Patrik Drid
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Science and Medicine in Combat Sports

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SCIENCE AND MEDICINE IN COMBAT SPORTS

PATRIK DRID
EDITOR

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CONTENTS

PREFACE

The number of studies in combat sports has significantly increased in the last decade. Consequently, needs for an updated volume to address this academic trend have emerged. The book *Science and Medicine in Combat Sports* is presented through 10 chapters, dealing with variety of complex problems that occur in combat sports. Each chapter contains an overview of relevant bibliographic references, based on which the reader can check the presented information and, more importantly, extend their interest through additional relevant information.

In *Chapter 1* author presents a review of the time-motion analysis of grappling, striking and mixed combat sports, as well as the physiological responses to typical training sessions, training means, simulated and official combat. The information about these two aspects (i.e., time-motion and physiology) is applied to improve training prescription to improve fighters performance. Performance in different physical abitilies such as aerobic power and capacity, anaerobic power and capacity, maximal strength, muscle power and strength endurance is considered.

Chapter 2 reviews youth participation in combat sports that provides an opportunity for the long-term development of healthy individuals and successful competitors. The existing literature is highlighted with respect to the newly presented Composite Youth Development model through an examination of the processes of talent, physical, and psycho-social development. Early exposure to combat sports and the appropriate transition from sampling to specialization are highlighted, along with the potential advantages of participation in these activities during childhood and adolescence

In *Chapter 3* authors presents psychological preparation of athletes is integrated unit of training process, but it application and role are rarely transparent. Instead, it's implicitly contained in interaction between training participants: couch, acting as conductor of psychological intervention and sportsman, as its recipient. Transformations on psychological plan are harder to observe and measure than changes of physical fitness or skill level. Also, explicit plan of mental preparation is rarely subject of concrete training unit in contrast to elaborate program of fitness development and technical-tactical training.

The strong body of scientific evidence has established that the exercise-induced stress promotes the generation of reactive oxygen species (ROS), an important bio-molecules in cellular homeostasis. On one hand, when the ROS production exceeds cellular antioxidant defense, oxidative stress appears resulting in lipid and protein oxidation, DNA damage, apoptosis, impaired muscle performance, and/or overtraining syndrome. Additionally, ROS also have a relevant signaling function, necessary for many physiological responses and beneficial adaptations to exercise, including mitochondrial biogenesis, muscle adaptations, or enhanced antioxidant defense. In this regard, several studies have argued that a moderate-intensity exercise prevents oxidative stress by improving the antioxidant capacity; however, exhaustive and high-intensity exercise might trigger high oxidative stress accompanied by inflammatory responses that induce harmful effects on health and performance. In light of this, the present *Chapter 4* reviews the scientific literature regarding the bond between oxidative stress and exercise in martial arts.

In *Chapter 5* authors discuss Mixed martial arts (MMA). MMA is an extremely demanding sport from a neuromuscular, energetical end psychological point of view. Next to physical and mental demands MMA brings greater health risks than other combat sports. Very often this sport brings fighters in real life survival situations. All of the mentioned reasons motivate fighters to establish a high level of physical preparedness. In this chapter, preparation period for *Final four Pride Grand Prix* (Tokyo, Japan, 2006) tournament is presented. The subject of this program was the winner of this tournament.

In *Chapter 6* authors presents quantitative experimental procedures for determining the correlation and impact of certain factors on success in judo are exclusively carried out by either testing subjects - judoka (model A) or by surveying judo experts (model B).

In *Chapter 7* authors presents The Special Judo Fitness Test (SJFT). SJFT is a relatively simple and ecologically valid method of sport-specific evaluation that can be used by judo practitioners from varying demographic backgrounds and skill levels. Due to its demonstrated sensitivity, the SJFT has been used to examine the response to intervention, including utilization of ergogenic aids and manipulation of both acute pre-exercise procedures and long-term training programs.

In *Chapter 8* authors presents a review of injuries in judo. Injury risk in elite judo athletes is average when compared to the other Olympic sports. However, concerning time loss injuries, judo is ranked second among combat sports at the previous two Olympic Games. Injury prevalence in judo, through review of published data, indicates that it is necessary to establish a long-term injury surveillance system in order to minimize injury incidence and time loss injuries. Knowledge about injury risk, severity, localization, type, and mechanism of injuries during training and competition is the first step towards adequate injury prevention and specific educational and preventive measures.

The conclusion of numerous research studies that have been conducted is that the high level of motor and functional skills, with emphasis on speed and anaerobic capacities, is essential for success in taekwondo. Despite their great popularity, scientific databases rarely contain articles dealing with validated specific measuring instruments for detecting the level of anaerobic capacity in the domain of taekwondo; rather they utilize *non-specific* tests for this purpose, which review in *Chapter 9,* among other topics.

Competitive karate activity involves a number of factors that affect performance in this sport. The differences in competitive kata and kumite requirements inevitably lead to narrow specialization and influence the athletes to choose between the two disciplines. *Chapter 10* reviews the scientific literature regarding two groups of athletes, kata and kumite.

This book is suitable for further education of coaches and combat sports professionals on one side, but also for current and future scientists who study problems of combat sports from various aspects, on the other side. Based on presented information, coaches and researchers can use this information to perform evidence-based selection, training, and competition process in combat sports, as well as to better understand a variety of analyzes, and comparisons based on relevant information in combat sports, with the main aim of its popularization and quality improvement worldwide.

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Chapter 1

COMBAT SPORTS TIME-MOTION ANALYSIS AND PHYSIOLOGY AND ITS IMPLICATIONS FOR FIGTHERS' STRENGTH AND CONDITIONING

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ABSTRACT

This chapter presents a review of the time-motion analysis of grappling, striking and mixed combat sports, as well as the physiological responses to typical training sessions, training means, simulated and official combat. The information about these two aspects (i.e., time-motion and physiology) is applied to improve training prescription to improve fighters performance. Performance in different physical abitilies such as aerobic power and capacity, anaerobic power and capacity, maximal strength, muscle power and strength-endurance is considered. Additionally, judo and taekwondo are taken as examples of grappling and striking combat sports, respectively, to provide detailed information concerning need analysis and training recommendations. Thus, coaches

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and sports scientists can use these data in their specific working settings to promote combat sports evidence-based training.

Keywords: temporal structure, physiological responses, grapplers, strikers, judo, taekwondo

INTRODUCTION

Combat sports represent ~25% of the Olympic medals and certain modalities (e.g., boxing and mixed martial arts) are watched by millions of spectators [1, 2]. Thus, over the last decades a growing interested in these sports has been observed and resources to improve training programs have been established in different countries. As these sports have a high physical demand, research concerning physiological demand of different combat sports have been conducted to increase the knowledge about the physical and physiological characteristics of combat sport athletes [3-6], as well as the determination of combat sports training modalities [7, 8, 9] and the time structure of competitive matches [10-21].

Studies concerning the anthropometrical profile of combat sports athletes have focused mainly in the body fat percentage, as in most of these modalities athletes are classified according to their body mass and an accurate adjustement to a specific weight category is considered important by athletes and coaches, especially to avoid rapid weight loss practices that are commonly used in these sports [22, 23, 24]. Additionally, somatoype analyses were also investigated as specific body types are considered more adapted to some technical actions [25].

The physiological profiling of combat sports athletes is probably the main focus of research concerning these modalities. Recent reviews [3-6] have presented the aerobic, anaerobic, strength and muscle power characteristics of combat sports athletes. Although all high-level athletes present highly developed physical fitness, some differences have been highlighted when grapplers (e.g., wrestlers, judo and jiu-jitsu athletes) and strikers (e.g., boxing, karate and taekwondo athletes) are compared. In general, grapplers present a higher developed upper-body anaerobic capacity, strength, strength-endurance and muscle power, while strikers present more lower-body muscle power and relative aerobic power and capacity.

One important area of research to improve knowledge about combat sports is the on-time physiological measurement [26-30]. In striking combat sports some investigations conducted physiological measurement during match simulations [26, 27, 28], allowing the energy systems contribution to be estimated. Such approach is not possible during grappling combat sports due to the close contact between opponents [30]. Thus, for grappling combat sports pre- and post-match measurements are normally used to infer the physiological demand or controlled combat sports-specific actions are investigated [7, 29].

Time-motion studies have been conducted to better understand the effort-pause ratio structure of competitive matches and to determine critical actions and moments during the combat [10-12, 15-17, 18, 19, 21].

Furthermore, in the last decade some investigations have been conducted to verify the influence of acute or chronic adaptations to different training protocols [31-34]. These studies include the effects of postactivation potentiation protocols on combat sports-specific tests [33, 34], training modeling approaches [31] and the influence of different strength training periodization on combat sports performance [32].

Thus, the present chapter has as main goal to review the main studies about the physiological demand and time structure of combat sports. Additionally, studies reporting training strategies to increase acute performance are also reviewed. Moreover, recommendations and suggestions to conduct an evidence-based training session are also provided.

TIME-MOTION ANALYSIS

Striking Combat Sports

Striking combat sports are characterized by actions using kicks, punches, elbow and knee techniques directed to the opponents and include Olympic sports such as boxing and taekwondo, as well as amateur (e.g., karate, kickboxing and Muay-Thai) and professional combat sports (e.g., boxing and mixed martial arts). The level of contact allowed depends on the specific sport rules, varying from light contact in the abdominal and thorax in some karate styles to knee and elbow techniques to the head in Muay-Thai and mixed martial arts (MMA).

Typically, the effort-pause ratio in taekwondo matches is 1:1, while the high to low-intensity ratio normally varies from 1:3 to 1:7 [9, 14, 19, 20]. Results from the 2012 Karate World Championship indicated that the effort-to-pause ratio was approximately ~1:1.5, from 8.8 ± 2.3 s of activity and 11.3 ± 5.8 s of pause. Activity phases contained 32.8 ± 8.3 high-intensity actions per fight lasting 1-3 s each, which resulted in high-intensity-actions to pause ratio of 1:8. Additionally, the frequency of occurrence of the different combat phases (fighting activity, 14.8 ± 4.1%; preparatory activity, 50.7 ± 12.3%; breaking activity, 12.8 ± 1.6%) as well as their mean duration (fighting activity, 1.4 ± 0.3 s; preparatory activity, 7.3 ± 2.2 s; breaking activity, 11.3 ± 5.8 s) did not differ between gender, match outcome and grouped weight division [21].

A total of 45 combats from two male Kickboxing World Championships were monitored using a time-motion analysis system and the results indicated that the time structures were high-intensity activity: 2.2 ± 1.2 s; low-intensity activity: 2.3 ± 0.8 s; pauses: 5.4 ± 4.3 s; and 3.4 ± 1.2 s between two subsequent high-intensity activity actions. The fighting to nonfighting ratio was found to be 1:1. Thus, kickboxing differed considerably from taekwondo and karate concerning time-structure. These differences can be attributed to the specificity of the sport. The technical and tactical aspects and rules of kickboxing are different from the rules of other combat sports that can influence the combat's effort-pause ratio (e.g., knockout system vs. control system, duration of match) [18]. For Muay-Thai, Cappai et al. [35] reported that 60% of the time of a round was spent in fighting whereas 40% was spent in study/preparatory phases, while Silva et al. [36] observed an effort-pause ratio of 1:1.5 during the matches.

Boxing is the single striking combat sport where only punches are allowed. When analyzing amateur boxing, Davis et al. [37] found an overall effort-pause ratio (not including intervals between rounds) of 9:1. Subsequently, the same group of researchers [12] reported that boxing bouts require the ability to maintain an activity rate of ~1.4 actions/s, comprising ~20 punches/min, ~2.5 defensive movements/min, and ~47 vertical hip movements/min, over 3 successive rounds each lasting ~200 seconds.

Thus, when striking combat sports are considered globally, the typical effort-pause ratio is 1:1, but a wide variation is observed, from 9:1 for boxing to 1:7 for taekwondo.

Grappling Combat Sports

In grappling combat sports, the contact between opponents is constant, as the general goal in these modalities is to throw the opponent or control him/her during groundwork combat. The most popular grappling combat sports are judo, wrestling and jiu-jitsu.

Studies have consistently shown that mean duration of judo matches is ~3min, although the time-limit is 5-min for men and 4-min for women, regardless of the level of competition [15, 38]. In a typical match, athletes perform approximatelly 11 periods of activity [13, 39]. The average time duration of each sequence of activity and pause is normally 20s and 10s [15, 16], respectively, resulting in a 2:1 effort-pause ratio. Although the effort-pause ratio provides important information for training organization [7, 40, 41], it is important to have additional data on what athletes perform during effort periods. According to Marcon et al. [13] preparation period (i.e., the phase that preceeds grip disputes) lasts 4 ± 1s to 4 ± 2s, grip disput phase lasts 16 ± 5s to 18 ± 3s, attacks lasts from 1.0 ± 0.4s to 1.7 ± 0.5s, and groundwork combat lasts 9 ± 4s to 17 ± 12s. Very similar results were reported by others [15], with the preparation period lasting 5 ± 8s, the gripping dispute lasting 14 ± 15s and the groundwork combat lasting 15 ± 14s when standing sequences were continued in this condition. Marcon et al. [13] reported that the grip dispute time represented 49 ± 10% to 56 ± 9% of total effort time, while the data from Miarka et al. [15] allow to calculate that gripping disputes represented 58% of all standing combat time and 28% of the whole combat time (i.e., pauses included).

Study analyzing Greco-Roman Wrestling World Championship [42] indicated that typical combat phase lasted 30s and pause phases were close to 10s, generating a 3:1 effort-pause ratio.

Andreato et al. [43] reported an effort/pause ratio of 6:1, while high-intensity actions lasted approximately 4 s, resulting in a low to high intensity ratio of 8:1, during jiu-jitsu championship.

Thus, grappling combat sports typically present an effort-pause ratio higher than 2:1. In general, more actions on groundwork result in higher effort-pause ratio, as judo has short periods of groundwork combat, wrestling a little more and jiu-jitsu is basically disputed in groundkwork.

Mixed Martial Arts

The first study [44] to analyze mixed striking and grappling actions was found reported that when the interval between rounds was not considered, the effort-pause ratio (between high-intensity effort to low-intensity effort plus pauses) was 1:2 to 1:4. Not surprisingly, this ratio is between ratios typical for grappling and striking combat sports. More recent studies analyzing UFC competitions between 2012 and 2014 [45, 46] reported that the high-intensity to low-intensity effort ratio varied between 1:8 to 1:9 for standing up actions, 1:1 for groundwork actions and 1:2 to 1:3 when all actions were considered in the three rounds, demonstrating a more intense profile in this competition compared to that analyzed by Del Vecchio et al. [44]. Del Vecchio et al. [47] also compared male and female MMA matches and demonstrated that females spent more time at low-intensity during standing fight (6min56s ± 4min48s) compared to males (4min20s ± 3min20s), but females spent less time in groundwork high-intensity actions (1min46s ± 2min7s) compared to males (3min6s ± 2min40s), suggesting a higher intensity for males' matches.

COMBAT SPORTS PHYSIOLOGICAL DEMAND

Striking Combat Sports

The energy systems contributions are considered important information to training prescription in different sports. The information about the predominant energy system as well as the specification of the system contributing most during determinant actions (i.e., score-related) can be valuable to direct the training process to improve it [48]. In high-intensity intermittent sports, the determination of energy systems contributions is more complex than in continuous sports, especially when an opponent or a team are in constant contact with the athlete [49]. Initially, studies were conducted using more controlled conditions (e.g., cyclergometer tests) to estimate the energy systems contributions during high-intensity intermittent exercise [50, 51]. Only in the last decade studies dealing with combat sports matches were published [26].

Beneke et al. [26] estimated the energy systems contribution during simulated karate matches and reported a predominance of the oxidative system (77.8 ± 5.8%), followed by the ATP-PCr system (16.0 ± 4.6%) and the glycolytic system (6.2 ± 2.4%). Similar results were found by Doria et al. [52] with three male world-medal winners in karate kumite: oxidative contribution = 74 ± 1%; ATP-PCr contribution = 14 ± 3%; glycolytic contribution = 12 ± 3%. For Muay Thai, Crisafulli et al. [53] reported an elevated energy release from both the aerobic and anaerobic systems during a simulated match. In particular, an elevated anaerobic demand was observed at the beginning of the activity, followed by a growing oxidative contribution throughout combat, although the exact percentage of contributions were not reported. Only one study produced the same kind of estimate in taekwondo

[27]. The contributions of the different energy systems reported in this study showed that the oxidative system was also predominant in taekwondo combats (three 2-minute rounds with 1-minute intervals between the rounds), contributing with 66 ± 6% of the total energy cost of combat. In contrast, the ATP-PCr and glycolytic systems contributed 30 ± 6% and 4 ± 2% of the total energy expenditure, respectively. The recent study with semi-contact amateur boxing [28] also reported a higher contribution of the oxidative system (77 ± 8%) compared to the ATP-PCr participation (19 ± 2%), which was higher than the glycolytic contribution (4 ± 1%).

Thus, for striking combat sports, the main energy system contributing to the total energy expenditure is the oxidative system, followed by the ATP-PCr system, with lower glycolytic contribution. However, it is important to emphasize that, although the predominance is oxidative, the technical actions resulting in scores are probably maintained by the ATP-PCr system.

Grappling Combat Sports

Due to difficulties in conducting physiological measurements during a match [49, 54], studies interested in the physiological responses to grappling combat sports have used one of the following strategies: (a) to determine the physical fitness profile of high level athletes in these modalities, especially comparing them with less successful ones [55-61]; (b) to conduct time-motion analysis to infer the metabolic profile of judo matches [13, 15, 42]; (c) to conduct physiological measurements during specific grappling combat sports training activities [7, 23, 29, 40]; (d) to conduct physiological and performance measurements during competitive or simulated grappling combat sports matches [62-71].

As the main interest for creating appropriate training programs is to understand the competition physiological demand and given the limitations to conduct physiological measurements during grappling combat sports matches, in the present chapter the main focus is the physiological response to official matches. However, as there are no many studies concerning multiple official competitive matches, studies dealing with simulated competition are also presented.

Blood lactate measurement has been used as an indirect indicator of glycolitic solicitation [72]. Several studies have measured blood lactate in official grappling competitive settings [42, 43, 73, 74]. Recently, a classification concerning glycolytic contribution during high-intensity intermittent exercise was proposed [75]: low: < 3 $mmol.L^{-1}$; moderate: >6 $mmol.L^{-1}$; high: > 10 $mmol.L^{-1}$ and very high: > 14 $mmol.L^{-1}$. Following these reference values, wrestling would be classified as presenting very high glycolytic contribution [42, 65, 71], judo would be classified as high or very high [74] and jiu-jitsu would be classified as moderate or high [43, 73].

Investigations conducted in real competitions have no control of combat or interval durations. When judo is considered, most studies have found higher lactate values than those found after match simulations, suggesting that competitive matches are more reliant on glycolytic metabolism than match simulations [30]. A similar trend is observed in jiu-jitsu [43, 73], and wrestling [42, 65, 71], although a study analyzing the same athletes in simulated and official competition conditions is lacking.

For judo, no differences in blood lactate concentration were found between winners and defeated athletes in regional level competition [76], although studies [77, 78] reported that the highest level athletes presented lower blood lactate compared to lower level ones. This result suggests that more technical athletes rely less on the glycolitic system [30].

Mixed Martial Arts

Only two studies investigating blood lactate response to mixed martial arts were found [79]. Amtmann et al. [79] studied six MMA athletes and reported blood lactate values between 13.3 and 18.0 $mmol.L^{-1}$ during a sparring session and between 10.2 and 20.7 $mmol.L^{-1}$ during an official competition. Coswig et al. [80] reported a significant increase from post-warm up (4.0 ± 1.7 $mmol.L^{-1}$) to post-simulated match (15.6 ± 4.8 $mmol.L^{-1}$). Thus, according to the classification proposed by Buchheit and Laursen [75], MMA would be classified as presenting high or very high glycolytic contribution.

TRAINING RECOMMENDATIONS

As there are many specific characteristics that should be considered when organizing the training program of combat sports athletes, the present section will analyze only one striking combat sport (taekwondo) and one grappling combat sport (judo), considering the main variables to be developed. Mixed combat sport (mixed martial arts) will not be described as a combined (striking and grappling combat sports) intervention can be created based on the previous examples, taking into account the mixed martial arts athlete profile. The approach directed to these combat sports can also be adapted for other modalities. It is not the goal of this chapter to present possible periodization models, as the calendar varies according to competitive level, nation, age category, gender and combat sport. Additionally, only recently, studies comparing different periodization strategies have been published and only short-term (6-8 weeks) training periods were used [32] and few information is available concerning longer training periods [31, 81].

Grappling Combat Sports: Judo as Example

As reported in the time-motion analysis section, after a low-intensity approximation, judo athletes engage in the most time-demanding task, i.e., to establish the grip dominance over the opponent. The gripping dispute phase varies according to competitive level, with higher level athletes performing more complex combinations before applying a throwing technique [82]. This phase seems to solicitate a high strength-endurance and anaerobic capacity from the upper-body, especially the forearms [83]. This is confirmed by the fact that maximal isometric handgrip strength is only moderately high in elite judo athletes [6] and not different from non-elite judo athletes [57], although dynamic strength-endurance evaluated using the grip on the judogi is significantly higher in elite as compared to non-elite athletes [83]. Thus, strength-endurance exercises are very important to judo athletes and chin-up exercises gripping the judogi, different forearms curl exercises, gripping dispute in a rotation system (e.g., one athlete against three to four opponents, each opponent at every 20-30s, with 10s intervals) have been recommended [8, 84].

