus of the training program. SJFT test was performed at the beginning of the ACP (T1), after ACP (T2), and after TP (T3). Results showed a higher number of throws at T3 in relation to T1, and T3 when compared to T2. Furthermore, the SJFT index was significantly higher at T1 when compared to T2, and when T2 was compared to T3. Together, these results showed that SJFT performance was sensitive to changes in training content across the block periodization phases and that this approach might be a useful alternative periodization strategy for judo athletes.

Ravier et al. [65] investigated the effects of seven weeks of HIIT on the aerobic and anaerobic metabolism of 17 elite karate athletes. Two groups were studied: 8 athletes in the karate training group (control group) and 9 in the HIIT group (experimental group). The MAOD test was applied before and after 7 weeks of intervention to evaluate the anaerobic capacity. The control group realized their normal karate activity of four to five times per week. The experimental group performed 7-9 sets of a 20s running exercise at an intensity of about 140% of VO2max velocity with a 15s rest between each bout. However, when the athletes could complete more than nine sets of the exercise, running velocity increased by 5%. After the training period, the experimental group increased significantly the MAOD when compared to the values before the training period, but there was no significant difference in relation to the control group. Furthermore, the lactate concentration increased and pH decreased after the supra-maximal test (Table 4).

Table 4: Maximal Accumulated Oxygen Deficit (MAOD, lactate concentration, and blood pH before and after 7 weeks of training in elite karate athletes. Values are expressed as mean ± standard deviation.

Variables	Training		Control	
	Before	After	Before	After
MAOD (ml·kg)	63.9 ± 6.2	70.5 ± 6.4*	65.5 ± 7.3	62 ± 10
Lactate (mmol·L^{-1})	20.2 ± 2.8	22.8 ± 2.6*	17.9 ± 1.3	18.1± 1.2
pH	7.07± 0.04	6.96 ± 0.05*	7.12 ± 0.04	7.14 ± 0.03

* Significantly difference ($p < 0.05$) when compared to values before the training. (Adapted from Ravier et al. [65]).

The increase in an anaerobic contribution after the HIIT may be due to an increase in glycolytic activity, possibly due to increased activity of phosphofructokinase enzyme [66]. Furthermore, the increase in lactate concentration and a decrease in blood pH after the training indicate an increase in production and/or liberation from the blood to the muscle during the exercise. In contrast, a possible limitation is that both the training protocol and the tests utilized were non-specific to modality. However, is possible to adopt this type of HIIT to the routine of athletes, with specific and actions of the modality as punches and kicks.

Farzard et al. [67] examined the effects of 4 weeks of sprint interval training (SIT) on the anaerobic performance of 15 trained wrestlers. The athletes were divided into two groups: 7 control group and 8 experimental groups. Before and after 4 weeks of training, the athletes performed four bouts of lower-body Wingate test with 4 minutes recovery between each 30s interval to evaluate the anaerobic performance. Furthermore, the lactate concentration was measured at 3, 15, and 30 minutes after the fourth Wingate bout. Both groups followed the same wrestling training sessions, including technique drills, wrestling practice, and strength training for four weeks, 3 sessions per week. Also, both groups had 2 sessions of weight training in the weight room and 1 session of plyometric training. In addition to this training, the experimental group performed a running-based SIT protocol. This protocol was performed in 2 sessions per week and consisted of sets of 6 x 35m sprints at maximum effort with a 10s recovery between each sprint. A set was added in each subsequent week with the same 3 minutes rest between sets. The training program is presented in table 5.

Table 5: Training program for both groups.

Days of week	Control group	Experimental group
Monday	Wrestling training	Wrestling training
Tuesday	Weight training	Weight training
Wednesday	Wrestling training	Wrestling training
Thursday	Weight training	Sprint Interval Training (morning) Weight training (evening)
Friday	Rest	Rest
Saturday	Wrestling training	Wrestling training (morning) Plyometric training (evening)
Sunday	Plyometric training	Sprint Interval Training

The experimental group showed significant improvements in peak power (PP) during the first and second bouts (+ 11% and 12%, respectively) of the Wingate test. Also, the mean power during the first and second Wingate bouts increased significantly (+ 6.1 and 8.9%) in the experimental group when compared with a pre-test.