Once the grip is dominated, the judo athlete executes a throwing technique, which has been characterized by a short-duration (0.98s to 1.7s) high-intensity action, involving both lower- and upper-body [13, 85, 86]. Plyometric exercises directed to the lower-body are considered important for muscle power development, as high-level judo athletes present lower contact-time and higher ground reaction forces during throwing techniques execution [61, 87]. For upper-body, explosive pulling and pushing actions involving upper-body and trunk muscles should be included in the training program for these athletes [30]. This is possible through pulley machines or judo-specific ergometers [88], where athletes can perform exactly the same movement as used during real unbalance (*kuzushi*) phase, in terms of arm displacement, speed and muscle action patterns. Additionally, it is important to include exercises performed in small base of support, as many judo throwing techniques are applied having only one foot in contact to the ground [25]. Unilateral plyometric and unilateral squat exercises are examples to develop this aspect. Other judo throwing technique characteristic is the need for rotation [25]. Thus, judo athletes must learn how to apply high muscle power while in rotation, as well as to block rotational forces. For these, isometric core exercises and dynamic power exercises in both directions should be included in the training program. Unilateral clean exercises, rotational pulling and pushing actions using landmine exercises or cable are examples to be incorporated in the training session. The use of ropes to pull heavy objects has also been recommended to develop strength-endurance in grappling combat sports' athletes [84]. Another relevant strategy to improve judo athletes muscle power is to induce postactivation potentiation (PAP). Indeed, Miarka et al. [33] indicated that the use of contrast exercises (i.e., squat and plyometric exercises) was effective to improve ATP-PCr-related performance in judo-specific actions. Thus, specific PAP protocols should be developed, tested and incorporated for different judo actions. However, to improve anaerobic capacity, combat sessions (*randori*) should be more intense, shorter in duration, and interspersed by longer intervals [8].

When the combat develops on the ground, technical actions involve a mix of wholy-body dynamic and isometric contractions. Thus, when preparing judo athlete to the groundwork phase of the match, his/her specific position in this phase must be considered, but in general, core exercises should be considered and isometric strength-endurance for upper- and lower-body is also relevant [8].

Despite the wide variety of actions performed in each of the combat phases, to date no study has examined the physiological demands in each of these phases in judo. Thus, the time structure characteristics have important physiological implications. The pauses are shorter than the efforts and, therefore, they are likely not sufficiently long (10s) to allow the resynthesis of the phosphocreatine (PCr) degraded during the effort phases [89]. As a result, the contribution of the oxidative metabolism increases during the match [90, 91, 92]. It is probable that judo matches have important anaerobic contribution in the first and increased aerobic contribution in the final minutes of the match [30]. Thus, aerobic training should be implemented, especially for athletes who have not a well-developed aerobic fitness. For those with moderate to well-developed aerobic fitness, one to two sessions per week are considered enough to maintain this physical profile, while avoiding interference [8].

Importantly, judo-specific techniques can be arranged in a way that high values of oxygen consumption are achieved [7, 29, 30], allowing VO_{2max} development or maintenance. *Uchi-komi* (technique repetition) and *nage-komi* (technique repetition with throwing phase) exercises can be used for metabolic training, with continuous steady-state or technique repetition every 10–15 seconds being useful for aerobic fitness development, whereas all-out intermittent protocols are useful especially for anaerobic development, but may elicit aerobic improvements as well [8]. Techniques involving trunk rotation and accentuated knee flexion (e.g., *seoi-nage*) are more physically demanding than frontal attacks (e.g., *o-uchi-gari*) [7, 29, 30]. Longer *randori* sessions with lower intensity combat sessions and shorter rest intervals are more appropriate for improving aerobic fitness [8]. One of the main principles of training is specificity, but it is common to observe judo athletes performing nonspecific, high-intensity, intermittent exercises [81]. This is partly because there are few studies reporting the physiological responses to judo-specific training protocols [7, 40].

Thus, the knowledge of the physiological responses during *uchi-komi* performed intermittently and in an all-out approach can help coaches to improve the training protocols for judo athletes. In this way, Franchini et al. [7] demonstrated that the physiological responses ($\dot{V}O_2$, lactate, and heart rate) did not differ among the *seoi-nage*, *o-uchi-gari* and *harai-goshi* when different amplitudes of a 1:1 effort-pause ratio were used (18 x 10 s/10s, 9 x 20 s/20s, and 6 x 30 s/30 s), and the techniques were performed in an all-out condition. The shortest protocol used (18 x 10 s/10s) resulted in higher oxygen uptake values during the activity phases, suggesting that it can be used when aerobic power development is the main goal. These *uchi-komi* protocols resulted in similar oxygen uptake and heart rate responses than those observed during both match simulations and match competitions, but the blood lactate concentration was lower compared with specific activities, most likely because of the grip disputes (*kumi-kata*) that occur during matches and not during *uchi-komi*. Thus, the inclusion of grip dispute would help to increase the stress on the glycolytic pathway. Another important finding of this study [7] was that the heart rate did not differ among the techniques or time protocols, whereas the energy expenditure and the number of techniques performed differed among the conditions, suggesting that heart rate should not be used to monitor training intensity during the intermittent judo training protocols.

Striking Combat Sport: Taekwondo as Example

As reported in the physiological demand and time-motion analysis section, taekwondo matches alternate high-intensity short-duration powerful kicks and low-intensity stepping phases [19, 20, 27]. During the high-intensity short-duration action the metabolic pathway contributing to the total energy needed is probably the ATP-PCr metabolism [27]. Thus, ballistic dynamic taekwondo specific techniques should be practiced to improve this combat decisive factor. General exercises directed to muscle power development such as squat, Olympic weightlift type lifts using optimal loads have been recommended to modalities where speed is a key performance factor [93]. Plyometric exercises can also be implemented to develop reactive strength, which is quite important in a sport where change of direction and feints are used frequently as in taekwondo [9].

PPA has been reported to improve taekwondo-specific performance compared to a control condition, when complex method (i.e., 3 x 2 rep at 95% 1RM half-squat + 4 vertical jumps above a 40 cm barrier) was used 10 min before the frequency of speed test (number of kicks in 10s) [34]. Thus, using a combination of heavy loads and plyometric exercises can be a strategy to increase the frequency of kicks, a factor that can be important during the taekwondo match. Moreover, it is likely that athletes who are submitted to training sessions where this specific combination may result in performance improvement would present increased long-term training adaptation [34]. One important recommendation given by these authors is that coaches should individualize the rest interval used or follow the interval used in meta-analysis studies, because when the taekwondo athletes were asked to self-select optimum intervals they were unable to choose one resulting in improved performance.

As suggested by Santos et al. [19] coaches should emphasize high-intensity interval training with a similar time structure to that of an official match (1:7 high-intensity action to low-intensity action ratio). More specifically, the authors recommended the utilization of high-intensity, short-duration (1–2 s) specific taekwondo techniques interspersed with skipping movements (approximately 7 s), performed mostly in the range from 7 to 10 repetitions. According to them, this approach should be adequate to prepare the athlete to handle the metabolic and physiologic demands of the match. They also suggested that it is important that the coach considers the range and frequency of occurrence for the actions performed during the match to create more specific circuit training protocols.

Conversely, the improvement of the glycolytic system has not been recommended, as the participation of this system during the taekwondo match has been demonstrated to be low [27]. Although some taekwondo-specific training modalities focus on glycolitic activation, these exercises should be seen with caution [9]. Confirming this assumption, it is important to emphasize that Matsushigue et al. [14] reported that that most successful taekwondo athletes used a lower number of techniques during the match, although they were able to obtain higher number of points, indicating that a higher technique volume may be not the best strategy to win the match. As the physiological response of winner taekwondo athletes was similar to that presented by non-winners, the authors hypothesized that each technique was performed at a higher intensity. Thus, increasing speed and power is probably a better approach than increasing athletes' endurance (i.e., improving his/her ability to perform kicks for 20-30s is not a key element to improve match performance).

The interval between high-intensity actions is normally 6 to 7 times longer than the period spent during these actions. During this period stepping is the main activity performed [14, 19, 20]. Thus, a moderate to high cardiovascular demand is placed upon the taekwondo athlete [9], and this can be noted when the oxidative contribution is estimated [27]. Consequently, although the determinant scoring actions are supported by the ATP-PCr metabolism, the oxidative system is the predominant during the taekwondo match and specific training sessions should be conducted to allow the athlete to cope with this cardiovascular and oxidative demand [9]. In general, the high-intensity intermittent exercise used to mimic the match seems to result in similar physiological responses – although the competition-related stress would result in different hormonal responses [94] – and can be used to improve the aerobic fitness of taekwondo athletes. Non-specific aerobic conditioning activities such as running, cycling and swimming have not been recommended for high-level taekwondo athletes, as the specificity principle is not followed when these conditioning activities are used and the training adaptation resulted from such approach may not be transferable to taekwondo-specific settings [9].

CONCLUSION

Effort-pause ratio and the analysis of the muscle groups involved in the different actions performed during the combat can be an excellent reference to organize the physical conditioning training program of athletes from these modalities. Studies indicated longer effort-pause periods for grappling combat sports (3:1 to 2:1), intermediary for mixed combat sports (1:2 to 1:4) and shorter for striking combat sports (1:1 to 1:7). These specific time structures result in different physiological demand, with a higher glycolytic contribution to grappling combat sports compared to striking combat sports. Although the oxidative metabolism is the main contributor to total energy expenditure, the scoring actions are normally supported by the ATP-PCr pathway. Thus, speed and muscle power are paramounts to successful combat sports performance. Need analysis and the physiological characteristics of each combat sport, considering the specific technical-tactical profile of a given athlete, are key components to improve training prescription in these modalities.

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Chapter 2

YOUTH DEVELOPMENT IN COMBAT SPORTS

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ABSTRACT

Youth participation in combat sports provide an opportunity for the long-term development of healthy individuals and successful competitors. The existing literature is highlighted with respect to the newly presented Composite Youth Development model through an examination of the processes of talent, physical, and psycho-social development. Early exposure to combat sports and the appropriate transition from sampling to specialization are highlighted, along with the potential advantages of participation in these activities during childhood and adolescence. Relevant physical and psycho-social changes throughout the process of maturation are addressed and comparisons between combats sports and with other forms of physical acitivity are covered. Previously reported issues related to injury prevention and weight management during youth development in combat sports are also examined.

Keywords: martial arts, childhood, adolescence, participation, weight categories

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INTRODUCTION

In order to encourage participation and increase the potential for future success, a variety of development models have been proposed for combat sports. With regard to martial arts, grading/belt (kyu/dan) systems provide an intrinsic approach to development, as well as specific goals and/or guiding tenets with regard to physical, social, and moral education. For example, many national judo organizations have junior rank requirements based off a standardized curriculum that includes proficiency in the areas of movement patterns and age-appropriate technique, knowledge of terminology and competition structure, and personal development [1].

The Long-Term Athlete Development model proposed by Balyi and Hamilton [2] provided the impetus for many countries around the world to further enhance their strategic framework with regard to youth athletes. This model recommends an early focus on physical literacy with an eventual shift toward performance enhancement via sport-specific skills. Judo Canada and USA Wrestling have produced comprehensive materials for various stages within the Long-Term Athlete Development model and made these resources publically available [3, 4]. However, the Long-Term Athlete Development model has been criticized for being overly simplistic and lacking scientific support both in general and with regard to combat sports [5, 6].

In response to concerns regarding the limitations of the Long-Term Athlete Development approach, the Youth Physical Development model was proposed with a greater emphasis on consistent training of a variety of physical abilities, including muscular strength, across maturity levels for those athletes interested in elite competition as well as those interested in recreational participation [7]. Furthermore, talent development models, featuring a wide range of topics, including sampling versus specialization [8] and giftedness versus talent [9] in youth athletes, have also been suggested. Subsequently, Lloyd et al. [10] devised the Composite Youth Development model in an attempt to utilize the strengths, while addressing the flaws, of existing models through consideration for talent, psychosocial, and physical development in children (defined as girls ≤11 years old and boys ≤13 years old) and adolescents (defined as girls 12-18 years old and boys 14-18 years old).In this model, the processes of maturation and development are quantified using chronological age as well as maturational status as indicated by somatic maturity using peak height velocity. For the purpose of this chapter, the existing combat sports literature will be described within the framework of the Composite Youth Development model.

TALENT DEVELOPMENT

The Composite Youth Development model employs the Developmental Model of Sports Participation framework of Côté et al. [8] featuring the sampling of a variety of sports during childhood followed by a transition to either a specialized or recreational focus during adolescence. Due to the highly technical nature of combat sports, early exposure to movement patterns, potentially prior to the myelination and synaptic pruning associated with adolescence [11], may be important for the acquisition of sport-specific motor skills which are likely requisite with elite performance. In other words, children may need to participate in combat sports at a relatively young age in order to progressively improve and acquire the technical ability needed to advance to the elite level. In support, Franchini and Takito [12] reported that Brazilian Olympic judo athletes began practice and competition at the ages of 8 and 10 years old, respectively. However, the competitive level achieved during childhood may not be an indicator of future success [13]. Julio et al. [14] noted that only a small proportion (5-7%) of state-level judo athletes maintained competitive success over a 10-year period (beginning from 9-10 years old) with the smallest fractions found in the youngest athletes. Thus, general involvement from an early age and continued participation within the combat sport may be sufficient. Furthermore, intensive training in child combat sports athletes may not be necessary as limited physical and sport-specific adaptations may occur compared to adolescent athletes [15]. In the sport of wrestling, collegiate and international athletes who began the sport at approximately 13 years old have been reported to devote similar periods of time to training until after the age of 18 years old [16]. While program resources have been identified as the primary reason for the inability of youth wrestlers to progress to the senior level, issues related to management, specifically relationships with coaches/trainers, development, and training, as well as injury and weight loss were also found to be relevant contributors [17].

An emphasis on talent identification or selection, rather than talent development, during childhood or at the onset of adolescent may lead to early specialization in a given sport [18]. The process of talent identification/selection is usually conducted by coaches due to the perceived complexities of combat sports and these procedures are generally not clearly defined or divulged to others. Those procedures that have been examined experimentally, range from relatively simple, such as a modified sumo contest [19], to more complex approaches, such as the ten-station judo-specific ability test [20]. However, the talent identification procedures documented in the extant combat sports literature have yet to demonstrate consistent utility [18, 20] and some authors have suggested that selection based on physical skill tests should be avoided until the later phases (i.e., adolescence) of the development process [21]. Subsequently, the longitudinal assessment of a wide range of physical, technical, and mental skills, and the evaluation of progression throughout the maturation process within a given sport has been recommended [18]. For example, British Judo has published the English Talent Development assessments that aim to determine the "capacity to train" in youth athletes defined as the "the physical ability to meet the training demands (volume and intensity) required for Performance Judo" [22]. The assessments include components dedicated to physical testing in relation to pre-established benchmark values and a judo-specific rubric used to evaluate actual judo performance. Furthermore, with the designation of British Judo "Trademarks," including "Throw for Ippon," "Win in Newaza," "Dominate Kumikata," "Contest Management," and "Fight without Fear," the United Kingdom has publically stated its focus on improving the technical foundation of cadet level athletes rather than an overemphasis on winning medals during the athlete development process [23].

The practice of early specialization is appealing due to the potential for a greater period of "deliberate practice" defined as engagement in "a practice activity (typically designed by their teachers), with full concentration on improving some aspect of their performance" [24] and achievement of a superior training age (~10 years or ~10,000 hours) [25].Hodges, Starkes [16] noted that the interpretation of "deliberate practice" differs depending upon the activity of interest. Specifically, in wrestling, the authors noted that training partners play an important role and that training activities (and durations) were similar for the first six years of the careers of elite and non-elite wrestlers [16]. Furthermore, the biological maturation process yields differential training adaptations and altered skill sets that may be difficult to identify in child athletes. Additional concerns with regard to early specialization include impaired physical literacy, overuse injuries, and selection of more physically mature rather than more talented children, as well as decreased overall participation and dropout amongst those selected [26-28]. The repercussions of these issues not only affect the participant pool that could develop into elite level talent, but may also result in fewer participants who could develop into coaches, referees, or technical staff.

A consequence of an emphasis on competitive success during childhood and early specialization, may be an unequal representation of relatively older athletes born early in a given selection period (commonly centered on a

January 1st cutoff date for competition [29-31]. This phenomenon, termed the relative age effect, also potentially results in an under-representation, through lack of participation or increased dropout rates, of relatively younger athletes [32] and has been evaluated in several combat sports, primarily to ascertain the impact of weight categorization during competitive events. Wattie, Schorer, Baker [33] proposed a constraints-based developmental systems model for examining relative age effects in sport. This approach allows for a thorough description of the nature of combat sports with regard to development and participation by examining individual, task, and environmental constraints.

Individual constraints, specifically sex and physical maturity/body size, vary amongst athletes with lesser influence in the lightest competitors, and with male combat sports athletes being affected to a greater degree than their female counterparts [31, 34, 35], potentially due to an earlier transition from childhood to adolescence. As combat sports generally feature individual competition/practice in an open skill setting, task constraints (physicality, participation level, and laterality) likely play a major role in the development of relative age effects. Grappling combat sports (judo and wrestling) have generally reported weight class-dependent relative age effects [31, 34, 35], whereas research in striking sports has been less clear with no relative age effects found in an international sample of taekwondo athletes [36] and mixed results in boxing, with country-specific data (France) conflicting with international data (medalists at the Olympics/world championships) [37, 38]. Citing these differences and potential issues with rapid weight loss prior to competition, Dubnov-Raz, Mashiach-Arazi, Nouriel, Raz, Constantini [39]suggested the use of height categories in an attempt to standardize body size (e.g., reach advantage) in striking combat sports and account for maturational difference in youth athletes.

With respect to participation level and relative age effects (Figure 1), cadet (U17y) judo competitors may be more greatly affected than junior (U20/U21y) judo competitors [31], whereas this phenomena may not be present in Olympic judo and taekwondo athletes [35, 36].However, male freestyle and Greco-Roman wrestlers at the Olympic Games have been shown to exhibit relative age effects, but the effects appear to be negated when examining only the medalists [35]. Laterality advantages (e.g., being left-handed when most competitors are right-handed) have been shown to minimize relative age effects in open skill sports, such as tennis [40], but, despite being a somewhat controversial topic [41, 42], has yet to be fully examined in combat sports.

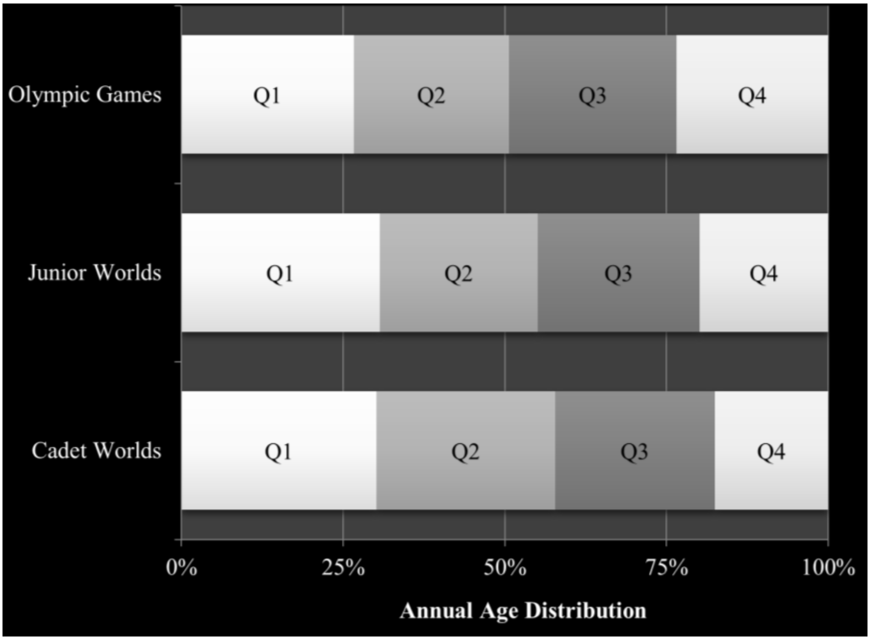


Figure 1. Example of relative age effects in combat sports with an overrepresentation of athletes in the first quarter of the year (Q1: birthdates in January, February, and March) compared to the fourth quarter of the year (Q4: birthdates in October, November, and December) in male and female judo athletes who competed at the Cadet and Junior World Championships, but a relatively balanced distribution of male and female athletes who competed at the Olympic Games. Q2: birthdates in April, May, and June; Q3: birthdates in July, August, and September. Adapted from Fukuda [31] and Albuquerque, Tavares, Lage, de Paula, da Costa, Malloy-Diniz [34].

Environmental constraints, such as grouping policies, popularity of the sport, and family and coaching/teaching influences, have been suggested to moderate relative age effects. Within combat sports, age and weight categories, as well as competition divided by skill/belt levels, are suggested to minimize the influence of varying maturity levels and encourage greater participation; however, the results of relative age effects investigations have yet to fully support this hypothesis [31]. A variety of teaching/coaching methods are employed both between and within combat sports which vary from a traditional martial arts oriented approach to a primary focus on sport/competition or the effective application of technique [43]. These varied approaches likely play a role in the development of young combat sports participants through specific goal orientations (ego versus task oriented). Furthermore, participants from different socioeconomic levels may gravitate toward specific combat sports due to familial or societal influences [44]. Finally, the popularity of a combat sport within a given country or competitive setting likely plays a role in this phenomenon [30]. When considering individual, task, and environmental constraints and the likely existence of relative age effects in combat sports in both the youth and adult settings, sporting organizations and those with a vested interest in athlete participation should consider a decreased emphasis on early specialization and competitive success during childhood.

PHYSICAL DEVELOPMENT

With regard to the Composite Youth Development model [10], the early childhood years should be devoted to learning fundamental movement skills in a fun environment, while middle childhood features greater competency of these skills through general fitness and muscular strength. During adolescence, a shift from sampling to specialization may be supported by more structured sport-specific training or the encouragement of recreational participation and continued development within the sporting environment [10].

Combat sports involve complex movement patterns that require motor control and coordination of the body which may enrich neuroplasticity. Research findings have shown that gray matter volume is more dense in elite level judokas compared to age-matched healthy controls [45] which is likely related to enhanced cognitive function [46]. The repetitive nature of martial arts training may provide an enhanced means for improved executive function (i.e., reasoning, problem solving, and inhibition) over traditional exercise in children [47]. Furthermore, Jacini, Cannonieri, Fernandes, Bonilha, Cendes, Li [45] suggested that the motor response, cerebral blood flow, or increasing levels of brain-derived neutrophic factor following long term training of judo specific movements may stimulate higher gray matter tissue. While observed in adult athletes, these findings provide evidence of the long-term benefits of youth participation in combat sports.

Combat sports participation during middle childhood has been shown to improve specific physical qualities to a greater degree than engagement in general recreation and team sports. For example, nine months of judo training (3 days per week and 45 minutes per session) in seven year old boys and girls has been shown to result in significantly greater improvements in body composition, muscular endurance, shuttle run time, and flexibility compared to participation in recreational sports [48, 49]. After a year of judo training, children (7-12 yr) have shown to exhibit improved balance, handgrip strength, lower body power, sprinting ability, and coordination [50]. In comparison, Violan, Small, Zetariuk, Micheli [51] examined 14 American boys (10.2 ± 2.0 yr) studying karate (Uechi-Ryu), as beginners, twice per week for 60-70 min and 10 team sport members (10.9 ± 1.4 yr) training up to three days per week with 60-90 min per session over the course of 6 months. Compared to baseline testing, both groups improved quadriceps and hamstrings flexibility and handgrip strength, while only the karate group, despite fewer of hours of training per week, improved balance with eyes closed and isokinetic leg extension strength [51]. As mentioned previously, early exposure to sport-specific movement patterns may have long lasting effects. In support, Polish judoka who began training before the age of 11 years old demonstrated more effective throwing techniques and medaled more frequently than those who began training after the age of 11 years old [52]. Interestingly, following an intensive four-week training period prior to competition, child judokas (9.9 ± 1.6 yr) improved sit and reach flexibility, but demonstrated no changes in body composition, grip strength, jump height/power, or sport-specific performance [15].

High-impact physical activity during adolescence likely results in long-term benefits with regard to skeletal health [53], including decreased risk of fracture and osteoporosis. Nasri, Zrour, Rebai, Neffeti, Najjar, Bergaoui, Mejdoub, Tabka [54] found that 50 Tunisian combat sport athletes (17.1 ± 0.2 yr with 5.4 ± 1.2 yr of experience) had greater bone mineral density (BMD) than 30 sedentary height and age matched individuals. Specifically, it was shown that the judoka and kyokushinkai karateka had greater BMD than karateka, boxers, and practitioners of kung fu [54]. In conjunction, combat athletes had greater lean body mass (LBM) than their sedentary counterparts (55.8 ± 6.1 vs. 49.5 ± 7 kg) [54].Strong correlations between activity index (calculated from the time spent training) and BMD (whole body: r = 0.85; leg: r = 0.71; arm: r = 0.63) were found with activity index explaining 72% of the variance within a whole body BMD regression model suggesting that long term sports practice may contribute to greater BMD [54]. Similarly, Kim, Shin, Noh, Jung, Lee, Kang [55] found that adolescent judoka (17.2± 1.2 yr) had significantly greater BMD in the forearm (+18.3%), lumbar spine (+22.7%), and femur (+24.5%) than age-matched controls. Furthermore, sedentary adolescents showed a significant imbalance in the BMD of the radius between dominant and non-dominant hands, whereas the judoka showed no bilateral differences [55].

Bala, Drid [56] showed significant differences in strength and whole body coordination between young judo athletes and untrained controls (boys and girls; 11-13 yr and 14-16 yr). These researchers found that functional coordination, muscular endurance, and triceps skinfold thickness were the variables that best distinguished between the trained and untrained youth [56]. Adolescent judoka have also demonstrated greater aerobic capacities than soccer players, gymnasts, and untrained controls [57, 58] which may have developed from long term adaptations in cardiac morphology due to participation in combat sports [59]. In support, near maximal heart rate values and lactate levels similar to intermittent cycling or running were noted in judo specific circuit training sessions for boys and girls 15-18 years old [60], while taekwondo-specific interval training has been shown to elicit comparable heart rate response and RPE to sprint interval training [61]. Short-term periods of combat sports training may influence anaerobic capability in adolescents. For example, Melhim [62] observed a 28% increase in anaerobic power and a 61.5% increase in anaerobic capacity over 8 weeks of taekwondo specific training in male novice TKD athletes (13.8 ± 2.2 yr), while Fukuda, Stout, Kendall, Smith, Wray, Hetrick [15] demonstrated a 27% increase in countermovement jump power following a 4-week of tournament preparatory period in male and female adolescent judoka (15.3 ± 2.0 y).

Combat sports may provide additive physical benefits to school-based physical education classes. Kim, Stebbins, Chai, Song [63] randomly assigned Korean female adolescents (15-16 yr) to a group that completed a 12-week introductory taekwondo program (2 days per week for 50 min each day) along with school-sanctioned physical education classes (2 days per week for 50 min each day) or a control group that only participated in the physical education classes. The taekwondo group demonstrated significant improvements in knee flexion peak torque at slow (60˚/s) and fast speeds (180˚/s), explosive performance in the standing long jump, flexibility in the sit and reach test, and percent body fat compared to the control group. However, taekwondo training had no effect on muscular endurance, grip strength, aerobic capacity, or speed and agility performance [63]. Likewise, a two-year twice-weekly judo training intervention added to standard school physical education classes showed positive results for adolescents between 12 and 15 years old [64]. Following the intervention, the judo training group (n = 174) had significantly greater circumferences and less subcutaneous fat in the upper extremities than the control group (n = 254) that completed just the physical education classes [64]. With regard to performance, the judo group showed greater muscular endurance in the one-minute sit-up test, improved coordination, and quicker times in the 20 m dash, but no differences were found in the bent arm hang, flexibility, or standing broad jump [64].

The human body relies on integration of the visual, vestibular, and somatosensory systems to maintain equilibrium while adjusting to physical tasks or environmental cues [65], and participation in combat sports may aid the progression of sensory development. Fong, Fu, Ng [66] compared the postural control and balance development of healthy adults (18-23 yr) to adolescents (11-14 yr) with (1-9 years of taekwondo experience) and without martial arts training. The adolescent taekwondo practitioners displayed lower sway velocity values in a single leg stance compared to adolescent controls, but faster values than adult controls [66]. No significant differences were found among the adolescent groups in visual or somatosensory function; however, adolescent controls showed significantly lower vestibular function than adolescent taekwondo practitioners during a sensory organization test [66]. The coordination and kinematic structure utilized during taekwondo training may result in enhanced vestibular function [67], while improvements in visual function for balance may be more closely tied to the maturation process [66].

The benefits of establishing fundamental movement skills during childhood likely translate into enhanced sport-specific skills during adolescence. For example, Special Judo Fitness Test index values, an indicator of judo-specific fitness, reportedly differ with incremental improvements between children, adolescents, and adults [15, 68, 69]. Furthermore, Lech, Jaworski, Lyakh, Krawczyk [70] found that the average number of attacks in the first two minutes of a match completed by junior judoka (17 ± 0.71 yr) positively correlated with kinesthetic awareness (Spearman $\rho = 0.82$) while the last two minutes of a match positively correlated with the number of mistakes during a spatial orientation test (Spearman $\rho = 0.75$). In addition, the authors found activity level (the total number of attacks divided by the number of fights fought) to be positively correlated to maximum (Spearman $\rho = 0.64$) and mean reaction time (Spearman $\rho = 0.65$) in the beginning of a match, while the difference in activity level between the first and second halves positively correlated with the frequency of hand movements (Spearman $\rho = 0.82$) in the second half of a match [70].

As a consequence of competition stratified by weight categories, athletes often engage in rapid weight loss strategies, which may decrease aerobic and anaerobic performance as well as self-esteem and vigor [71]. Roemmich, Sinning [72] examined the dietary habits of nine American male adolescent wrestlers (15.4 ± 0.3 yr) during pre-season, late season, and postseasoncompared to recreationally active controls (15.0 ± 0.4 yr) matched for physical characteristics and maturation level. Despite a significantly greater level of physical activity during the season, the wrestlers' energy intake was half of the recommended daily allowance and they failed to meet dietary guidelines throughout the week [72]. The resulting energy deficits caused a linear reduction in weight (-4.8% of body mass) in an effort to prepare for competition [72]. This systematic weight loss did not appear to slow maturation as both the control group and the wrestlers incrementally progressed in height (i.e., bone growth) over the course of the season; however, limited protein intake and subsequent lean tissue loss likely resulted in significant strength and power reductions in the wrestling group from pre-season to late season that quickly reversed post-season when they gained a significant amount of weight [72].

PSYCHO-SOCIAL DEVELOPMENT

In conjunction with the multitude of physical benefits, advantages with regard to mental health may be conferred by combat sports participation. For example, martial arts may reduce depression and levels of aggression, improve self-esteem, and provide therapy for children with attention-deficit/ hyperactivity disorder or be implemented as a means to improve behavior in delinquent children [73]. In a perspective piece, Law [74] discussed how the practice of taekwondo may provide children with the five basic needs (e.g., belonging, power, fun, freedom, and survival) while providing a fundamental bond amongst its practitioners through teamwork, community, and philosophy. Furthermore, the variety of techniques, the expression of one's self, the practice and competence of self-defense techniques, receiving positive feedback, and the instructional roles may empower and fulfill children's needs [74]. Within the Composite Youth Development model, the early childhood years should be devoted to the learning of new skills with an emphasis on fun and social interaction, while middle childhood presents the opportunity to enhance self-esteem and empowerment, as well as responsibility, in the learning process [10]. During adolescence, further growth in the aforementioned areas is established, while young athletes should begin to develop sport-specific psychological skills or motivation to continue on as recreational practitioners [10].

Engagement in martial arts has shown to aid in psych-social development during early childhood. With as little as two days per week of judo training for

5-24 months, parents rated their children (4-6 yr) more socially adept with greater sensitivity, kind-heartedness, courage, and self-discipline [75]. Furthermore, parents rated their children as having a positive attitude towards physical activity and in turn, performing exercise at home during their leisure time [75]. Discipline is a primary feature of combat sports, particularly within martial arts, which may provide enhanced self-regulation for beginners. Lakes, Hoyt [76] examined the impact of a school-based traditional martial arts program (Moo Gong Ryu; taekwondo) on physical, cognitive, and affective regulation in 193 boys and girls (5-12 yr) who participated in approximately five months of traditional martial arts instruction or standard 45 min physical education classes. In comparison to those participating in the standard physical education classes, the children in the martial arts group demonstrated greater improvements in the constructs of self-regulation (physical, cognitive, and affective subscales), classroom conduct, pro-social behavior, and self-esteem [76]. Additionally, boys in the martial arts group had a tendency to benefit, more so than girls, in response to the dimensions of cognitive self-regulation and showed greater improvements in classroom conduct [76].

A distinction may be made between traditional and modern martial arts training with traditional classes featuring an integration of psychological and philosophical training emphasizing specific character traits (respect, humility, honesty, responsibility, confidence, and perseverance), which some authors have claimed are deficient in modern classes [76, 77]. Boys trained under modern classes have shown a greater tendency towards aggression along with a decreased self-esteem and social ability when compared with traditional classes [77]. In support, Law [74] further clarified this potential distinction in taekwondo describing a modern approach as placing an emphasis on full-contact sparring and self-defense, and a traditional approach as emphasizing self-control, conflict avoidance, and non-contact sparring. While additional research is needed to identify differences between these approaches, their influence should be considered with regard to positive youth development [76, 78]. Alternatively, Reynes, Lorant [79] surveyed 43 children (8-10 yr) who were active competitors in either karate (n = 9) or judo (n = 14) and an age-matched control group (n=20) to examine if aggression was different between martial arts. Over the course of several competitive seasons, the authors reported that judoka scored significantly higher on anger and verbal aggression scales than the karateka and control groups; however, total aggression was not observed to be different among the groups showing that the effects of competitive martial arts did not seem to strengthen self-control in children

[79]. Thus, specific combat sports may be more appropriate for children exhibiting unique behavioral characteristics.

Morand, Meller, Theodore, Camenzuli, Scardapane [80] examined the efficacy of a 10 week martial arts training intervention compared to an unstructured exercise program (i.e., ultimate Frisbee, basketball, jumping rope) and a control group. Eighteen American boys (8-11 yr) with attention-deficit/hyperactivity disorder were evenly split into one of three groups (martial arts, exercise group, or control group) and rated by their teachers in multiple adaptive and maladaptive behaviors [80]. The martial arts intervention appeared to be the most effective at increasing homework completion rate, academic achievement, and classroom preparedness while decreasing the amount of rules they broke in class and the amount of times a participant left their seat inappropriately [80]. Therefore, martial arts training generally improved all facets of classroom behavior in children with attention-deficit/hyperactivity disorder and may provide a viable treatment option. Another study by Lakes, Bryars, Sirisinahal, Salim, Arastoo, Emmerson, Kang, Shim, Wong, Kang [81] assessed boys and girls (11-13 yr) in measures of executive function (i.e., working memory, cognitive flexibility, attention, behavioral control). Ninety-eight low-income students from southern California were randomized into either a school-based taekwondo class or an enhanced physical education class for one academic year [81]. Results showed that the taekwondo group performed computerized executive function tasks with significantly greater accuracy than the enhanced physical education students [81]. In addition to higher executive function, parents rated students in the taekwondo group with significantly greater improvement in behavioral control than students in the physical education group, and many students had positive reflections, particularly related to fitness, self-control, attention, and enjoyment with regard to their taekwondo experience [81].

It has been shown that children who exhibit violent and aggressive behavior may participate in combat sports to help alleviate unsettled hostility toward others and the outside world (cathartic effect) [82, 83]. Although not definitive, participation in traditional martial arts programs may be beneficial for adolescents prone to violent behavior given there is a qualified teacher and a strong philosophical component [84, 85]. In contrast, Endresen, Olweus [78] observed an association (r=0.09 to 0.14) between martial arts behavior and both violence and anti-social behavior in Norwegian male youth (n = 477; 11-13 yr). The researchers sought out to examine whether or not youth were seeking out these sports because they already displayed violent and/or antisocial behaviors, but this was not confirmed [78]. Vertonghen, Theeboom, Pieter [44] examined the influences and predisposition of adolescents participating in different martial arts as well as hard (e.g., kickboxing/Thai boxing) versus soft (e.g., aikido) style martial arts. Three different self-report questionnaires were administered to 477 adolescents (*M* = 14 yr) and it was reported that Thai boxers displayed more physical aggression and misconduct than judoka, karateka, and aikido practitioners [44]. Additionally, aikido practitioners were significantly more task-oriented (i.e., reaching their goals and performing to their potential) than judoka and Thai boxers, but displayed similarities with karateka [44]. When taking into consideration all styles, advanced athletes had fewer emotional problems than novices, but only the karateka demonstrated a reduction of behavioral problems with greater experience level [44]. The authors implied that practitioners with aggressive behavior may be more predisposed to hard styles rather than the act of participating in these styles invoking aggressive behavior [44]. Nonetheless, determining this cause and effect relationship and selection bias remains critical for future discussion [86].

Engagement in combat sports has also been shown to improve life satisfaction, quality of life, and benefits from training may be transferable to other areas of life in youth practitioners [87, 88]. Matsumoto, Konno [87] surveyed 90 judoka (11-18 yr; average duration of training: 3.8 yr), who reported higher overall satisfaction of life scores compared to normative data from non-judo participants. While the researchers were unable to conclude whether or not the judo participants were happy to begin with or happy due to judo participation, significant positive relationships were found between judo training and well-being, life satisfaction, and self-perceived math and sports competency [87]. When physically- and emotionally-prepared adolescent athletes are placed in the appropriate environment with qualified coaches/trainers, psychological development likely occurs during combat sports training and the concepts learned may be transferable to both sport-specific and general life skills. Qualitative research in high school wrestlers (14-17 years) has shown the ability of these athletes to apply the skills developed (enhanced confidence, work ethic, personal empowerment, enhanced thought processes, and interpersonal skills) during an intense short-term (14-day) wrestling camp to challenges faced immediately after the training and nine months following the training [88]. The authors reported that due to the rigorous technical training and structure of the camp, the youth wrestlers were able to remain calm when facing adversity in competition, were more persistent in the face of severe injury, and more disciplined in their school work and studies [88].

INJURIES IN YOUTH COMBAT SPORTS ATHLETES

Physical adaptations from participation in combat sports may provide a decreased risk of injury. For instance, Fong, Ng [89] mention several studies where taekwondo athletes exhibited hamstring to quadriceps ratios that exceeded clinically accepted thresholds (~60%) associated with protective effects with regard to lower body injury. Youth karate and taekwondo practitioners primarily endure lower leg, foot, and ankle injuries [90], whereas youth judoka commonly experience shoulder and upper arm injuries [90, 91]. Noh, Park, Kim, Lee, Yang, Lee, Shin, Kim, Lee, Kwak [91] reported that wrestlers showed the highest incidence of herniated discs within grappling sports and taekwondo practitioners suffered the most fractures within striking sports. Using injury data reported in 100 U.S. emergency rooms between 1990 and 2003, Yard, Knox, Smith, Comstock [90] showed that karate accounted for the largest number of pediatric martial arts related injuries (79.5%). However, only 1.2% of injuries reported by youth martial artists (taekwondo, karate, and judo) were admitted to the hospital and of those admitted, 50.8% were due to fractures resulting from falling (34.4%) [90]. Meanwhile, the majority (~75%) of injuries in combat sports appear to occur during practice, particularly during overly aggressive training sessions, and approximately 85% of athletes are re-injured, due to "stubbornness" and hastened return to training (~49%) [90]. This implies that while athletes participating in certain combat sports may be more prone to specific injuries, many can be avoided through appropriate monitoring of training sessions and well-planned rehabilitation.

When comparing five different martial arts over a period greater than one year, Zetaruk, Violan, Zurakowski, Micheli [92] reported the highest injury rates in taekwondo (59%), followed by aikido (51%), Shotokan karate (38%), and tai chi (14%). Participation in Shotokan had a significantly lower risk for injury than taekwondo, which may be due to the full contact nature of taekwondo compared to the non-contact nature of the Shotokan style involved with this study [92]. The combination of age and experience appeared as a risk factor for injury as older athletes (> 18 yr) were four times more likely to endure injury than younger athletes (< 18 yr), while athletes with at least three years of experience were twice as likely to sustain injury compared to less experienced athletes [92]. For the younger athletes (< 18 yr), it was found that each additional hour of training, beyond their average of 3.3 hours/week, increased their risk of injury by 50%, while an additional two hours of training doubled this risk [92]. Interestingly, the odds of injury in brown belt karateka are more than six times those of lower ranked karateka [93], while limited age effects with respect to injury have been reported [94].

Altered rule sets in youth karate have been successfully implemented to reduce the risk of injury [95]. Specifically, protective equipment, light contact, adequate training, rest, proper diet, and strict judging with tough penalties for uncontrolled strikes have been advised [95]. Organizers in the combat sport of wrestling have been proactive with the recommendation of an initial screening assessment aimed at reducing injury rates [96]. After examination of the mechanisms of injuries in wrestling, Açak [96] outlined a comprehensive battery of tests, including those focused on flexibility (shoulder, hips, and back), muscular strength (pull ups, leg lifts, and push-ups), muscular power (vertical jump and broad jump), and speed (25 m sprint), with its own scoring system in order to evaluate physical readiness. In an effort to promote injury prevention, the Wrestling+ warm-up program was developed which consists of 14 exercises separated into three parts:1) running, grips, and bridges, 2) core, leg strength, and balance (with progression through three levels of difficulty), and 3) wrestling simulation [97].

Despite the physical nature of combat sports, the overall injury rate does not appear to be higher than in popular team sports [93, 98, 99]. A systematic review by Spinks, McClure [100] examining 13 different sports and activities in youth from the age of 5 to 15 years, including martial arts, showed ice hockey and soccer to have the highest rates of injury per season. In another comprehensive review of contact sports (American football, rugby, soccer, boxing, ice hockey, judo, karate, and taekwondo) spanning 15 years of data, boxing was found to have the highest frequency of concussions in males of all ages engaged in individual sports (boxing, karate, and taekwondo) at the recreational and competitive levels [101]. In comparison, taekwondo athletes showed the highest incidence of concussion in female athletes regardless of age [101]. Another five-year study found those engaged in judo and karate to have the highest injury rate per 1000 person years of exposure when compared to those engaged in soccer, ice hockey, volleyball, and basketball with most of the injuries occurring in adults (20-24 years) as opposed to adolescents (<15 years and 15-19 years) [102]. In addition, most of the karate and judo injuries (70%) occurred during training, whereas most of the injuries in team sports (46-59%) occurred during competition [102].