In resume, the SIT when added to a training routine of karate [65] and wrestlers athletes [67] showed an efficient strategy to improve the anaerobic capacity. Furthermore, this type of intervention with a low volume of training can be implemented in the pre-season and during the season when the purpose of the training was to increase the performance during the short-time period. Although these studies utilized a SIT protocol with non-specific actions of modalities, this training strategy can be utilized with specific techniques of each modality.

4. Non-specific tests to monitor the anaerobic fitness of combat sports athletes

4.1 Wingate test

The Wingate test requires a subject to complete a brief warm-up/lead-in period, pedaling or arm cranking on a stationary ergometer, followed by a 30 s all-out effort at maximal speed against a constant resistance. Peak power is achieved in the first 3 to 5 seconds of this test and thus is dependent on the phosphagens system pathway. Conversely, the power generated during the 30s period is denominated as mean power and related to glycolytic metabolism [69]. Furthermore, the fatigue index is calculated according to Equation 1:

Fatigue Index = (peak power – lower peak power during the test) X 100 / Peak power **(Equation 1)**

The Wingate test results for combat sports athletes are reported in table 6.

Table 6: Wingate results in combat sports athletes. All data are presented as mean ± standard deviation.

Reference	Athletes characteristics	Modality	Load	PP (W)	PP (W/kg)	MP (W)	MP (W/kg)
[22]	Italian Men (3) Female (3)	Karate kumite	7.5 % of BM	NR	 9.1 ± 1.1 9.7 ± 0.6	NR	 7.9 ± 0.6 7.8 ± 0.2
[53]	Czech Men (5) Female (3)	Taekwondo	6% of BM	NR	 14. 7 ± 1.3 10.1 ± 1.2	NR	NR
[69]	Korean Men	Wrestling		NR	11.2 ± 1.8	NR	6.7 ± 1.0
[70]	Brazilian Elite (34) Non-elite (56	Judo		468 ± 63 394 ± 53	5.7 ± 0.8 5.4 ± 0.8	623 ± 80 493 ± 92	7.6 ± 1.0 7.0 ± 1.3

NR: no reported; UB: upper-body; PP: absolute (W) and relative (W/kg) peak power; absolute (W) and relative (W/kg) power.

Recently, Franchini [71] developed a normative classificatory table for upper-body Wingate test performance for judo athletes from different weight categories (Table 7). This normative classificatory table created may be useful as a reference in judo athletes' anaerobic evaluation.

Table 7: Absolute and relative peak and mean power classificatory table in adult judo athletes (n = 179).

	Peak power		Mean power	
	Absolute (W)	Relative (W/kg)	Absolute (W)	Relative (W/kg)
Excellent	>950	>11.41	>620	>7.71
Good	765-950	9.46-11.41	551-620	6.71-7.71
Regular	486-764	6.56-9.45	362-550	4.87-6.70
Poor	377-485	5.42-6.55	298-361	4.33-4.86
Very poor	<377	<5.42	<298	<4.33

5. Specific tests to monitoring the anaerobic fitness of combat sports athletes

5.1 Special Judo Fitness Test (SJFT)

SJFT is divided into three periods (A = 15 s; B and C = 30 s) with 10 s intervals between them. Each partner was positioned 6 m apart and the athlete being tested was required to run to each partner and then throw them as many times as possible using the *ippon-seoi-nage* technique. Both partners had a similar height and body mass as the athlete performing the test. The total number of throws completed is summed; Just after and 1-min after the test, HR is measured. The SJFT index was calculated according to the following equation:

Index = (HR after + HR 1minute after)/total number of throws. **(Equation 2).**

The Intraclass Coefficient of Correlation (ICC) for the total number of throws (0.73), HR after the test (0.93), HR 1 minute after the test (0.89), and index (0.89) is high (1). Furthermore, the index showed a significant correlation with total work performed in the Wingate test (r = 0.71), while the total number of throws presented a significant correlation with relative total work performed in the Wingate test (r = 0.71), fatigue index (r = -0.52) and velocity associated at anaerobic threshold (r = 0.67). The SJFT has a classificatory table based on variables measured during the test (the index, HR immediately and 1 minute after the test, the total number of throws) [72] (Table 8).