WEIGHT CATEGORY CONSIDERATIONS

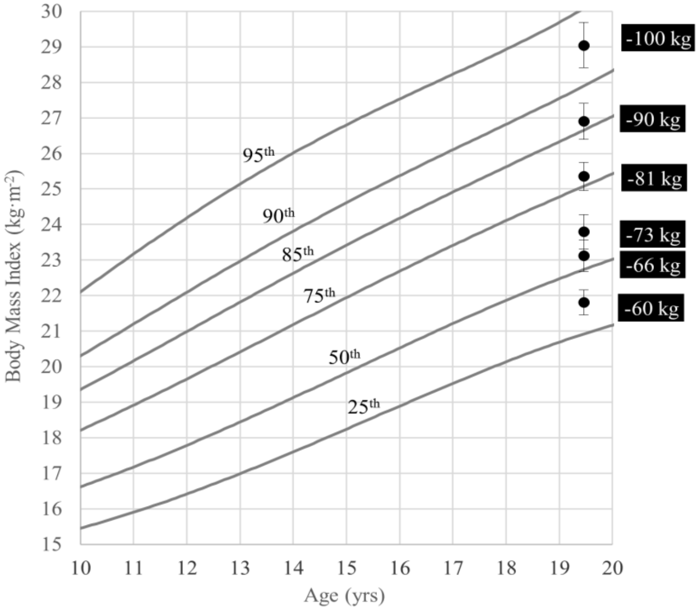
The process of youth development in sport should include a dietary component that works to establish appropriate nutritional habits from a young age and adjustments throughout the process of maturation as well as any shifts in training foci[103]. As previously noted, combat sports athletes are commonly separated by weight categories in an effort to allow for equitable competition and to limit the potential for injury. In an effort to gain potential competitive and/or mental advantages [104-106], athletes in combat sports often engage in gradual or rapid weight loss via energy or fluid restriction and dehydration through reportedly dangerous practices such as laxatives, diuretics, plastic/rubber suits, and saunas [71]. The reported negative health effects of rapid weight loss include declines in lean body mass, reduced glycogen stores, impaired thermoregulation, immunosuppression, and altered mood states[71, 107-109]. The impact of rapid weight loss on performance, particularly with adequate recovery duration, is unclear [107]; however, the impact of the weight cutting/cycling process on the quality or volume training has been relatively unexplored. Following the death of several collegiate wrestlers, wrestling organizations in the United States established minimum wrestling weight criteria in an effort to encourage appropriate weight management[110, 111]. Subsequently, similar approaches have been advised, but have yet to be fully implemented, in other combat sports [112]. Citing these concerns and others, Artioli, Saunders, Iglesias, Franchini [107] recently suggested that rapid weight loss should be banned prior to competition.

The practice of weight loss in combat sports has been reported to start at a relatively young age with average values between 12 and 14 years old [113-115], but individual instances of children less than 10 years old have been cited [116]. Extreme weight management behavior in wrestlers has been shown to be related to the age at which weight cutting began [115], while cadet judo athletes have been shown to be at a greater risk of suffering from anxiety and disordered eating as a result of weight loss as compared to senior judo athletes [117]. More than 60% (and up to 90%) of combat sports athletes reportedly engage in rapid weight loss of 2-10% during the week prior to competition [71, 107] and 66% of a sample of 108 youth judo athletes reported that this practice was highly influenced by coaches [114].

Malnutrition during sensitive periods of growth and altered thermoregulation due to dehydration are two major issues of concern with regard to the use of weight loss practices in youth combat sports athletes. Weight loss in youth combat sports athletes is achieved by increased physical activity, skipped meals, and fasting which likely result in a caloric deficit [114].During the adolescent growth spurt, the intake of an additional 500 kcal per day has been recommended and protein requirements are likely higher for youth athletes compared to non-athletes to support the growth of lean body mass and other training related physiological processes [118, 119]. The high-intensity intermittent activities associated with combat sports rely heavily on the glyocolytic system and adequate carbohydrate consumption may be needed prior to and following training or competition in order to maintain glycogen stores [120-122]. Taken together, malnutrition related to weight management may result in caloric imbalance and inadequate intake of both macro- and micronutrients which could compromise growth, development, and performance.

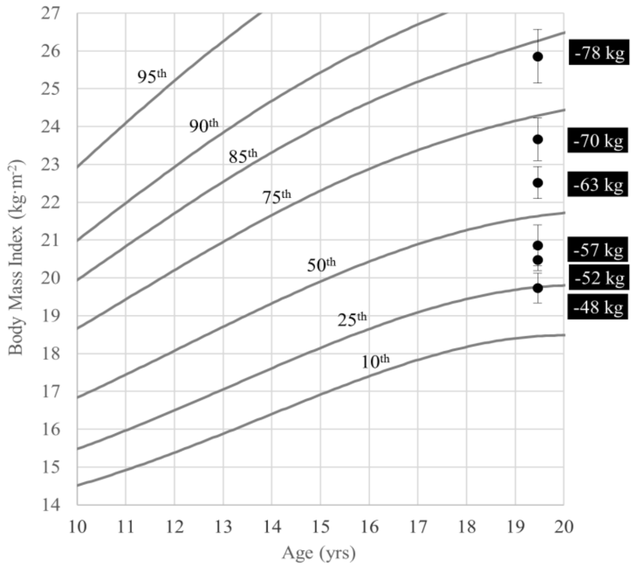
Dehydration during rapid weight loss in youth combat sports athletes poses a significant health risk due to altered thermoregulation primarily attributed to a greater surface area-to-body mass ratio and reduced sweating capacity in children compared to adults [123]. After arriving to a typical training in a dehydrated state (without intervention), late pubertal judo athletes have shown to decrease body mass to a greater extent than mid pubertal athletes (1.9% vs. 1.3%, respectively) following a 90-min practice in a high heat stress environment with normal drinking behavior [124]. While both groups recovered body mass following a 24-h recovery period, the majority of the athletes remained dehydrated [124]. Increased surface area-to-body mass ratio yields an increase in heat gain in a high stress environment and limited sweating capacity minimizes cooling offered by evaporation in children [123]. These factors coupled with dehydration due to training and/or rapid weight loss may result in significant elevations in core body temperature compared with adults.

Youth combat sports athletes, or their parents or coaches, are commonly burdened with the responsibility of selecting a weight category for competition. With the aforementioned issues, particularly the desire for competitive success in the near term, this decision is difficult and the positive/negative ramifications may not be fully understood until later in the development process of an athlete. In an effort to assist in this process, Figures 2-5 provide body mass index growth chart percentile curves (between the ages of 10 and 20 years old) from the Centers for Disease Control and Prevention (CDC) [125], as well as the average (black circles) and 95% confidence intervals (error bars) for body mass index of combat sports athletes from the 2012 Olympic Games for select weight categories [126]. As a point of clarification, body mass index (calculated from the upper limit of the weight category and publically available stature data) in these figures should be interpreted as a metric of frame size or body build/proportions [127], rather than as an indicator of obesity. This information may be used to provide guidance with regard to the youth athlete's potential senior-level weight category particularly in situations where an intimidating weight differential may be imposed due to wide spanning categories. For example, a 14 yr old male judo athlete with a body mass index of ~21 kg·m^{-2}that weighs 68 kg might be encouraged to compete at -73 kg, rather than 66 kg, due to the projection of an eventual body mass index similar to an elite -81kg athlete. Knowledge of future weight categories could also be used to guide training practices with regard to category-specific technical-tactical specifications [128]. Interpretation of these figures is meant provide guidance, but strict interpretation is limited due to the presumption that Olympic athletes undertook rapid weight loss procedures prior to competition and that the growth chart data is from the CDC in the United States. Nonetheless, these figures are intended to shift the focus in youth athletes from weight management and short-term competitive success to technical development and long-term participation in combat sports.



a

Figure 2. (Continued)



b

Figure 2. Body mass index growth chart percentile curves and estimated body mass index values (mean with 95% CI) of a) male and b) female judo competitors at the 2012 Olympics for select weight categories.

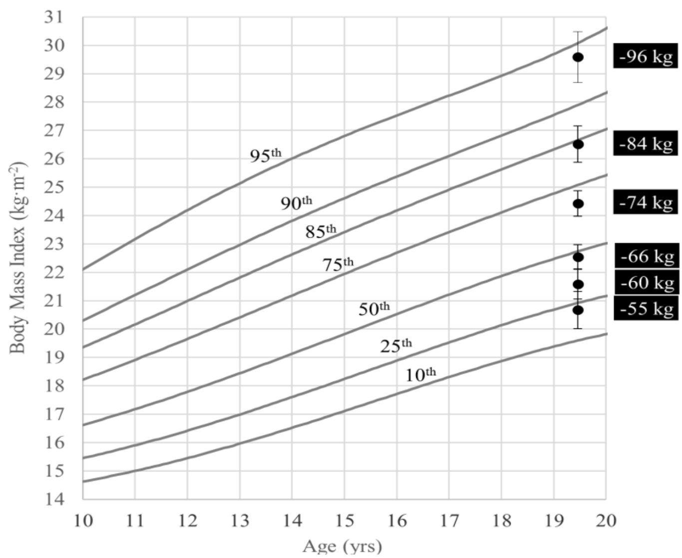


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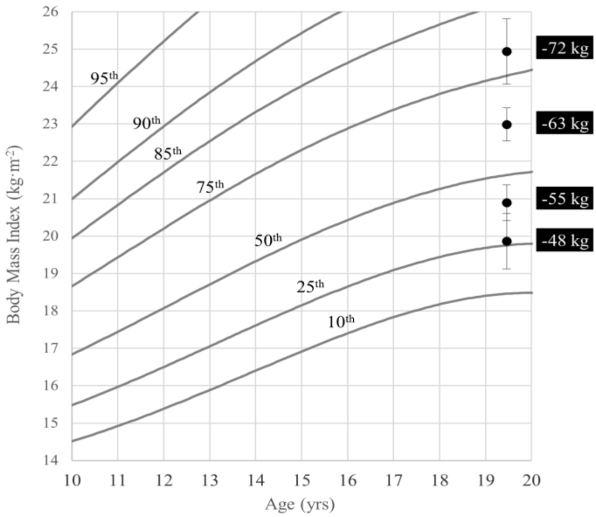
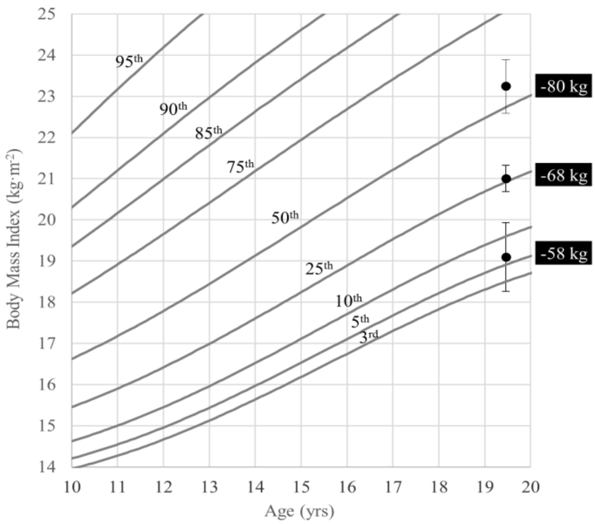
Figure 3. (Continued)



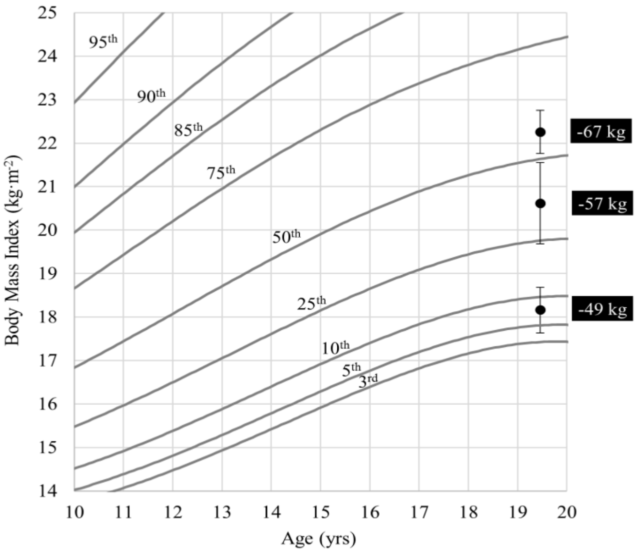
b

Figure 3. Body mass index growth chart percentile curves and estimated body mass index values (mean with 95% CI) of a) male and b) female freestyle wrestling competitors at the 2012 Olympics for select weight categories.



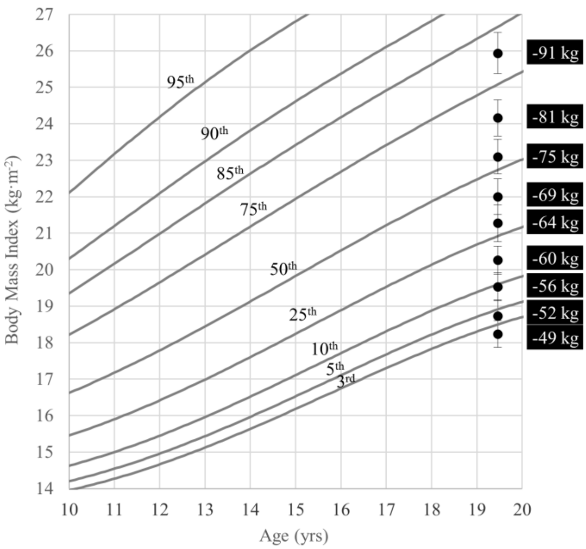
a

Figure 4. (Continued)



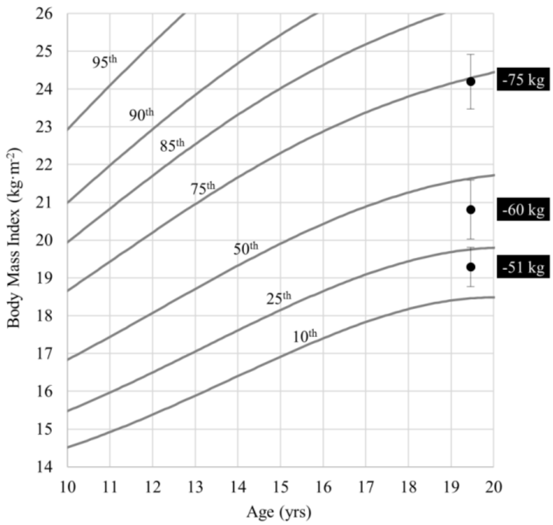
b

Figure 4. Body mass index growth chart percentile curves and estimated body mass index values (mean with 95% CI) of a) male and b) female boxing competitors at the 2012 Olympics for select weight categories.



a

Figure 5. (Continued)



b

Figure 5. Body mass index growth chart percentile curves and estimated body mass index values (mean with 95% CI) of a) male and b) female taekwondo competitors at the 2012 Olympics for select weight categories.

CONCLUSION

The process of youth development in combat sports provides an opportunity for sporting organizations, coaches, support personnel, and family members to have a positive long-term impact of the lives of children and adolescents. Specific considerations must be given to achieve these goals in the areas of talent, physical, and psycho-social development as outlined in the Composite Youth Development model. Varying individual, task, and environmental constraints exist amongst the various combat sports that may influence participation, while injury prevention and weight management tend to be areas of concern for youth athletes and recreational participants engaged in these activities.

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Chapter 3

PSYCHOLOGICAL PREPARATION IN COMBAT SPORTS: AN UPDATE

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ABSTRACT

Psychological preparation is a relevant element of success in combative sports. In this chapter we will discuss the main concerns in combative sports regarding sport psychology practice. Our focus will be on topics such as regulation of anxiety, attention, motivation, pre-competition routine management, overtraining and psychological rehabilitation after injury. A brief introduction of the theoretical basis of each topic is followed by a presentation of some psychological techniques in resolving problems of interest.

Keywords: mental training, martial arts, psychological skills

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INTRODUCTION

Psychological preparation of athletes represents an integral unit of a training process, however its application and role is rarely transparent. Instead, it is implicitly contained in the interaction between training participants: coach, acting as a conductor of psychological intervention and a sportsman, as its recipient. Transformations on psychological plans are harder to observe and measure than changes of physical fitness or skill level. Also, an explicit plan of mental preparation is rarely the subject of a concrete training unit as opposed to the elaborate programs of fitness development and technical-tactical training.

Mental preparation comprises psychological skills and strategies that athletes use in order to optimize their resources and comply with external demands, with an aim to achieve better performance. Further on, it is suggested that the purpose of mental preparation is to provide that particular personality structure which allows athletes in the training process to adapt to the sports environment in such a way that will maximize their mental potentials and eliminate, or minimize their psychological deficiencies.

Before introducing psychological intervention it is necessary to conduct diagnostics on psychological characteristics and psychomotor abilities in sportsmen. It was discovered that combative athletes have a low level of neuroticism, or in other words, a high level of emotional stability, high extraversion, significantly developed eye-hand-leg coordination, vigil attention (attention that characterizes a fast change of focus) and faster reaction times [1-4].

Every individual manifests prevailing forms of reactions in regards to a particular stimulus whose generator is a personality structure. When an athlete is evaluated, one should be aware that personality traits are weak and an inconsistent predictor of sports success. More information is obtainable from the dynamic aspects of the personality, such as goals, motives and values, than from stable personality features. The way that athletes perceive and react has a greater impact on their psychological state and cognitions than on their personality characteristics. For this reason it is necessary to differentiate between a personality trait and a psychological state which is provoked by some external stimulus, such as competition in sports. Let us take aggressiveness as an example. Aggressiveness as a trait is a consistent pattern of physical and verbal aggressive behaviors, hostility or anger [5]. An aggressive state is induced by competition and disappears or gradually declines when the triggered situation is stopped. Persons who possess aggressive traits exhibit dominant and frequent aggressive reactions across various situations. Aggressiveness as a state indicates how various people commonly react to specific situations. So, in the first case, emphasis is placed on the person and in the latter on the situation.

When combative athletes have aggressive traits there is an intention to harm the opponent, whereby harmful intention itself is the goal of an aggressive behavior. On the other hand, judokas who are attacking throughout the whole competition could be observed as aggressive, although they may not be at all aggressive outside the tatami. When we talk about the state of aggressiveness we should point out the distinction between instrumental aggressiveness and assertiveness. Instrumental aggressiveness also distinguishes the intention to harm the opponent, but as an instrument to attain a specific goal such as victory. For example, in judo, various behaviors could be classified as instrumental aggressiveness. When performing throws or a lever grasp, a judoka could harm his rival, but those behaviors are considered a means to accomplishing a point or a victory. On the other hand, assertive behavior implies vigorous, forceful and combative behavior on a game court without any intention of hurting a competitor. In this case judokas could be aggressive in guard or take initiative, cut the opponent when moving and use the opportunity to attack. This kind of judoka would be perceived as assertive.

Taking into consideration the circumstances stated, martial arts can be defined as a sport of interest, therefore we will briefly sketch the most common areas where it is possible to apply knowledge and skills of sports psychology in individualized sports[1], and those are:

1. Regulation of arousal level and pre-competition anxiety
2. Attention focusing
3. Enhancement and sustaining motivation for training and competition
4. Pre-competitive routine management
5. Overtraining and burnout syndrome
6. Psychological rehabilitation after injury
7. Solving problems outside the sports environment which affect performance[2].

[1]The list is not exhaustive.
[2]We'll not elaborate in this chapter.

Regulation of Arousal Level and Pre-competition Anxiety

This topic is perhaps of primary interest in sports psychology in regards to individual sports, because anxiety cannot be distributed between teammates, and it remains in the “possession” of an individual. Anxiety represents an overwhelming worry over the upcoming event. In order to understand anxiety as a phenomenon, it is important to differentiate between:

- Trait anxiety and state anxiety, and
- Models which represent uni and multidimensional natures of anxiety.

“Trait-State” Approach to Anxiety

Trait anxiety is a personality characteristic, which exhibits a stable disposition of a labile and excitable nervous system. This system influences the dominant response towards the upcoming event, which is characterized as a negative affect (worry, felling of insecurity and helplessness) and somatic symptoms of fearfulness and tension, which intensifies the overload demand of a real situation. On the other hand, state anxiety is a reaction to a specific trigger, such as competition. That is why in this case, the symptoms are of a reactive character, and they change depending on our perception of physiological body reactions during the match. To resume, one can say that state anxiety is a reaction that is common for most people in most situations that induce evaluation. On the other hand, trait anxiety is a common, pervasive reaction of a particular person when confronted with a future event, the outcome of which is uncertain. In first case, accent is placed on a situation and in the second on a person.

We also should distinguish between fear and anxiety since those are not synonyms. Fear is a justified and expected response to a real threatening situation and is directed towards the current danger. It can be explained as a subjective experience of massive and intensive changes happening within the body provoked by an autonomous nervous system, which encourages athletes to exhibit a “fight-flight” behavior – a desire to confront the danger or to escape from it. Unlike fear, anxiety is oriented toward the future, symptoms and situations that provoke it are less intensive, and do not represent a danger to life or integrity, but rather as a threat to our system of value. Regarding the aforementioned, we can consult Endler's opinion [6] concerning five factors that contribute to the level of anxiety, such as:

1. Ego threat
2. Danger from injury
3. Ambiguity
4. Disruption of routine
5. Negative social evaluation threat

These five factors can complement each other, therefore the greater number of factors working together, the greater the anxiety. The most common display of anxiety occurs in situations where we perceive that our internal standard (ego threat), and/or our external standard (negative social evaluation threat) are jeopardized. Ambiguity is a consequence of an unsuccessful communication between a competitor and others who participate in the contest, while disruption of a routine, as source of anxiety, appears within athletes who are rigid toward changes in pre-competition routine and those who are prone to over-controlling external conditions. Danger from injury can be a real source of anxiety in combative sports like judo, but when athletes are concentrating on an injury, they are anxious, not fearful.