Table 8: Classificatory table for the total number of throws, heart rate (after and 1 minute), and index in the Special Judo Fitness Test (Adapted from Franchini et al. [72]).

Classification	Total of throws	HR after (bpm)	HR 1 min after (bpm)	Index
Excellent	≥ 29	≤ 173	≤ 143	≤ 11.73
Good	27 – 28	174 – 184	144 – 161	11.74 – 13.03
Average	26	185 – 187	162 – 165	13.04 – 13.94
Poor	25	188 – 195	166 – 174	13.95 – 14.84
Very Poor	≤ 24	≥ 196	≥ 175	≥ 14.85

5.2 Frequency Speed of Kick Test (FSKT)

The FSKT has a duration of 10s and during its execution, each athlete is placed in front of the stand bag equipped with a simple trunk taekwondo protector. After a command, the athletes perform the maximal number of kick possible, alternating right and left legs. The turning kick, known as *bandal-tchagui* is using during the test. Performance is determined by the total number of kicks during the test. FSKT was developing by Villani et al. [73]. The reliability of this test was reported as ranging from r = 0.71 to 1 (92) and from 0.82 to 0.86 [74]. Moreover, the FSKT can discriminate female taekwondo athletes, with international/national realizing a higher total number of (91 kicks) kicks when compared to state and regional levels (86 kicks) athletes [75].

5.3 Taekwondo anaerobic test (TAT)

Recently, Sant'Ana et al. [76] propose a method for evaluation of the anaerobic power and capacity of taekwondo athletes. The test consists of kicking a punching bag as many times as possible at maximal intensity over the 30s. The test duration was based on the Wingate test. The athletes start the protocol with their dominant leg, alternating with the kicking leg. The test is performed in a 2 x 2 area, and the kicks (Bandal-Tchagui) had to reach the punching bag at a height between the umbilical scar and xiphoid process. In this test is possible to calculate the number of kicking cycles, mean kicking time, and best kicking time. Furthermore, is possible to identify the magnitude of the impact in each kick in the bi-lateral axis through the highest kicking impact and mean kicking impact over the 30s of the test. In the end, the authors proposed the fatigue index calculated using the mean kicking time and mean the impact of initial 20% cycles and the mean of the last 20% cycles, according to the equations:

Fatigue index by time = (LC – IC)/IC) *100. (Equation 3).

Fatigue index by impact = (IC – LC)/IC) *100. (Equation 4).

Where: LC: mean kicking time/impact on the last 20% of cycles; IC: mean kicking time/impact on the initial 20% of cycles.

The results of the test demonstrated that the number of kicking cycles and mean kicking impact can be considered as indicators of the anaerobic capacity of taekwondo athletes. Furthermore, the best kicking time represents the anaerobic lactic power.

6. Strategies for developing the anaerobic fitness of combat sports athletes

Combat sports are classified as high-intensity intermittent activities with a predominance of aerobic metabolism. However, anaerobic metabolism is important for high-intensity actions during the combats. Therefore, considering the principle of training specificity, the training prescription should be based on the temporal characteristics and the energy contribution of each modality. The effect of high-intensity intermittent training (HIIT) on performance has been related in the literature

[19,77]. By definition, the HIIT involves repeated short to long bouts of rather high intensity interspersed with recovery periods [78]. Recently, the use of sprints and all-out exercises have appeared in the literature [79]. These types of HIIT include Repeated-Sprint Training (RST: sprints lasting from 3 to 7s, interspersed with recovery period lasting generally less than 60s) [79] or Sprint Interval Training (SIT: 30s all-out efforts interspersed with 2-4 minutes of passive recovery period) [77] (Figure 14). Although these training strategies have been utilized during running and cycling activities [78,80], the HIIT can be an effective strategy to improve the physical fitness of combat sports athletes.

Buchheit and Laursen [77] reported several physiological responses desired during a session of HIIT. For example, (1) metabolic, but eliciting essentially large requirements from the O2 transport and utilization systems, i.e. cardiopulmonary system and oxidative muscle fibers; (2) metabolic but with a certain degree of neuromuscular strain; (3) metabolic but with a large anaerobic glycolytic energy contribution; (4) metabolic plus a certain degree of neuromuscular load; (5) metabolic with essentially an important anaerobic glycolytic energy contribution and a large neuromuscular load; (6) eliciting a high predominant neuromuscular strain.

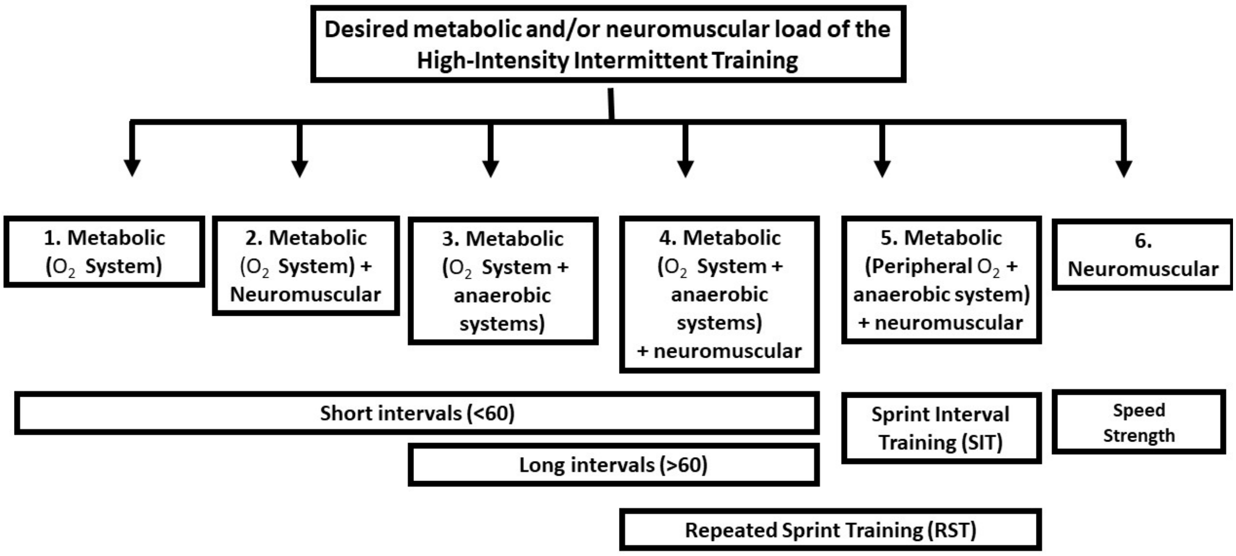


Figure 17: Decision process for selection high-intensity intermittent training (HIIT) based on expected acute physiological responses (adapted from Buchheit and Laursen et al. [77].

Although there are several approaches that, considered in isolation, will achieve a similar metabolic and/or neuromuscular training adaptation outcome, the ability of the coach to understand the isolated acute responses to various HIIT formats may assist with the selection of the most appropriate HIIT session to apply, at the right place and time during the training process. Furthermore, at least nine variables can be manipulated to prescribe the different HIIT session.

The intensity and duration of work and relief intervals are the key influencing factors. In relation to the intensity of effort, Buchheit and Laursen [77] described the variation of intensity according to the objective of HIIT session based on speeds associated with VO2max (vVO2max) or maximal sprinting speed (MSS). For example, during sprint interval training, the intensity of exercise should be corresponding to 180% of vVO2max or intensity corresponding to 95% of MSS. On the other hand, during repeated sprint training the intensity can be between 160-140% of vVO2max or 50-75% of MSS. Although the intensity of exercise is defined through incremental protocols using a treadmill or cycle-ergometer, in combat sports the intensity of exercise can be adapted utilizing specific techniques. For example, judo athletes can be utilized a higher number of throws while taekwondo athletes can utilize a higher number of kicks during a time interval. Furthermore, Buchheit and Laursen [19] related that the manipulation of both duration of exercise and intensity/duration of recovery may substantially impact the glycolytic contribution during the exercise. In activities of 4, intercepted with activities interval lower than the 20s, the lactate concentration after the exercise is consistently higher > 10 $mmol \cdot L^{-1}$. After that, the number of intervals, the number of bouts, the intensity, and duration between each bout determine the total work performed.