Unidimensional and Multidimensional Models of Anxiety

Unidimensional models define anxiety as a phenomenon which emerges along the arousal continuum. Arousal is a concept that is often mixed with anxiety and refers to the generalized physiological and psychological activation of an organism which extends from deep sleep (comatose condition) to pronounced euphoria [7]. Arousal is a neutral phenomenon since it is not automatically related to either the pleasant or unpleasant situation: the same amount of arousal could emerge in the context of pleasant or unpleasant events.

The influence that arousal has on sports performance depends on the sports competence of the athlete and the complexity of the task. High arousal will have a decreasing effect on a beginner in the sense that they will make more mistakes, but will encourage the experienced competitor to perform better. If the task is in the learning phase or is complex by nature, it is best that the arousal level is held low, and in the case of a well-learned task or a simple one, a high level of arousal will provide good results.

The relationship between arousal and success in sports is elaborated through different models [7], but the most empirical evidence was gained by the "inverted U" hypothesis [8-10] which claims that the successfulness of the task increases as the arousal increases, until at one point in the continuum success begins to decrease as the arousal continues to increase. Anxiety could emerge below that point, but it's still functional and under control. After the "breakpoint", the effects of anxiety on the performance are detrimental. The point at which anxiety occurs, depends on the particular level of "alertness" of the nervous system, which is conditioned by its characteristics: labile/stable, excitable/inhibitory, perceived level of self-esteem, perceived importance of sports competition and uncertainty about outcome.

Few authors (e.g., [11]) agreed that the change in the relationship between arousal and performance could be prescribed to just one moment, or could it be placed in the middle of the continuum. Instead, we should refer to the zone, and to the optimal one, which gave the best results, which is not necessarily in the middle of the continuum, but can also be below and above the middle. The implication which arises from this notion is that various sportsmen require a different intensity of pre-competition warm-up. For example, one karateka would perform better if he/she conducts a mild warm-up, while others only after a vigorous warm-up. In the first case, the zone of optimal functioning is below the middle of the continuum, and in the latter it is above the middle. But this individualized approach does not solve the whole puzzle. If the competitor performs his best when under the condition of overheating his body, it will rarely happen if he "overheats" his mind. So, the next piece of the puzzle is to understand the conceptions that introduce a multidimensional nature of anxiety. In this sense we can differentiate between the two aspects of anxiety:

Somatic anxiety refers to physiological cues of anxiety, such as tachycardia, hyperventilation, enhanced sweating, dry mouth, excessive need for hydration, an increased need for urination, muscle hypertension, and subjective symptoms as "butterflies in the stomach" or "heart in one's mouth."

Cognitive anxiety concerns cognitions of athletes before and during the game which are exhibited as worry and discomfort. It usually indicates dysfunctional thoughts which could sabotage sports success.

Somatic anxiety on average, emerges the day before the competition, followed by an exponential increase as the competition gets closer. Then, just before the competition begins, the level of somatic anxiety rapidly declines and disappears. On the other hand, pre-competition cognitive anxiety stays relatively stable until the game starts, and further develops during the game depending on the perception of success/failure in the game [6].

Some conceptions which postulate a multifaceted structure of anxiety have introduced a new perspective in explaining the relationship between arousal and success, emphasizing relevancy of perception in case of anxiety direction. One of them, called the catastrophe model [12] suggests that the relationship between accomplishment and arousal follows the “inverted U” trend only in cases of low level cognitive anxiety. When its level is high, just a small increase in somatic anxiety will produce a drastic, catastrophic decrease instead of linear decrease according to the model “inverted U.” For example, unexpected injury or opponent scoring and rebounding by the end of the game, could disturb an athlete so much that he/she could start making beginners mistakes. Recovery from that kind of catastrophe takes longer, so “resetting” is recommended, first with physical relaxation, and then with restructuring negative thoughts and reactivating an optimal level of arousal. Kerr’s “reversal” theory suggests the importance of anxiety symptoms interpretation for a particular athlete: does he/she experience them as unpleasant anxiety or pleasant excitement? And besides that, how does he/she interpret its effect: are they facilitative or debilitative to performance? [13, 14].

Treatment of Competitive Anxiety

The level of arousal before the game should be optimal, i.e., the alertness level of the nervous system which will produce the best effects during the game. In order to successfully conduct psychological interventions, one should know the following:

- In which part of the state of arousal continuum is the athlete at the moment in which he attains best results, and
- To which aspects of anxiety should psychological intervention be applied

As for the first, any level below optimal suggests the athlete is in a state of apathy and insufficient motivation, while levels above optimal imply an over excitable nervous system and excessive worry about the outcome of the game. These states have different implications with regard to the application of psychological tools: In the first case, athletes should be “energized” (through positive self-talk or mantras), and in the latter, they should be calm (through relaxation and autogenous training).

Considering the second question, we should be aware that somatic and cognitive anxiety are treatable with different mental techniques. Somatic anxiety could be regulated through different techniques of relaxation, such as regulation of breathing, meditation, relaxing self-talk and bio-feedback. It is also useful, in the beginning of the treatment, to educate athletes in a simple manner, how somatic anxiety can affect performance in order to understand the appropriateness and inevitability of physiological changes in the body.

Cognitive anxiety can be reduced with various techniques from the cognitive-behavioral paradigm, such as cognitive restructuring, stress inoculation and stress management training [15]. The recognition of irrational beliefs and cognitive distortion is the essence of cognitive restructuring [16, 17] and resides in the background of thoughts and sabotages the game performance (e.g., “I must win” or “I won’t handle defeat” or “I will lose the game”). This is followed by the disputation of negative thoughts and beliefs and their replacement with rational and constructive statements.

Stress inoculation and stress management training are techniques by which athletes in vivo, or using their imagination, expose themselves to situations in which they progressively increase stress in order to prepare themselves for the upcoming event. Athletes begin with desensitization (or adaptation to concrete level of stress) from the least stressful situation passing through gradually towards a more stressful situation, to the most stressful ones, as, for example the finals at the Olympic Games, World championship, in order to learn how to handle the pressure.

In the context of treatment, we should also mention a matching hypothesis which implies that somatic anxiety should be treated with physical relaxation while cognitive is to be treated with mental relaxation. For example, Jacobson’s progressive relaxation (form of physical relaxation) yielded better results toward decreasing somatic anxiety than mind control (cognitive technique), but it was also helpful in reducing cognitive anxiety, although to a lesser extent. The opposite also stands. Due to the influence on both anxiety states, it’s often suggested to use multimodal approach, such as the abovementioned stress management training and stress inoculation. One technique within these approaches is the competition simulation (“competition roll play”) in which the intensity and form of competition is nearest to the real contest. Public sparing is one of those simulations.

Attention Focusing

A few consequences of high arousal and anxiety are distractibility and a problem with concentration. Elevated anxiety narrows the field of attention (e.g., “tunnel vision”), unlike low arousal which makes the attention field too broad [18]. An athlete from the martial arts who is over aroused can concentrate on performing his own movement while at same time neglecting the body position of his opponent which could change in a moment. The one who is below optimal level would let the fight on the other tatami divert his attention.

Signal detection theory (Easterbrook, 1946; according to Cox [6]) provides for an interesting guideline in the area of sports psychology. This theory implies that people, when judging others and other situations, have either mild criterion (they perceive signals even when they are not there, so called “commission mistakes”) or a strict one (they miss reacting to some important signals, so called “omission mistakes”). The theory predicted that in the case of a high arousal athlete, he/she will react to a wrong signal, e.g., an opponent’s feint, while in the case of low arousal, he/she will neglect to perform a contra attack once the opponent has completed his action.

Every sportsman has a dominant style of attention, which according to Nideffer [18] could be classified along two dimensions: width (“broad-narrow” field of attention) and direction (“internal-external” focus of attention). In order to achieve a notable result, every sportsman, depending on the task demands, should learn to change their focus of attention: in case of a nonverbal cue, which the opponent’s coach addresses to his competitor, his next move is important. The field should be extended, only later to be narrowed in order to perform a contra attack at the right moment. Also, paying attention to physical fatigue symptoms (internal focus) could suggest an athlete reduce the intensity of the fight and, at the same time, reverse the focus to the opponent (external focus), pulling away his thoughts on fatigue. Nevertheless, if an athlete focuses too much on internal sensations, he/she could elicit contradictory effects: in the worst case scenario, he/she could experience a panic attack and consequently a catastrophic efficiency decline.

Combative sports could be classified as a sport with a dynamically-competitive competition environment, with rapid changes in stimuli, where an appropriate and timely reaction is very important in order to develop anticipatory skills and skills of fast focus shifts. Efficient scanning of the visual field will depend on how fast and accurate an athlete combines information from central and peripheral vision. Research shows that elite sportsman use scanning strategies of the visual field more efficiently than sub-elites, although there is no difference in the receiving capacity between them [4, 19].

Other than a fast focus shift, or vigilance, it is also important to keep the attention during the longer time period. This aspect of attention is called tenacity, or concentration, and it is a basic feature of endurance/fatigue of the central nervous system. Successful combative athletes should have a broader focus and a more vigil attention then a shooter or gymnast, but narrower then collective sports athletes. The most advanced level of attention is the divided attention, which implies splitting cognitive resources or multitasking. In order to adopt this advanced type of attention, some movements should be automated through numerous repetitions so that cognitive capacities could be redirected toward new information and movements.

At the end of this topic, we should know that attention is trainable using various techniques. One of them is self-talk, although it could also be interfering. When an inner monologue is directed to a task or guided by a keyword (e.g., “zoom” or “concentrate”), it could be helpful to a positive outcome. A useful technique is also thought stopping [20], whereby sharply saying “STOP” tends to suppress the negative thoughts, followed by a deep exhale and counting backwards. This technique could be advanced by replacing negative thoughts with positive ones. We should also mention an interesting technique called “mental box” [21] for storing and “locking away” the disruptive cognitions, so the player could go into the game, “shrink the court” and redirect attention to relevant cues, respectively.

Enhancement and Sustaining Motivation for Training and Competition

Motivation is defined as the direction and intensity of one’s effort [7]. In sports context we often think about achievement motivation: the effort to master the assignment and skill, to perform better than others, to achieve a high level of competence and to overcome obstacles in order to achieve the goal. In sports, the achievement motive or competitiveness is the aspiration to perform better in regards to some standard or a rival, when there is appraisal by the others [22].

In sports psychology special attention is devoted to motives of participation in the sport. In this sense it is significant to understand two things:

1. Relationship between intrinsic and extrinsic motivation, and
2. Difference between orientation to outcome and orientation to process

Relationship between Intrinsic and Extrinsic Motivation

Intrinsic motivation is directed towards a self-rewarding activity. For that reason, an individual feels satisfaction and pride when the assignment is accomplished. Intrinsic motivation is focused on the process, so we can observe it when someone just enjoys performing the activity. However, it could be also oriented towards the outcome (desire to win) when the incentive to win comes from the persons themselves rather than others. When participation in sports is encouraged by others using the rewards, motivation becomes extrinsic.

At first, the relationship between intrinsic and extrinsic motivation was considered as additive, in the sense that the addition of extrinsic incentives reinforces intrinsic motivation. Instead, several researchers show that extrinsic incentives causes decreased motivation [23]. That notion has opened up a new chapter in motivation theory which suggested a multiplicative relationship which implies interaction between intrinsic and extrinsic rewards in such a manner that the latter ones could contribute to the enhancement or reduction of intrinsic motivation.

Intrinsic motivation increases with the feeling of self-esteem, self-efficacy and competence which could be gained through positive feedback on the advancement and skill mastery. To accomplish this, it is useful to apply the so called “sandwich approach” which is comprised of three parts: First, boasts by the athlete (e.g., “it’s much better than the last time”), then criticism or offering suggestions (e.g., “see if you can pull the opponent of balance next time”), and finally, to encourage them (“just keep like that and you’ll master it”). In the practical sense, coaches should comply with the conditions in which athletes could feel competent much easier: matching with teammates of similar weight and skill level, providing feedback appropriate to an individual, applying principles from lighter to heavier tasks but which are slightly above the current abilities so they can provoke and sustain interest.

Difference between Orientation to Outcome and Orientation to Process

Outcome (also goal or ego orientation) and process orientation (or task orientation) are parts of an achievement goal theory [24]. Athletes focused on the outcome estimate their competence in sports in relation to other competitors, so the estimate of one’s own ability is in relative terms. In contrast, athletes oriented to task compare their previous and actual performance upon which they conclude their own ability. Both estimates are related to the feeling of self-esteem. In order to better understand how the goal is chosen, it is necessary to know how the orientation develops. Children from two to six years of age are mostly oriented on the task, from six to seven years they begin comparing themselves with other children, while children from eleven to twelve years show both orientations depending on the situation. So, in the latter case it is important to be aware of the role which the environment plays in transmitting the sports participation attitude and which could be winning or mastery-oriented. It should be taken into account that these two dimensions are quite independent from each other which implies that athletes could obtain high values on both dimensions. As a matter of fact, athletes for which both orientations are salient, demonstrate the most prominent motivation and highly value their own competencies [6, 25]. However, coaches should primarily cherish task orientation since it influences more efficiently on sustaining the motivation.

When it comes to the significant fluctuation in motivation level and when it is necessary to resolve the adherence problem, it is convenient to use a strategy called “goal setting.” It is a behavioral technique with a directive role in the attainment of sports plans. Goals have two purposes: informational-corrective and motivational. In order to be efficient, they have to be:

1. Concrete and measurable – e.g., enhance percentage of successfully accomplished wazari by 20%.
2. Short-term and aligned with long-term goals – e.g., master mental techniques in small units of time, so it can be rehearsed until the main competition.
3. Moderately difficult: neither too difficult – in order to be feasible, nor too light – in order to be challenging. (e.g., practice new blocking technique, which is a little more difficult than the trained one).
4. Oriented toward the process rather than toward the outcome – e.g., devote time in training to improve elements of throwing techniques over hip, rather than focus on winning or achieving an ipon.

PRE-COMPETITIVE *ROUTINE* MANAGEMENT

As noted, one of the anxiety formations can be a pre-competitive disruption of a routine [6]. Because of that, it is useful that a sportsman has an activity plan before the competition. This, of course, does not mean that the plan should be unchangeable and that an athlete should be rigid toward possible changes to the plan. Anxiety can also be increased by delaying the competition schedule or by loosening a piece of equipment or a personal thing.

The anxiety phenomenon is associated with the competitor's perception of uncontrolled competition conditions and it is increased further if nothing is going "according to the plan." It is notable that a large number of athletes have rituals before and during the game, in order to gain control over the outcome. Superstitious beliefs, that they will lose if they do not repeat some compulsive actions go hand in hand with these rituals (e. g. repeatedly fixing your hair and clothes or crossing the lines only with the right foot); or that they will lose if things do not go according to plan (e.g., if they lose a piece of an equipment before the game).

Time management, logistics and organization of social and emotional support are important aspects of pre-competition stress regulation. Some competitors who are not dealing very well with the pressure, especially beginners whose anxiety is increased by inexperience, should enjoy the assistance of a coach or a sports psychologist in managing stress. Routine establishment helps a sportsman to use time properly before and during a match as well as the breaks between matches (or interruptions in the match), while helping athletes to maintain a competition focus [7]. Orlick and Partington [21] interviewed the Canadian Olympic team and came to the conclusion that effective pre-competitive plan activities have to be used in focusing concentration on performance, not on the outcome factors, that is, on factors that are more controllable.

Pre-competitive activity in combat sports includes a regulation of a body weight before weigh-in and regaining of weight before competition. Research shows that athletes from combative sports often exhibit eating disorders with symptoms that usually have subclinical intensity [26-28]. Not only that a sportsman needs to deal with a regulation of body weight to compete in a lower category, but the reason for weight loss can be also found in research which supports a negative correlation between the percentage of body fat and achievements in various sports [7]. This has led coaches to put pressure on athletes to lose body weight, often below optimum levels.

Rapid weight loss before the match leads to dehydration and a general body exhaustion which can increase chances of defeat. In the psychological sense, it could alter the mood, increasing fatigue, tension and confusion and decreasing vigour [29, 30]. That is the reason why it is important to plan the regulation of body weight and to start with adequate nutrition and rest [31, 32].

A sportsman often feels that the diet is psychologically difficult. The technique of cognitive-behavioral paradigm, named “keeping a diary” technique, could give favorable results. For example, if we plan the eating schedule, not to eat during the day, we have to take into consideration what a person eats, how they feel physically and what they think about during the day. Using the technique of stopping the negative thoughts will block the constant thinking about hunger, which has to be replaced by encouraging, self-talking and pleasurable activities that will distract a person from hunger. Nevertheless, weight management is not merely gaining the competitive edge over opponents, it is also a coping activity to reduce anxiety and focus on the goal [33].

OVERTRAINING AND BURNOUT SYNDROME

Burnout syndrome is the last phase of the overloading of the sportsman's body, which often leads to giving up on a sport's career. The stages that precede this process are overtraining and staleness. All three phenomena occur as an inadequate response to training stress.

Overtraining occurs when the intensity and extent of the training process increase in a short period of time (from several days to two weeks). Unlike the optimal schedule of training and rest, which improves performance results, overtraining will lead to attainment decline. Overtraining prevails more in cases of younger and inexperienced competitors [34].

Staleness occurs when an athlete cannot “catch up” with other competitors for a long time or when reaching the sports standards that are expected of him (in a period for more than two weeks). This is the reason for a significant fall in sports performances. Studies confirm that this syndrome shows signs of declining in cognitive efficiency as well [35]; so it is understandable that such individuals suffer from increased distraction followed by an increase in the number of technical and tactical elemental errors in the training.

Burnout is a massive psychophysiological body response which progresses to a failure in adapting the training requirements for a long time period. Burnout syndrome is followed by complete exhaustion, decrease of a vital dynamism (loss of energy, appetite, and sleep), anhedonia (loss of interest, not only for sports but for any other activity), isolation from coaches and teammates, extreme mood changes, low self-esteem, a sense of failure, increased perfectionism (elevated concern because of the errors) etc. [36]. Most of these symptoms are characteristic of depressive clinical cases, and it is not surprising that 80% of overtrained athletes are depressive [7]. The study of Silva [37] indicates that 47% of the surveyed athletes experienced burnout in a certain period of their career. Also, studies have shown that elite level athletes are more exposed to the risk of burning out than competitors at lower levels [7], but, once experienced, there is a higher probability of remission [38].

A coach has an important role in recognizing the burnout syndrome symptoms. It is important to allow a sportsman to take some rest; to redefine the motivation and aims; to reduce the training loads until they are ready to return to the game (coach's awareness that “more” is actually “less”) and to provide emotional and social support.

Since sportsmen (especially young professionals and athletes) build their identity on success in sports [39], they should learn to rate the success in terms of their performance, not in regards to the sports outcome, allowing them to enjoy more while they are training, breaking the monotony of training by adding elements of other sports to their specific sport and getting involved with regulating the post-game emotions [40]. The last topic includes coaches who provide support immediately after the game, talk about the match and use emotions by stating strengths and offering constructive criticism of a bad performance, including joint activities and actions after the game (e.g., go to dinner). A coach should not allow a sportsman to gloat too much over the success or to underestimate himself because of a failure, but to help him focus his attention on the next competition.

REHABILITATION AFTER INJURIES

Considering sports injuries brings us back to the topic of anxiety. The greater the anxiety feeling, the greater the tension will be. It impairs coordination of movements and causes loss of concentration, which can lead to a higher probability of injury occurrence (or renewal) [41].

Psychological factors appear to be mediators between the physical and technical-tactical factors on the one hand, and the level of injury on the other. The level of perceived stress is a significant mediator in the injury emergence. It is interesting, as well, that life stress has a significant effect on the occurrence of injuries. Major life changes, loss of a loved one, a change of environment, changes in financial situation, unfavorable family relations, and also exposing yourself daily to micro stressors, which can have a cumulative effect, can highly increase a person's risk of injury in training or matches. A particularly vulnerable group of athletes is the one with poor social support and with inadequate stress-solving strategies when they are going through a period of significant life changes [42].

An interesting part of a research shows that sportsmen are more concerned about the psychological factors of their injuries rather than the physical factors. An injury very often leads to the frustration of not playing, the fear of returning to the field after the injury, fear of renewed injury, the feeling of exclusion from the sport and from the other sports crew, lack of attention, as well as a lack of confidence [43].

The attitude of the coach can also contribute to the occurrence of the injury, for example, insisting that athletes perform to 110% of their capabilities and sending out an explicit and implicit message that they are worthless if they are injured [44]. These are the attitudes of coaches who think that victory is more important than the health of the athletes.

Although some sports psychologists believe that an athlete's sports injury experience is similar to the loss of a loved one where they go through the stages of grief [45], recent studies have shown that emotions which are characteristic of different phases of the grief process, may be carried out simultaneously. The stages are not fixed and they can return to a stage that has already passed. However, we recognize three general categories as responses to injuries [7]:

1. The processing of information relevant to injuries; information related to the emergence and extent of injuries, the awareness of the possible consequences of the existing injury, the possibility of recovery and therapy.
2. Emotional phase as a response to the injury - the experience of shock and disbelief, self-pity, anxiety and frustration.
3. Positive attitude and coping with an injury – the injury is put into realistic limits of recovery measures which would be undertaken by physical and psychological coping strategies to solve the injury both on the physical and mental level.

Although some athletes overcome stressor- induced injuries more easily, psychological recovery for some athletes might take a longer time. Indicators of prolonged recovery are: prolonged feeling of anger and confusion, denial of the seriousness of the injury, rapid mood change, withdrawal and isolation from other competitors, obsessive desire to return to the field, over-exaggerated emphasis on previous achievements and etc. [7].