Therefore, the training for combat sports athletes can be directed in a manner to 1) induce responses of lactate concentration in specific activities of the modality similar to those to observe during competitions, as combat simulations with effort:pause ratio similar to those observed during real competitions; 2) adopt supra-maximal intensities, assuming a linear relationship between workload and physiological demand; 3) adopt a series of exercise in which athletes perform the greatest possible effort in a fixed period of time, with intervals for recovery that consider the resynthesis of some energetic substrates or removal of metabolites from anaerobic pathways; 4) adopt the execution of intermittent exercise with intensity, effort, and pause duration similar that occur during a competition [52].

The training stimulus needs to simulate the physiological demand of modality, in this case, the glycolytic demand, that occurs in real conditions of competitions. In this sense, the judo' coaches can perform a short series of *uchi-komi* at the higher intensity possible with short recovery intervals. For example, the protocol utilized by Franchini et al. [62] which utilized different temporal structure (18 x 10s/10s of recovery, 9 x 20s/20s of recovery and 6 x 30s/30s of recovery), but with the same effort: pause ratio. In other words, the number of bouts can vary, but the time of effort of each bout should be the same as the time of recovery. Furthermore, the total time of activity can be based on the duration of combat, 5 minutes for men, and 4 minutes for women.

The taekwondo combats show an effort: ratio around 1:7 to 1:9, with approximately 7-10 attacks per round. Thus, the coach can realize a specific training session of HIIT accordingly to the time-motion that occurs during real combat. For example, execution of specific techniques in the higher intensity possible with a short-term period (1-2s) intercepted with rest intervals (~7s) during 7-10 times. This dynamic can be executed in 3 blocks of 2 minutes, intercepted by a recovery period of 1 minute between each block to simulate the total time of taekwondo combat.

Karate combats show an effort: ratio of 1:10 demonstrating intermittent characteristics. Furthermore, the combat time represents 6% of the total time of combat and the high-intensity actions have a duration of 2s. Therefore, the karate training sessions can adopt this period of time as a reference, subjecting athletes to short high-intensity actions, intercalated with a period of low intensity 10 times repeated over the total time of combat.

HIIT circuit training can be an interesting strategy, in this case, athletes will go through stations, performing the exercise without rest periods. This type of training can be realized based on effort: pause ration and should be applied during the competitive period 3-5 weeks before the principal competition. In relation to circuit training, Del Vecchio et al. [13] described a proposal of training based on this method, for example, two segments of low-intensity standing effort for 9s. After this would be a 10s of passive rest interval followed by three segments of low-intensity groundwork with technical displacement for the 20s, followed by high-intensity groundwork combat ("ground and pound") for 15s, and a 10s passive rest or low-intensity groundwork technical displacements for 20s.

Based on the training circuit proposed by Del Vecchio et al. [13], Shick et al. [81] described an example of circuit HIIT intermittent training in which the training is based on specific actions and effort:pause of MMA. For example, the athletes can shadow box for 1 minute, kick the heavy bag for the 30s, do takedown drills with a partner for 1 minute, perform a shrimping drill for 30 seconds, and finish with guard passing drills for another. The fighter will then rest for 1 minute before starting the circuit again because of a rest period in between sets reflect the duration used in a real fight.

7. Final considerations

Several studies have been demonstrated that combat sports are high-intensity intermittent activities in which the glycolytic demand is high, as inferred by the lactate concentration presented in these studies. However, high lactate concentration did not represent a predominance of glycolytic contribution. On the other hand, other studies demonstrated that when the delta values are analyzed, the glycolytic contribution decreased during the combats or rounds. Furthermore, studies analyzed the energy system contribution of these modalities and demonstrated a predominance of oxidative metabolism, although the decisive actions are determined by anaerobic metabolism. Thus, there is a need to develop the anaerobic fitness of fighters. In this case, the execution of specific actions that consider the effort:pause ratio of each modality can be an efficient strategy to improve the anaerobic fitness of fighters.

Conflict of interest

None declare.

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