The role of a trainer and a sports psychologist, in the psychological way of healing injuries, is reflected in providing empathy and emotional support to injured athletes. A coach, in cooperation with a physiatrist, also needs to present a realistic situation to the competitor: to provide information about healing flow, which training program will be implemented during rehabilitation, the possible appointment of returning to training and matches, as well as to encourage athletes to have a positive attitude and optimism while they are recovering.

An athlete needs to adopt certain coping strategies, such as: positive self-talk, goal settings, visualization and relaxation [45]. Positive self-talk is recommended for reducing low self-confidence, which is a common side effect of existing injuries. A useful technique is goal setting where athletes could divide the recovery objectives for a short period. This ensures that a part of a sports goal is in compliance with the current capacity of the body, in order to increase its recovery progression and avoid the renewal of injuries. Visualization has an important psychological influence in several ways: firstly, athletes can visualize the movement of the body that was injured, and to do that before the physical movement. Secondly, the visualization can be used in a situation where an athlete imagines that he/she is in the game (in training or a match) where they maintain the level of technical performance and accelerate their return to the field. The recovery can be faster when the sportsman imagines removing the injured part of the body and replacing it with a new, healthy part [7]. We likewise differentiate internal and external visualization. The internal one is naturally kinesthetic, because the individual "tracks" the motor performance from inside the body. The external visualization is, on the contrary, "monitoring" performing motor tasks outside one's body, looking at oneself from the outside, where there is self-perception, but not the feeling. Some studies consider that internal visualization is superior to external [6]. Relaxation techniques can be used for relieving pain, reducing stress, as well as reducing muscle tension and improving sleep.

CONCLUSION

Some of the techniques that we have listed above, such as visualization, goal setting, positive self- talk, thought control and replacing negative thoughts with positive ones, are just part of a psychological arsenal which aims to affect mental strength before the performance. None of these "tactics" will be efficient enough, if they are not practiced. Since nobody finds time to practice mental skills while they are in training, sportsmen have to take time to use the techniques of psychological preparation. The same way that numerous repetitions induce the occurrence of a certain movement or combination of movements in automatic fashion, relaxation techniques, energizing and focusing attention need to be included in training to produce the optimal mental state in the shortest time possible and with the best possible results.

It is important to have a holistic approach while practicing any psychological skill. This means that results will not be completed if only the mental technique is taken into account. The influence of other factors of personality and the environment have to be taken into consideration as well, which is why it is recommended to use the "the whole person program."

Studies show that elite athletes cope with stress in sports very well, if they have well developed psychological skills and strategies for it [21]. Because of that, psychological preparation before the match is an important part of success in every sport, and in combative sports as well.

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Chapter 4

OXIDATIVE STRESS AND TRAINING IN MARTIAL ARTS: THE ROLE OF MITOCHONDRIA

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ABSTRACT

The strong body of scientific evidence has established that the exercise-induced stress promotes the generation of reactive oxygen species (ROS), important biomolecules in cellular homeostasis. On one hand, when the ROS production exceeds cellular antioxidant defense, oxidative stress appears resulting in lipid and protein oxidation, DNA damage, apoptosis, impaired muscle performance, and/or overtraining syndrome. On the other hand, ROS also have a relevant signalling function which is necessary for many physiological responses and beneficial adaptations to exercise, including mitochondrial biogenesis, muscle adaptations, or enhanced antioxidant defense. In this regard,

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several studies have argued that a moderate-intensity exercise prevents oxidative stress by improving the antioxidant capacity; however, exhaustive and high-intensity exercise might trigger high oxidative stress accompanied by inflammatory responses that induce harmful effects on health and performance. In light of this, the present chapter reviews the scientific literature regarding the bond between oxidative stress and exercise in martial arts. Although the main source of ROS are mitochondria, other production pathways (e.g., xanthine oxidase activation) might be relevant during the practice of martial arts and explosive actions during combats. Despite the fact that martial arts and combat sports at the elite level require high-intensity training regimes, this practice seems to generally improve antioxidant mechanisms that prevent oxidative stress. Moreover, in martial arts, oxidative stress biomarkers are widely used as indicators of exercise-induced muscle fatigue and, in conjunction with other methods and parameters, might be useful in preventing overtraining and monitoring training programs.

Keywords: antioxidants, muscle fatigue, biomarkers, combat sports, exercise, training

INTRODUCTION TO MITOCHONDRIA

Mitochondria are bacterium-sized organelles found in all mammalian cells with a double-membraned structure distinguishing five compartments (see Figure 1). A large number of enzymes and proteins involved in energy metabolism are located both inside the mitochondria, as through the inner membrane. Indeed, mitochondria are mainly responsible for catalysing the oxidation of organic nutrients and transforming them into energy, primarily, in the form of ATP (adenosine triphosphate) molecules. Many important cellular functions occur in the mitochondria, such as the Krebs cycle or oxidative phosphorylation [1].

It must be noted that the mitochondria structure is dynamic, leading to fission and fusion cycles, with mitochondrial cycling seems to have an important role in exercise performance [2, 3]. Mitochondrial complexes are not randomly distributed within the inner mitochondrial membrane and they can form supercomplexes comprising complexes I and III and up to four copies of complex IV [4], and these features seem to impact its function and oxidative stress.

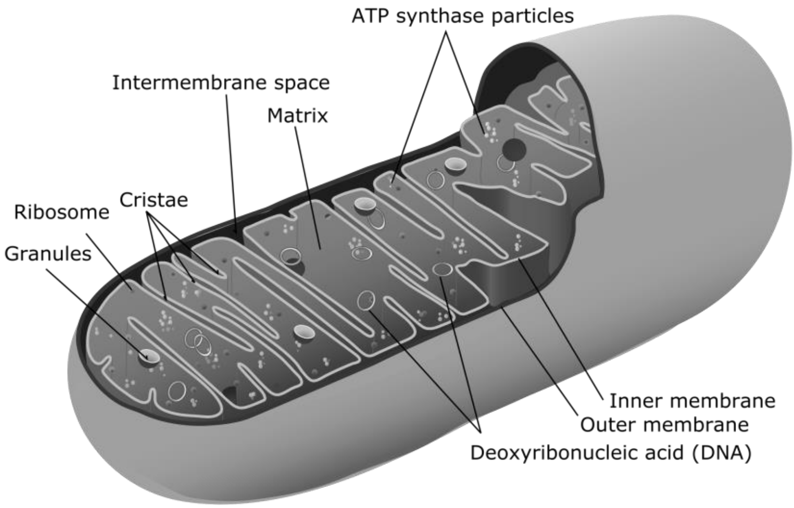

Figure 1.Mitochondrial structure.

Therefore, mitochondria are dynamic organelles that constantly fuse and divide, and exercise training may improve these processes which are necessary for the above mitochondrial functions. Specifically, it has been reported that prolonged exercise, and its consequently increased metabolic demand, promotes the gene expression of mitochondrial fusion and fission proteins in skeletal muscle improving, consequently, the efficiency of oxidative phosphorylation [5, 6].

However, the mitochondrial energy production depends not only on training status, but also on genetic factors. These genetic factors are encoded by the nucleus and the mitochondrial DNA (mtDNA) modulating the mitochondrial function. Moreover, the diet must provide a proper availability of fuels (e.g., fatty acids, sugars, and proteins) in order to maintain optimal functioning [5, 7]. It is noteworthy that mitochondria, in contrast to other membranous structures, contain their own mtDNA and RNA molecules, and own ribosomes. Furthermore, the paternal mtDNA does not contribute at all to the inheritance of mtDNA; instead of this, it is maternally inherited, and thus some sex-specific differences in mitochondria could be attributed to this fact.

Mitochondria have the ability to encode or synthesize the proteins necessary for both its functioning and division, resulting in mitochondrial biogenesis [3, 5, 7]. The frequency, intensity and volume of the exercise are determinant factors in muscle adaptations and mitochondrial biogenesis. The mitochondrial biogenesis encompass both the increase in the number of mitochondria and composition changes (e.g., an increase in the volume and density of mitochondria) [8]. Hence, a higher number and higher quality of mitochondria chances some physiological processes which are relevant in the response to exercise and training.

The stimuli that triggers mitochondrial biogenesis is the muscle contraction [9]. A higher number of mitochondria leads to a better exercise performance, saving carbohydrates and oxidizing a higher amount of lactate inside the organelle [10] by the actions of lactate dehydrogenase and monocarboxylate transporter 1 (MCT1) [11]. Moreover, an increased number of mitochondria prevents oxidative stress [12] both at rest and in response to exercise.

OXIDATIVE STRESS AND MITOCHONDRIA

Life is an oxidation process; during aerobic respiration, mitochondria generate reactive oxygen species (ROS). ROS are free radicals - atoms and molecules with one or more unpaired electrons - and other molecules based on oxygen that act as oxidizing agents. ROS refers to radical and non-radical but reactive derivates of oxygen [13] that, at high levels, might cause oxidative damage resulting in impaired cellular function [14].

Redox reactions involve the reduction and oxidation of proteins and metabolites; the mechanisms that regulate them are key to guarantee homeostasis, health and performance. ROS have bactericidal effects on invading bacteria participating in the innate immune systems. Nevertheless, ROS can also augment inflammation and immune disorders [15]. Therefore, the antioxidant mechanism (e.g., superoxide dismutase, catalase activity) are essential in preventing oxidative stress by reducing ROS.

During respiration, the oxygen is transformed into H_2O within the mitochondria, although a smaller part (about a 2-5% of the oxygen consumption) is converted into ROS. Hence, in response to the mitochondrial electron transport chain, the anion superoxide ($O_2^{\bullet-}$) is produced, one of the main free radicals generated in the cell. Superoxide anion generated within the mitochondria need to be converted into hydrogen peroxide by the action of superoxide dismutase in order to cross the mitochondrial membrane [16, 17]. Despite hydrogen peroxide can diffuse out of mitochondria for metabolism by catalase, it occurs within peroxisomes, not mitochondria. Then, the main system of ROS removal takes place within mitochondria, involving the oxidation of reduced GSH catalysed by GPx with recycling back to reduced glutathione catalysed by GRx [16, 17].

Now that we defined ROS and some redox reactions, we can deepen our understanding of oxidative stress. The concept of oxidative stress is commonly defined as an imbalance between pro-oxidant and antioxidant factors, in favour of the first ones, leading to potential damage. Hence, oxidative stress can be explained as a situation where the production of pro-oxidants overwhelms the antioxidant defence mechanism, leading to oxidative damage [15].

Thus, when ROS exceed the available antioxidant capacity, oxidative stress appears. Oxidative stress can be linked to inflammation, DNA damage, mitochondrial damage, and cell death [18-20]; and these processes, in conjunction with genetic instability of nuclear and mitochondrial genomes, have been related to aging [21]. Moreover, ROS are recognised components of a wide range of pathophysiologies ranging from cancer to cardiometabolic diseases, including sepsis and neurodegenerative pathologies such as Alzheimer's disease [16, 22, 23].

Mitochondria are main cellular sites responsible for ROS production and main targets of the attack of this oxidant molecules. MtDNA can be a key target for damage due to its proximity to the electron transport chain. The oxidative stress-mediated damage of mtDNA can contribute to a cycle of ROS generation what also increases oxidative damage compromising cellular homeostasis and commonly known as the "mitochondrial catastrophe hypothesis" or "toxic oxidative stress" [24, 25].

Notwithstanding, it is important to highlight that physiological levels of ROS are essential for various biological functions, including cell survival and growth, proliferation, and differentiation [26]. In fact, the ROS have a relevant role in redox cell signalling and, its disruption leads to signalling dyshomeostasis and disease. Therefore, ROS are not only "toxic agents," they also play an important role in several adaptations to exercise, and their potentially damaging effects appears only when the antioxidant capacity is overwhelmed as mentioned before.

In this regard, the harmful effects of ROS can be repaired and also prevented by antioxidants. In particular, mitochondria-targeted antioxidants can protect these critical organelles from oxidative damage [24, 27], since mtDNA is more susceptible than nuclear DNA to oxidative damage because of the lack of protective histones and its proximity to the electron transport chain [24]. It is well documented that, in order to combat and prevent oxidative damage, several interacting endogenous antioxidant mechanisms exist including enzymatic and non-enzymatic pathways. Thus, some of the more remarkable enzymatic antioxidants are glutathione (GSH), superoxide dismutase (SOD), cytochrome c, and catalase activity; while non-enzymatic antioxidants include vitamin E (tocopherol), vitamin A (retinol), vitamin C (ascorbic acid) and coenzyme Q10 [17].

OXIDATIVE STRESS AND EXERCISE

In recent years, interest in the study of oxidative stress associated with physical exercise has significantly increased; hence, a large number of studies analysed this fact describing the adaptive capacity of antioxidant system in response to exercise-induced ROS production. Recent advances in the field of oxidative stress and exercise describe the major principles of exercise-induced oxidative stress and its impact on skeletal muscle function.

There is a scientific consensus about the fact that regular practice of physical exercise has numerous benefits on health, acting as a preventive factor on numerous diseases, and decreasing all-cause mortality [28]. Accordingly, low to moderate doses of exercise-induced ROS play a key role in adaptation to training, control of gene expression, regulation of cell signalling pathways, and modulation of skeletal muscle force production [29]. However, some studies argue that intense and exhaustive exercise induces harmful effects due to oxidative damage, increasing cell apoptosis and immunosuppression, over-reaching and over-training [30, 31].

On one hand, it is well established that the exercise-induced stress promotes the generation of ROS and triggers an inflammatory response [32]. Thus, acute and intense exercise increases oxidative stress with disturbances in intracellular homeostasis, and might cause severe harmful effects on health. On the other hand, the habitual practice of moderate exercise prevents oxidative stress by improving the antioxidant capacity [32]. Consequently, it is important to distinguish between acute exercise and training. After acute exercise ROS production augments yet at the same time regular moderate training program seems to improve the antioxidant defence mechanisms. It appears that exercise-induced stress triggers several skeletal muscle adaptations by regulating nuclear gene transcriptions [33].

About 2-5% of the oxygen consumption is converted into ROS, and during exercise this oxygen consumption increases. Therefore, the main site for exercise-mediated ROS production is mitochondria, with ROS act as signalling molecules in order to maintain homeostasis by activating several transcription factors [34]. However, ROS can be produced during exercise through various cellular sources. The different sources acquire relevance in function of the type of exercise performed, although they are not mutually exclusive and can be simultaneously activated.

Hence, despite mitochondria is the main source of ROS during aerobic exercise, other mechanisms are responsible for ROS generation during anaerobic exercise. The xanthine oxidase enzyme (XO) is the main source of free radical production during the ischemia-reperfusion processes. In this regard, during intense exercise, some tissues, including skeletal muscle, suffer a transitory hypoxic condition. After exercise, the reoxygenation occurs in these tissues which increases ROS levels by transforming xanthine dehydrogenase in xanthine oxidase.

Moreover, there are other pathways of ROS production during exercise (e.g., H^+ and catecholamine levels, peroxisomes, neutrophils, etc.) that also explain the ROS generation during anaerobic efforts. Some specific conditions might affect the athlete's ability for ROS production including red cell haemolysis, iron deficiency, dehydration, altitude, sunlight and associated ultraviolet radiation (UVB and UVA), heat stress, diet poor in fruit and vegetables, psychological stress (e.g., competition), infection, use of anti-inflammatory drugs, sterile tissue trauma and associated inflammation resulting from a contact injury, muscle damage or sleep deprivation [31].

Aerobic and anaerobic exercise increase ROS, with the differences between both types of exercise on oxidative stress have been well described [35], although it is not established which one promotes the greatest increase in oxidative stress markers. Nevertheless, the weight of scientific evidence agree that untrained subjects have higher oxidative stress and higher exercise-induced oxidative damage than trained people, due to increases of the endogenous antioxidant capacity, as assessed through enzymatic antioxidant biomarkers such as catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (Gr) and superoxide dismutase (SOD) [15, 19].

Thus, scientific evidence has established that an exercise-induced ROS production, if accompanied by appropriately antioxidant mechanisms and resting periods, produce beneficial physiological adaptations to exercise training, such as enhanced antioxidant and oxidative stress-repairing system, mitochondrial biogenesis, appropriate muscle function and muscle hypertrophy [18, 20, 31]. Therefore, trained people show better antioxidant capacity and lower oxidative stress than sedentary, since ROS production is a fundamental feature of mammalian physiology, cellular respiration and cell signalling.

Previous studies have reported acute post-exercise changes in biomarkers of oxidative stress in untrained, moderately trained and well trained subjects [36, 37]; with training status attenuating the acute post-exercise increases in markers of oxidative stress (e.g., MDA, PC, 3-nitrotyrosine, TAC). Notwithstanding, as fitness and training load increases, biomarkers of lipid peroxidation and antioxidant enzyme activity also increase in tandem [31, 38].

Although training enhances the antioxidant defence system, if the balance between load and recovery is disturbed, oxidative stress appears [39, 40]. For example, insufficient recovery periods after high-intensity efforts can produce oxidative stress not only in sedentary people, but also in well trained athletes. Furthermore, if there is an additional environmental stressor such as an important competition or an inadequate diet for rapid weight reduction (as commonly occurs in martial arts) oxidative stress augments.

Intense exercise at non-habitual intensity increases oxidative stress and this process up-regulates cytokine-mediated inflammatory cascade [18-20]. Consequently, although the elite athlete have a better antioxidant defence than sedentary person both at rest and in response to exercise, athletes might produce such quantity of ROS that overwhelms their antioxidant capacity leading, with inappropriate recovery, to fatigue and overtraining [19].

In summary, during exercise, the ROS production rises as a consequence of the acceleration of oxidative phosphorylation, with an increase of oxygen consumption in tissues, the decrease in pH caused by the accumulation of protons and the increase of Ca^{2+} concentrations, causing muscle fatigue among other effects. Inadequate recovery periods in high-intensity training regimes might lead to impaired muscle strength and performance, and ultimately overtraining syndrome [19]. Therefore, adequate recovery periods are relevant in preventing oxidative stress leading to beneficial effects of training mediating through a moderate production of ROS.

Oxidative Stress and Training in Martial Arts

Martial art athletes are subjected to demanding training regimes with high-intensity intermittent efforts among others. Competitive matches are characterized by explosive actions but adequate aerobic capacity is also determinant for success in competition and recovery between matches. Consequently, the assessment of biomarkers of exercise-induced muscle fatigue in martial art athletes is recommended to assure great performance.

The athletes' performance can be assesssed throught various methods; the direct methods, such as competition ranking, are more reliable but other indirect methods are necessary to program the pre-competitive training load and recovery in order to achieve the best performance in competition. For that, the use of biomarkers is widely recommended and, specifically, the use of oxidative stressbiomarkers at rest and after high-intensity effort might be included during the training program of elite athletes.

In this line, the type of sport and training status are recognised to influence pre- to post-exercise changes in oxidative stress biomarkers [31]. Moreover, the ROS production in martial arts is noticeable compared with other sport disciplines; this is due to the fact that the origin of ROS production in martial arts is not only from mitochondria, but also from other pathways such as the ischemia-reperfusion phenomenon and local inflammation for combat sport-related trauma and injuries [41]. This could increase the risk of oxidative stress in martial art compared with other disciplines, specifically during combats instead of katas.

Furthermore, martial arts and combat sports involve several disciplines with specific technical, tactical and physiological demands. In light of this, Dopsaj et al. [42] compared the leveles of oxidative stress between different karate, kickboxing, and wrestling disciplines; reporting that wrestlers presented a low pro-oxidant-antioxidant balance and higher SOD activity that might be due to the strenuous type of exercise practiced in wrestling.

In addition, alterations in redox homeostasis are not similar across the training and competition phases in elite athletes. Due to the relationship between oxidative stress, illness and performance, it is recommended to longitudinally monitor oxidative stress biomarkers among the annual training cycle [31]. These variations between training phases are explained by the differences in training loads and recovery periods, and the training program should be properly adjusted in order to avoid harmful effects of oxidative stress.

The annual training periodization of martial art athletes is structured through general preparation, specific preparation, and competitive phases. Each phase consisted of micro- and meso-cycles, forming the macrocycle. Due to the different characteristics of each training phase, the alterations in redox homeostasis in martial art athletes varies among the periodized training program. Most of the studies pointed a decrease of lipid perioxidation markers across the macrocycle because the athletes enhance the adaptations to that training [31].

In this regard, the inclusion of a martial art training has been proven to enhance the glutathione antioxidant system in middle-aged adults [43]. Hence, this training prevents the oxidative stress since the induction of cellular antioxidant enzymes protects against excessive ROS production. Moreover, the mentioned antioxidant increase reduce the ROS-mediated cell apoptosis, as evidenced by polyphenols; where martial art athletes showed different kinetics of antioxidant enzymes than sedentary in favour of the first ones [44].

Moreover, there are studies analysing the effect of training on oxidative stress in elite athletes concluding that their antioxidant system is adequate for maintain optimal redox balance despite the high demining training program required in martial arts. For example, Radovanovic et al. [45] assessed the oxidative stress of judo athletes during a 4-week pre-competition training period and reported that natural antioxidant defences of the athletes responded adequately to intense training with no evidences of oxidative damage.

Although the martial art practice promotes some benefits on oxidative stress and health, Demirkan [46] reported that elite young wrestlers (about 15 years of age) who performed a 9-month training program, showed higher oxidant status and lower antioxidant levels than non-athletes, even after a 12-week detraining period. This might be due to the fact that the endogenous antioxidant system of adolescent athletes is still immature; therefore young athletes can be more susceptible than adults to exercise-induced oxidative stress since the antioxidant defence mechanisms seem to be less efficient [47].

Moreover, Radjo et al. [48] compared enzymatic antioxidant biomarkers between judokas with different age who performed high-load training. The authors showed higher increases of antioxidants in senior judokas than in younger categories after the training period. Thus, cadet, junior and senior athletes who are subjected to a martial art training, present different oxidative stress responses and adaptations, where younger athletes may present a more immature antioxidant capacity.

Despite the fact that adolescent athletes can have an immature antioxidant capacity and they present higher alterations of the redox status than adults during the course of the macrocycle [47, 49], Dae-Sun at al. [50] reported that the Taekwondo practice enhances the antioxidant capacity preventing the oxidative stress in adolescents. Accordingly, it has been proven that adolescent who undergo a professional training regime can show adequate antioxidant capacity [51].

In addition, it has been reported a decrease of total antioxidant activity in combat sport athletes after a 4-week intensive endurance training regimen, but without changes in some enzymatic antioxidants [52]. Thus, it is important to include appropriate recovery periods in function of the training load and phase, and these requirements should be age-specific. Excessive oxidative stress increases could lead to impaired performance by promoting muscle fatigue after martial art training session [53, 54]. Great muscle strength is essential for the explosive actions in martial arts, consequently, appropriate antioxidant mechanisms to prevent exercise-induced oxidative stress seem to be necessary for elite athletes that are subjected to high-intensity training programs.

Additionally, although Trivic et al. [55] did not find differences in the total antioxidant activity in elite judokas after a 4-week training program, they reported a statistically significant impairment of the athletes' lipid profile. Specifically, the above authors found increases in total cholesterol and LDL-cholesterol and a decrease in HDL-cholesterol, what could alter endogenous antioxidant capacity since, for example, the vitamin E availability is also related with lipids.

Impaired antioxidant capacity supposes higher lipid peroxidation increases in response to exercise and training and, as has been mentioned, this is associated with the degree of fatigue and inversely associated with plasma levels of vitamin E [56]. Thus, it is important to prevent excesive increases of exercise-induced lipid peroxidation since it is related to competition performance [31]; however Filaire et al. [57] concluded that n-3 fatty-acid supplementation is not effective in preventing oxidative stress promoted by martial art training sessions. Therefore, antioxidant capacity should be enhanced by adequate training loads and recovery, in conjuction with a balanced diet in macro- and micro-nutrients.

It is important to discriminate between exercise and training in martial arts. Acute exercise or single martial art training session promotes lipid peroxidation increases even in trained athletes [58], and this exercise-induced oxidative stress is also modulated by genomic DNA. In this regard, the glutathione-S-transferase M1 (GSTM1) null genotype has been associated with higher oxidative DNA damage and lipid peroxidation in young wrestlers after strenous exercise [59]. These responses to exercise also modify the mtDNA and trigger several adaptations to exercise.

In this line, it has been previously described that the increase of pro-oxidant levels are accompanied by a plasmatic decrease of non-enzymatic antioxidants, such as tocopherol, retinol, and coenzyme Q10 [60]. Moreover, this antioxidant mechanism has been also reported in martial art athletes [41, 61]. This is an antioxidant defence mechanism which indicates a quickly mobilization of non-enzymatic antioxidants from plasma to exercise-activated membrane tissues [62, 63]. For example, some isoforms of alphatocopherolstimulate the peroxidase activity of cytochrome c decreasing, consequently, hydroperoxides [63].

Furthermore, enzymatic antioxidant decreases (SOD, CAT, GPx, Gr) after intense exercise might be consequence of a flux of new neutrophil pool sampled; increased antioxidant enzyme degradation and turnover; and/or the release of antioxidant enzymes into the circulation in response to an exercise challenge [64]. Therefore, both enzymatic and non-enzymatic antioxidants are indispensable for oxidative stress-mediated adaptations to exercise, and, as we mentioned before, appropriate vitamin but also fat intake modulates the availability of some antioxidants highlighting the relevance of appropriate and balanced diet in elite athletes, specially in the competitive phase where oxidative stress is increased.

Oxidative Stress and Rapid Weight Loss

Most competitions in martial arts are divided by weight categories and this fact makes the martial art athlete more vulnerable to oxidative stress compared with other sport disciplines. It has been widely documented that martial art athletes usually reduce significant amounts of body weight (2-10%) in the 2-3 days prior to competition in order to belong to a lighter weight category [65]. A previous review estimates that more than half of athletes in weight-class sports have practiced rapid weight loss before competition weight-in [66].

Common methods for this rapid weight loss prior to competition consisted in calorie-restricted diets and dehydration methods (fluid restriction and intentional sweating). Both methods might impact on oxidative stress of the athletes. Firstly, the dietary intake is closely related to oxidative stress due to several antioxidants are provided through diet (e.g., vitamin E) and also properly dietary intake is necessary for normal mitochondrial functioning. Secondly, pro-oxidant and antioxidant changes during exercise are dependent on fluid balance [67]. Thus, adequate fluid consumption during exercise attenuates exercise-induced oxidative stress [68, 69].

In this line, Reljic et al. [70] have shown that the intakes of vitamins A, E and folate were below recommended values in elite combat sport athletes, and this vitamin deficit is increased in those athletes who practice rapid weight loss during the pre-competition week. Therefore, athletes under rapid weight loss might present higher exercise-induced lipid peroxidation levels. Moreover, a β-alanine supplementation seems to be ineffective in reducing tissue damages and oxidative stress induced by the weight reduction and exercise [71].

Petterson and Berg [72] established that the prevalence of hypohydratation in athletes from diffetent combat sports was 89% in the morning of competition day, with serious hypohydration ranging from 42% to 50% depend on the weigh-in moment (night before competition vs. competition day morning). However, although athletes with one night between weigh-in and cometition have more time for rehydration, this was not associated with better hydration status the following morning [72].

Thus, although athletes try to achieve competitive advantage through rapid weight loss, this fact is debatable since dehydration seems to impair exercise performance, increase DNA damage and increases oxidative stress [73]. In addition, Drid et al. [74] reported that weight loss before competition induces alteration in haematological parameters of martial art athletes, what could negatively affect their functional state and exercise ability. Nevertheless, other authors [75] did not find differences in physiological and psychological variables and performance in competition between martial arts athletes who perform a 7-days dietary restriction and those who maintain adequate dietary intake.

In conclusion, although the impact of rapid weight loss on oxidative stress and performance still remains controversial, the evidence suggests that the aggressive methods to achieve the body mass reduction are detrimental for health and, additionally, they can be considered unfair methods in sport [65]. For all this, martial art athletes should try to maintain their body weight avoiding weight cycling that has been related to health risks.

PRACTICAL APPLICATIONS OF OXIDATIVE STRESS BIOMARKERS

In the field of sport science blood biomarkers can be used to make inferences about the athlete’s underlying physiology and health, particularly in the context of adaptation to training, and the impact of environmental stressors [31]. Blood biomarkers offers a potentially more accurate method for evaluating inflammation caused by exercise indicating the relative state of recovery [76].

The knowledge on the oxidative and inflammatory response to judo-specific tasks and competitive matches can help athletes and coaches to improve their training prescription avoiding overtraining syndrome and, maximizing the athlete’s health and performance. Unfortunately, there is no single time point that best describes the post-exercise changes in oxidative stress. The ideal sampling point will depend on the assay used, the type of exercise, and the training status of the athletes [31, 77].

Oxidative stress and inflammatory biomarkers are not a replacement for performance tests, but they can be used in conjunction, improving training adjustments and recommendations. The physiological and biochemical monitoring of athletes is considered useful for performance enhancement. However, oxidative stress responses to competition are expected to be higher than in performance assessments since psychological stress also impacts on ROS production.

Moreover the relationship between oxidative stress biomarkers and performance should be interpreted with caution since there are other parameters which are determinant for success in martial arts. Notwithstanding, some oxidative stress biomarkers have been related with performance as the drop in counter movement jump with GSH/GSSG ($r = 0.91$) and F2-isoprostanes ($r = 0.78$), decline in one repetition maximum power clean with GSH/GSSG ($r = 0.89$) and F2-isoprostanes ($r = 0.92$), and drop in mean power in Wingate test with GSH/GSSG ($r = 0.85$) and F2-isoprostanes ($r = 0.77$) [31, 78]; although more studies are needed in martial arts.

CONCLUSION

The balance of pro-oxidant and antioxidant factors is altered by exercise and training. Although excessive ROS production has harmful consequences for performance and health, ROS also play an important role in promoting adaptations to exercise. In summary, acute exhaustive exercise promotes lipid and protein oxidation, DNA damage, and cell apoptosis. However, adequate and periodized training program prevents exercise-induced oxidative stress by enhancing antioxidant capacity.

Furthermore, oxidative stress depends on several factors involving the martial art athletes, including nutritional status and dehydration (especially relevant if rapid weight loss occurs), age-category, training load and volume, recovery periods, and training phase. Additionally, there are oxidative stress differences between martial arts disciplines when comparing, for example, taekwondo and judo athletes. Thus, the type of exercise and training impact on oxidative stress responses and exercise-induced adaptations of the antioxidant mechanisms.

It is suggested that longitudinal monitoring of oxidative stress may allow the optimization of workload, tapering and performance, preventing heavily fatigues states and impaired health in martial art athletes. Despite its utility, they must be accompained by other tools for assessing the athletes' performance and health which are especially needed during competitive periods, rapid weight loss reduction, or after very high-intensity training loads.

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Chapter 5

PHYSICAL CONDITIONING IN MIXED MARTIAL ARTS: FROM EVIDENCE TO PRACTICAL EXPERIENCE

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ABSTRACT

Mixed martial arts (MMA), also referred to as "ultimate fighting," is a complex combat sport with different subsport components such as boxing, judo, Brazilian jiu jitsu, Muai Thai kickboxing, Greco-Roman wrestling, free style wrestling, karate and tae-kwon-do. MMA is an extremely demanding sport from a neuromuscular, energetical end psychological point of view. Next to physical and mental demands, MMA has great health risks. Very often, this sport puts fighters in real life survival situations. All of the mentioned reasons motivate fighters to establish a high level of physical preparedness. The aims of physical conditioning in MMA are: development of neuromuscular and energetical abilities and capacities, improving body composition and the health status of the athlete. All the aspects of physical conditioning are aimed to enable

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the fighter to show his combat skills and arts during competitions. Each fighter has his own combat style which should have a basic and specific physical background. Also, the fighter should be well prepared for the different combat styles of his opponents. Every fight could be finished in a few dozen of seconds but it could also last the full time (3 – 5 sequence of 5'). That is the reason why physical conditioning specialists train their combat athletes for extreme competition demands and why the top level MMA fighters often report that "physical conditioning is the best winning technique in MMA." In this chapter preparation period for the final four Pride Grand Prix (Tokyo, Japan, 2006) tournament will be presented. The subject of this program was the winner of this tournament.

Keywords: mixed martial arts, physical conditioning, periodization

INTRODUCTION

Mixed martial arts (MMA), also referred to as "ultimate fighting," is a complex combat sport with different subsport components such as Boxing, Judo, Brazilian Jiu Jitsu, Muai Thai Kickboxing, Greco-Roman wrestling, Free style wrestling, Karate and Tae-kwon-do. MMA uses wide range of kicking, punching, clinching and grappling techniques. The key characteristic of MMA is the ability of competitors to fight in any way they find as appropriate.

In order to successfully compete, diversity in various attacking and defending techniques and a highly developed and broad scope of physical abilities are needed. Furthermore, mixed martial artist will need to possess high levels of basic physical abilities such as maximal strength, strength endurance, power, agility and speed. MMA athlete must also have the physical resilience to absorb frequent high-intensity collisions. Finally, the sport has high-intensity intermittent endurance characteristics, which requires high level of aerobic and anaerobic capacities [1].

A specific needs analysis of both MMA as a sport and MMA fighters are necessary for an adequate physical conditioning program design. The aim of this chapter is to provide combination of evidence based and experience based knowledge from the field of physical conditioning of mixed martial artists.

MMA – Needs Analysis

Competition Structure

MMA is a combat sport which incorporates a variety of striking and grappling techniques. Fights are won by knockout, submission, referee intervention, or a judges' decision at the end of the regulation time. Typical amateur bouts are scheduled for 3-minute rounds, whereas professional and higher-level amateur bouts often fight in 5-minute rounds. The highest level of competition (professional main fights) comprises of five 5-minute rounds. All rounds at each level of competition are separated by 1 minute of rest [1].

Each round consists of intermittent activity expressed as high intensity to lower intensity (Hi:Lo) ratio of 1:2 to 1:4 [1]. Such work-to-recovery interval necessitates engagements from both fast and slow glycolysis in addition to oxidative metabolism. Therefore, physiologically, MMA is intermittent in nature and requires multiple high-intensity efforts, which underpin its high-intensity intermittent endurance foundation [2]. In addition, post bout lactate levels reach 18.7 and 20.7 mmol/L [3]. These levels are similar to those found in other grappling sports such as wrestling [4] and judo [5]. Due to the end product of the fast glycolytic pathway which is lactate, it can be concluded that mixed martial artists rely heavily on this system. This especially applies to brief grappling battles lasting approximately 30–90 seconds.

Every combat sport consists of numerous techniques which are used in competition. Six elementary groups of techniques are recognized in most of them (Table 1): kicking (by foot, fore leg and knee), punching (by fist and elbow), grappling (on the ground and standing positions), clinching, takedowns and throws. Only MMA consists of all of the mentioned complex movements above.

Table 1. Basic combat techniques in different combat sports

Sport/ specific movements	Kicking	Punching	Grappling	Clinching	Takedowns	Throws
Muai Thai	X	X		X		
Boxing		X				
Wrestling			X	X	X	X
Judo			X	X	X	X
Karate	X	X				X
B Jiu Jitsu			X	X	X	X
MMA	X	X	X	X	X	X

Table 2. Energetical sources in MMA

Energetical pathway	Type of activity	Duration	Practical examples
Anaerobic phosphagen system	Explosive and fast activities	Up to 8-10’’	Strikes (repetitive punches or kicks)
Anaerobic glycolytic system	Intensive prolonged activities	10-120’’	Maintaining ground controlling positions
Aerobic system	Moderate endurance activities	More than 120’’	Circling an opponent (recovery between anaerobic bursts)

BIOENERGETICS

MMA is a very physiologically demanding sport and can potentially challenge all of the energy systems. Every MMA match is aerobic by definition (lasting more than several minutes), but it is made up of many relatively high intensity anaerobic (immediate adenosine triphosphate-phosphocreatine (ATP-PCr) and glycolytic systems) episodes that last for only a few seconds. They are intermixed with several lower intensity paced periods that can be thought of as mini active recovery phases [7]. Therefore, MMA is predominantly anaerobic activity consisted of both phosphagen and lactate system. Also, the length of an MMA round and short recovery between rounds necessitates the athlete to develop aerobic capacities.

Energy demands depend on fighting style or on combat situations (Table 2). Wrestling clinch and ground grappling tend to be intensive with anaerobic energy background. Standing combat can be counterbalanced by low intensity periods between combinations of punching and kicks having the support of the aerobic system. Extremely demanding situation is changing position from laying to standing (orthostatic phenomenon).

STRENGTH

The fact is that MMA is defined by punching, wrestling, kicking, grappling, and therefore, to be successful, MMA fighter needs a wide spectrum of strength and power abilities. This applies to the core strength, upper and lower limb strength and power and neck strength. The grappling battles experienced by MMA athletes resemble that of wrestling and thus require expressions of both dynamic and isometric strength [8]. The combination of striking and grappling styles involve upper and lower limb strength and power through multiple planes of motion and through the open and closed kinetic chain. Due to the need for remaining within a particular weight class, which is appropriate for their size, functional and relative strength to work against an opponent's body weight is more important than hypertrophy.

In grappling or wrestling situations, a fighter often has to use isometric contraction of the trunk, neck or limb to take down, control or submit an opponent. Another commonly overlooked area is grip strength. A strong grip is needed to dominate an opponent during the many grappling tie-ups that are encountered during a fight. Mixed martial artists need to grasp an opponent's wrist, ankle, back of the head or trunk to control them, stop a punch or submit their opponent. Although MMA can be dangerous, the injury rates in regulated professional MMA seem to be similar as that of other combat sports [9]. Also, neck strength will reduce the MMA fighter from injuries [10].

POWER

The fighter who has more power is more likely to be in an advantage over a less powerful opponent. Specifically, a fighter needs to have power endurance, which is the ability to perform power-based movements repeatedly without undue fatigue. Ideally, fighters should specifically possess powerful hips, trunk, and shoulder musculature. This should be of utmost concern to the individual who trains fighters. Furthermore, a powerful fighter will be more successful at taking an opponent down, performing a reversal or escape when opponents are grappling on the ground, securing submissions, and throwing devastating punches or kicks [7].

Power is an essential feature which allows successful striking and the ability to control opponent's position. In addition, force transfer through the transverse plane is essential for striking [11]. The delivery of strikes, including punches and kicks, require rapid application of force under unloaded conditions. Aagaard et al. [12] noted that a punch is delivered in 50–250 milliseconds, thus, exceptional rate of force development (RFD) capabilities are required. In the only investigation using elite MMA athletes, McGill et al.

[13] have determined that a rapid contraction-relaxation strategy of trunk musculature is used when performing powerful punching and kicking actions. Additionally, when executing takedowns, forces applied require high rates against the mass of an opponent. Therefore, the expression of power under loaded conditions is another key element in MMA.

The speed of sequence movements at low resistance implies the maximum performance speed of individual movements (kicks by foot or hand). Sources state that the speed of striking can reach as low as 250 ms, which means that the MMA fighter has to have a higher than average speed capability of sequence movements, especially when it comes to hitting and winning the fight with a knockout [12].

SPEED AND AGILITY

Frequency speed implies achieving high speed of cyclic movements. This ability is important for MMA fighter when he strikes the high frequency strikes, for example with hands. MMA fights often lead to a series of strikes in a row, or a mutual exchange of hitting, where it is important that an athlete has a high frequency of hits, meaning he must deliver many strikes in the shortest time possible.

The reaction time is vital for MMA fighters, and it implies the latent time of motor reaction, apropos visual response to a movement (anticipation) of an opponent. Fighter must react quickly to the attacks of an opponent and at the same time choose the appropriate, optimal reaction to the same attacks (choice reaction time) [14].

In MMA, just like in many other combat sports, speed and accuracy of foot placement are important. The ability to precisely move yourself towards a controlled position or a close distance, strike, complete a takedown, or defend through evasion is relevant for any MMA fight. One of the most important complex speed shapes that the athlete needs to possess is agility. MMA fighter needs the agility to quickly and efficiently avoid the kicks and grasps (interventions) by the opponent.

Agility is required to adequately change direction and to avoid an opponent in different distances and to set up an attack [10].

INJURIES

Injuries in MMA typically involve the upper limb (22.7%); head, neck and face (38.2%); and lower limb (30.4%), and mostly occur during training [15]. The specific fighting style will predispose different injury area [16]. Kickboxers are similarly at a risk of an injury, especially injuries of striking limbs (knee, elbow, foot, hand) and the area that is struck (face, ribs, thighs). Other sport analysis identifies risk areas in free style wrestling as the knee, shoulder, ankle and neck [17]. In boxing, risk areas are shoulder, elbow, back and neck. Injuries that are common in wrestling may also be seen in other grappling sports [10]. Methods for minimizing injuries are important for the success of MMA fighters. Athletes at increased risk should be targeted, while integrating these tasks into a training plan in a way that minimizes the impact on training time will improve compliance [6].

PHYSICAL FITNESS SCREENING

Program design in MMA is based on detailed screening of the athletic state of preparedness. Two main ways of screening are commonly used. First, periodical screening consists of laboratory and field tests which can provide useful information about fighter initial state of preparedness. These information are necessary for appropriate program design. Second, acute, continuous screening is used for control of current state of preparedness, day by day. Every day data are used for controlling realization of training tasks and they should have influence on changes in program design.

Periodical screening consists of:

- training history (martial arts training history, current MMA record, MMA strategy, physical training history);
- health status (injury history, actual locomotors problems, immunological status);
- laboratory testing (age, gender, body mass and height, body composition, Functional movement screen, VO_{2max}treadmill test, Lactate threshold test, BOSCO tensiometry protocol, bench press 1RM, squat 1RM,).

Acute control of state of preparedness is consists of:

- body weight;
- RPE;
- radar medicine boll throwing;
- CMJ;
- HR record of training routines;
- HR variability;
- CK, lactates;
- orthostatic test.

PROGRAM DESIGN AND PERIODIZATION OF THE MMA TRAINING PROGRAM

Program design is a complex process which includes determining general and particular training goals and ways to achieve it. First phase of program design includes recognition of human, infrastructural and material conditions. Second phase includes selection of contents, loads, methods, locality and equipment which are necessary for finalizing of the sport preparation process.

Periodization of MMA program depends on the number of official competitions planned in one year training cycle. Most year cycles have 2-4 competitions. Average duration of each preparation cycle for competitions lasts between 8-12 weeks. After every single competition MMA fighter spends 1-2 weeks in recovery regimen. Rehabilitation from injuries and soreness is the main goal of this short recovery period. Also, this period is used for detailed analysis of the previous preparation period and last fight. The next preparation period usually starts with a low to moderate training week including testing procedures and equipping a new team of sparing partners.

The primary training contents of each preparation period are specific (technical/tactical) and general (physical conditioning) preparations. Specific preparation in MMA consists of boxing (Muai Thai and classic boxing) grappling (floor and standing techniques) and situational sparing (close to real competition situation). General (physical conditioning) preparation consists of neuro muscular (preventive, strength, strength endurance, power, agility and mobility programs) and bioenergetics (aerobic and anaerobic programs).

While designing a program for a particular training cycle all previous stages of sports preparation should be considered. Next training cycle is always recumbent on previous cycles. Constructing the program depends on athletes' training history, health status, current preparedness (physical, psychological, technical and tactical) and competition schedule. In this chapter preparation period for Final four Pride Grand Prix (Tokyo, Japan, 2006) tournament will be presented. The subject of this program was the winner of this tournament.

Preparation Period for MMA Pride Competition

The preparation period for the MMA Pride Final Four tournament had a goal to prepare an excellent MMA fighter for the high requirements of the final competition. The final tournament consisted of two possible matches in one night with a 90' break between matches. Pride's rules require a match with two rounds (10'+5'). The participants of the Final Four were the best four MMA fighters in the world at the time, who have fought out to the final after two rounds of competitions.

The preparation period for this competition lasted for 9 weeks. The week before the beginning of the preparation was dedicated to regeneration and rehabilitation after the quarterfinal match in Osaka. For every training in the cycle (Table 3, parts I, II, III), time of training in a day (T), training duration (D), internal load through RPE (IL) and training goal (G) are presented. Additionally, every week is presented with arbitrary units (AU) of load (the sum of RPE values in the trainings in the week x the full number of training minutes in the week). An estimate of subjective load is taken from the athlete on a scale from one to ten (Table 4), 30' after training. Technical and tactical training goals were set with basic martial content of the training: box – BOX (classic box, Muai Thai), grappling – GRA (wrestling, judo, and Brazilian jiu jitsu), a specific combined type of training through simulation of battle – SPEC SIM (all martial arts), sparring – SPA (close to competition). The physical conditioning part of the training included: preventive-corrective protocols (PCP), maximal strength training (FMX), strength endurance circuit training (SEN), strength endurance polygon training (POL), complex strength training (KPX) and aerobic training with different heart rate zones (AER).

The beginning of the cycle (first week) has been oriented towards the gradual introduction into training including one training a day and low to moderate loads (AU = 2210). Basic conditioning content included extensive aerobic training (Table 13), preventive corrective protocols (Table 9), and strength endurance training (Table 6 and 7). Technical-tactical training was oriented on the development of special techniques of boxing and grappling. In the second week the load was significantly increased (AU = 5132) in both physical conditioning and specific training. The conditioning part is represented with preventive corrective protocols and maximum strength training (Table 8), and extensive aerobic training. Specific training includes more intense and longer lasting martial sequences of the program. The first peak of the load in the cycle was achieved in the third week (AU = 6035).

Table 3. Preparation period training program (part I)

	10.07.	11.07.	12.07.	13.07.	14.07.	15.07.	16.07.
LOW WEEK (AU = 2210)							
T	8.00	8.00	8.00	8.00	8.00	8.00	
D	60	90	60	90	60	30	
IL	5	5	6	6	6	6	
G	BOX GRA	AER PCP SEN	BOX GRA	AER PCP SEN	BOX GRA	AER PCP	
	17.07.	18.07.	19.07.	20.07.	21.07.	22.07.	23.07.
HIGH WEEK (AU = 5132)							
T	8.00	8.00	8.00	8.00	8.00	8.00	
D	75	90	75	90	75	60	
IL	7	8	7	8	7	8	
G	PCP FMX AER	BOX	PCP FMX AER	BOX	PCP FMX AER	BOX	
T	18.00		18.00		18.00		
D	75		75		75		
IL	7		8		7		
G	GRA		GRA		GRA		
	24.07.	25.07.	26.07.	27.07.	28.07.	29.07.	31.07.
HIGH WEEK (AU = 6035)							
T	8.00	8.00	8.00	8.00	8.00	8.00	8.00
D	90	90	90	90	75	75	60
IL	8	8	9	7	9	8	8
G	POL AER PCP	BOX	POL AER PCP	BOX	POL PCP AER	BOX	BOX
T	18.00		18.00		18.00		
D	90		75		90		
IL	7		8		7		
G	GRA		GRA		GRA		

Table 3. Preparation period training program (part II)

	1.8.	2.8.	3.8.	4.8.	5.8.	6.8.	
MODERATE/HIGH WEEK (AU = 3240)							
T	8.00	8.00	8.00	8.00			
D	75	60	75	60			
IL	6	8	6	8			
G	KPX PCP	BOX	KPX PCP	BOX			
T	18.00		18.00				
D	75		75				
IL	9		9				
G	GRA		GRA				
	7.08.	8.08.	9.08.	10.08.	11.08.	12.08.	13.08.
HIGH WEEK (AU = 5443)							
T	8.00	8.00	8.00	8.00	8.00	8.00	
D	75	90	75	90	75	60	
IL	9	8	7	8	7	8	
G	POL AER PCP	BOX	FMX AER PCP	BOX	POL AER PCP	BOX	
T	18.00		18.00		18.00		
D	75		75		75		
IL	8		9		7		
G	GRA		GRA		GRA		
	14.08.	15.08.	16.08.	17.08.	18.08.	21.08.	22.08.
MODERATE (AU = 2925)							
T	8.00	8.00	8.00	8.00	8.00	8.00	8.00
D	60	75	60	60	60	60	60
IL	8	7	8	8	6	9	9
G	BOX	FMX AER PCP	BOX	KPX BOX PCP	BOX	SPA PCP	KPX SPA
T		18.00					
D		75					
IL		8					
G		GRA					

The most significant contribution to the intensification of the physical conditioning training is given by the basic polygon training (Table 10) and an intensive aerobic training. Specific training is described with longer and more demanding sessions of boxing and grappling.

Table 3. Preparation period training program (part III)

	23.08.	24.08.	25.08.	26.08.	27.08.		
MODERATE WEEK (AU = 3442)							
T	8.00	11.00	8.00	8.00			
D	60	90	75	60			
IL	8	10	8	7			
G	BOX	SPA SIM	SPA PCP	BOX			
	28.08.	29.08.	30.08.	31.08.	1.09.	2.09.	3.09.
MODERATE WEEK (AU = 3105)							
T	11.00	11.00	11.00	11.00	11.00	11.00	
D	90	75	60	60	60	60	
IL	9	9	6	7	8	7	
G	KPX SPA PCP	SPA	BOX PCP	KPX	BOX PCP	BOX	
	4.09.	5.09.	6.09.	7.09.	8.09.	9.09.	10.09.
LOW WEEK (AU = 1345)							
T	11.00	11.00	11.00	TRAVEL	11.00	11.00	11.00
D	90	75	60		60	60	GP
IL	8	8	7		8	8	
G	SPEC SIM PCP	SPEC SIM	SPEC SIM PCP		AER SPEC SIM	SPEC SIM	

T – day time, D – training duration, IL – internal load (rpe), G – training goal, AU – arbitrary units (rpe), PCP – preventive/corrective, protocols, BOX – boxing training, GRA – grappling training, SPA – sparing training, SPEC SIM – specific simulation training, GP – grand prix pride, SEN – strength endurance training, FMX – maximal strength training, POL – polygon strength endurance training, KPX – complex strength and power training, AER – aerobic training.

The fourth week followed reduction of the overall load (AU = 3240) in order to allow the body of the athlete to be regenerated from the two previous cycles, and to avoid the state of overtraining. In that week training duration and such conditions allowed the implementation of complex training (Table 12), which is focused on explosive properties. Aerobic training again takes on an extendable shape of lower intensity. The specific part of the training is more focused on technique and special preparations for the opponents. In the fifth week followed a new high raising of the overall training load (AU = 5443). This is also the last week of the high loads in which the athlete is exhibiting the accumulation of efforts that should cause delayed transformational effects in the upcoming microcycles preceding the competition.

Besides the preventive corrective protocols and more extensive aerobic training, training with loads combines specific polygon training (Table 11) and maximal intensity training. The specific training simulates the energetic and neuromuscular conditions of the competition. In the sixth week load was decreased (AU = 2925), dominantly at the account of more moderate specific training which has generated the largest amount of load in the previous cycles. Maintaining high intensity in the micro cycle insures physical conditioning training of one by one maximal intensity training and complex training, as well as maximal aerobic training.

In the seventh and eighth week a trend of maintaining moderate loads was continued, (AU = 3442 and 3105) which should secure the stabilization of conditional readiness. In these micro cycles the proportions of the conditional content (preventive/corrective protocols and complex training) decreased and specific ways of training dominated. Sparing matches and the simulation of realistic competitive conditions increase the intensity of the training, but at the same time they cause a decrease of general volume of training loads. With this approach (tapering), conditions for improvement upon energetic and neuromuscular characteristics of the fighter is ensured, which enables him the maximal level of competitive efficiency. In the ninth week the training process aimed maintaining the physical conditioning state exclusively with specific content with reduction of the total load (AU = 1345). Three days before the competition a trip to Tokyo was envisioned, with the idea of staying in his own biorhythm, without time adaptation to the Japanese time zone.

The total training load is represented through three types of weekly micro cycles. Low week had up to 3500 arbitrary units, moderate/high week had 3500 to 5000 arbitrary units, and high week had over 5000 arbitrary units. The undulating periodization model was applied during the weekly preparation period. The distribution of load (Figure 1) shown in arbitrary units (AU) followed two principles. The first principle is represented by the exchange of micro cycles with low, moderate or high total loads. The second principle ensures the domination of micro cycles with high loads in the first two thirds of the preparation period, while in the last third of the preparation period, micro cycles of low and moderate total load are located. Such periodization approach should ensure controlled loading of the fighter with the intention of achieving the highest levels of physical condition for the targeted competition (Pride Final Four).

Table 4. Rate of perceived exertion scale [18]

RPE	Intensity
0	Rest
1	Very Easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Very hard
8	Very, very hard
9	Near maximal
10	Maximal

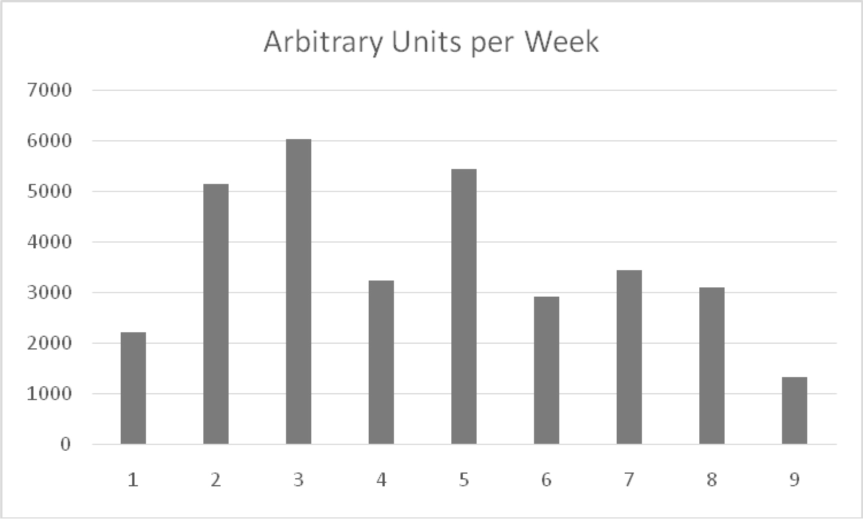

Figure 1. Rate of perceived exertion values during preparation period.

Table 5. Resistance training general periodization of preparation period

Week	Resistance Training Target
1	Strength endurance Preventive/Corrective
2	Maximal strength Preventive/Corrective
3	Strength endurance Preventive/Corrective
4	Power Preventive/Corrective
5	Strength endurance Maximal strength Preventive/Corrective
6	Maximal strength Specific power Preventive/Corrective
7	Specific Strength endurance Specific power Preventive/Corrective
8	Specific Strength endurance Specific power Preventive/Corrective
9	Preventive/Corrective

Resistance Training

Resistance training (Table 5) had a goal to create neuromuscular and energetic conditions for the optimal competitive performance of the fighter. The complexity and difficulty of MMA requires coverage of all aspects of strength and power. Maximum strength, strength endurance and explosive speed and power are the main prerequisites for the neuromuscular performance of a wide range of technical elements in every fight. Accordingly, it is important that during the preparation period all mentioned aspects are represented. To what extent will an individual aspect be present in the program, will depend on: the near and distant training history, individual physical conditioning status of the fighter, the dominant style of fighting, the opponent's fighting style and the rules of the fight at the specific competition. In the specified training program with load, there is a notable training line which begins with the domination of the maximal strength and strength endurance program, and ends with the domination of basic and specific explosive and speed strength. Of course, due to the energetic and neuromuscular width requirements of mixed martial arts, some training requirements are in a competitive relationship. Competitive relationship training of strength/power on the one side, and endurance on the other side, points at the need for caution while designing a training program. In this program the above was attempted to be achieved in two ways. In the first part of the preparation period, micro cycles of different goals alternate, but in the second part of the preparation period, training days of different goals alternate. The final polishing of physical condition happens through the domination of specific technical-tactical content which includes neuromuscular and energetic requests.

Table 6. Strength endurance (circuit training) parameters ("A" protocol)

Exercise	Intensity/ Weight	Intensity/ Tempo	Repetition	Sets	Rest Intervals
Pull Up	Body Weight	Moderate	12-20	6-8	Exercise – 10-20," Circuit – 3-4'
Dips	Body Weight	Moderate	20-30	6-8	Exercise – 10-20," Circuit – 3-4'
Dead Lift	80-100 kg	Moderate	8-10	6-8	Exercise – 10-20," Circuit – 3-4'
Bench Press	80-110 kg	Moderate	10-15	6-8	Exercise – 10-20," Circuit – 3-4'
Squat	80-160 kg	Moderate	8-10	6-8	Exercise – 10-20," Circuit – 3-4'
Curl Press	30-40 kg	Moderate	12-15	6-8	Exercise – 10-20," Circuit – 3-4'

Table 7. Strength endurance (circuit training) parameters (“B” protocol)

Exercise	Intensity/ weight	Intensity/ tempo	Repetition	Sets	Rest intervals
Dumbbell Row	24-30 kg	Moderate	12-15	6-8	Exercise – 10-20’’ Circuit – 3-4’
Push Up	Body Weight	Moderate	30-40	6-8	Exercise – 10-20’’ Circuit – 3-4’
Dumbbell Lunge	Db14-20 kg	Moderate	8-10 Each leg	6-8	Exercise – 10-20’’ Circuit – 3-4’
Dumbbell Arm Curl	20-36 kg	Moderate	10-12	6-8	Exercise – 10-20’’ Circuit – 3-4’
Dumbbell Jerk	16-24 kg	Fast	8-10	6-8	Exercise – 10-20’’ Circuit – 3-4’

Strength endurance in the structure of MMA fighting comes to expression in standing and lying positions mainly while keeping contact situations (clinch, holding, grips), but also in the extended alternation of hits in standing position and on the floor. Training programs of basic strength endurance (Table 6 and 7) are executed in a circular way. The circular way of training implies an execution of exercises in a row (circular way), within which there are rest intervals lasting 10’’-20’’, or as much time it is needed for transition from one workspace to another but within a brief break. Rest intervals between circuits are 3’-4’ long. This type of training involved 5-6 exercises, which were executed 8-30 times, through 6-8 sets. The tempo of execution was moderate.

Maximal strength allows the fighter to overcome a great load (body weight of opponent) in standing and lying grappling situations. In maximal strength training only three triple extension exercises were applied, which were executed with submaximal and maximal intensity, through 1-6 repetitions in 5-7 sets. Rest intervals between sets were 2’-3’ long, and between exercises 4’-5.’ The tempo was specified by the size of the load, and varied from explosive to moderate.

Table 8. Maximal strength training parameters

Exercise	Intensity/Weight	Intensity/Tempo	Repetition	Sets	Rest Intervals
Dead Lift	80-150	Moderate	1-6	5-7	Exercise–2-3,' Sets–4-5'
Bench Press	60-150	Moderate	1-6	5-7	Exercise–2-3' Sets–4-5'
Squat	80-180Kg	Moderate	1-6	5-7	Exercise–2-3' Sets–4-5'

Table 9. Preventive/corrective training parameters

Exercise	Intensity/ Weight	Intensity/ Tempo	Repetition/ Position	Sets	Rest Intervals/ Sets
Classic Plank	Body Weight	Static	30-90''	3-5	1'
Crunches	Body Weight	Moderate	45-90	4-6	1-2'
Back Extension	Body Weight	Moderate	20-40	4-6	1-2'
Fore Arm Flex	Barbell + 10-20Kg	Moderate	10-20	4-5	1-2'
Neck 4 Sides (Conc/Ecc)	Manual Resistance	Moderate	8-10	3-5	1-3'
Mobility Complex (5-10 Exercises)	Body Weight	Slow/Static	10-45''	1-3	20-30''

Preventive corrective protocols (Table 9), whose goals are functional strengthening, stability improvements, mobility, flexibility of individual muscle regions and joint systems, have a special importance in programming a strength and power training. The goal of preventive corrective protocols is, firstly, protecting the fighter from injury. Injuries in MMA are common and often dangerous. For these reasons, fighters dedicate their time to preventive training. The other function of preventive corrective protocols is a better performance of every move in sports. Namely, by improving the stability and mobility of joint structures assumptions are created for the efficient and specific movement of the fighter. In this training program preventive corrective exercises were executed in circular and multiple set (multi station) methods, mostly with their own body weight or with low/moderate external loads. The exercise duration was determined by the number of repetitions or by time duration. They were executed in 1-6 sets with rest intervals 20''-3' long.

Table 10. Basic polygon/strength endurance training parameters

Exercise	Intensity/ Weight	Intensity/ Tempo	Repetition/ Position	Sets	Rest Intervals/ Circles
Squat	80-120 kg	Con – Fast, Ecc-Mod	8-10	6	2’
Dips	Body Weight	Moderate	8-10	6	2’
Dead Lift	80-100 kg	Con – Fast, Ecc-Mod	8-10	6	2’
Curl Push	Barbell 20-40 kg	Con – Fast, Ecc-Mod	8-10	6	2’
Lunge	Body Weight	Moderate	8-10 Each leg	6	2’
Clutch	Body Weight	Fast	10-15	6	2’
Pull Up	Body Weight	Moderate	6-10	6	2’
Push Up	Body Weight	Con – Fast, Ecc-Mod	15	6	2’
Military Cycle (db)	2x10 kg	Fast	8-10	6	2’

Table 11. Basic/specific polygon training parameters

Exercise	Intensity/ Weight	Intensity/ Tempo	Repetition/ Duration	Sets	Rest Intervals/ Circles
Dead Lift	80-100 kg	Con–Fast, Ecc-Mod	8-10	6	1-3’
Laying/ Stand Up	Body Weight	Moderate	8-10	6	1-3’
Curl Push	20-40 kg Barbell	Con–Fast, Ecc-Mod	8-10	6	1-3’
Tie Catch	Opponent Body Weight	Fast	8-10	6	1-3’
Pull Up	Body Weight	Moderate	8-12	6	1-3’
Push Up	Body Weight	Moderate	10-15	6	1-3’
Double Abb Flex	Body Weight	Moderate	10	6	1-3’
Spro	Body Weight	Fast	10	6	1-3’
Box Bag Punches	Body Weight	Fast	45’’	6	1-3’

The second type of strength endurance training was executed in polygon form. This type of training is performed with a fast transition from exercise to exercise without rest intervals, in which the start and finish of the polygon are known. Two polygons were designed. The first one had a basic character and consisted of classic strength exercises. The second one involved alternating execution of basic and specific exercises. Both polygon types were executed with moderate/high loads and a different tempo for the eccentric (mostly moderate) and concentric (mostly fast) phase. Normally there were 6 circuits performed with rest intervals of 1’-3’ between circuits.

The explosive power in MMA is important for performing a force as great as possible in a short period of time. It is particularly important in single punches and kicks, throwing the opponent and escaping from dangerous positions. Speed strength is mainly exerted in high frequency of punches and kicks in a short period of time.

Complex training was performed with the aim of developing explosive and speed strength. It consisted of two exercise complexes. The first one was a basic exercise with moderate/high load while the second one was specific exercise including conquering the opponent’s body weight. The preloading exercise tempo was moderate while the realization exercise tempo was explosive. Rest intervals between exercises were 2”-20.” The complexes were performed in 6 sets with rest intervals of 3.’

Table 12. Complex strength/power training parameters

Exercise	Intensity/ Weight	Intensity/ Tempo	Repetition/ Duration	Sets	Rest Intervals/ Circles
Dead Lift + Guillotine Lifting the Opponent	80-100 kg + Opponent Body Weight	Moderate/ Explosive	5-8	6	3’
Bench Press + Pushing the Opponent from Laying Position	80-100 kg + Opponent Body Weight	Moderate/ Explosive	5-8	6	3’
Squat + Ejection the Opponent from Laying Position with Raising	80-100 kg + Opponent Body Weight	Moderate/ Explosive	5-8	6	3’

Table 13. Aerobic training parameters

Exercise	Modality	Intensity/Tempo	Repetition/Duration	Sets	Rest Intervals/ Circles
Standard Aerobic Running	Extensive	50-75% HR Max	1 X 20-30’	1	
Fartlek Aerobic Running	Intensive	75-90% HR Max	Warm Up 5’10 km/H, 20’ Alternate 12/16 km/H, Cool Down 5’ 8km/H	1	
Interval Aerobic Running	Vo2 Max	90-95% HR Max	Warm Up5’ 8-12 km/H, 2-3’15-18 km/H, Cool Down10’ 8 km/H	3-5	1-2’

Table 14. Cardio–respiratory fitness profile

Parameter	Results
Weight	100 kg
Height	185 cm
Fat Mass	8.7% (8.7 kg)
Fat Free Mass	91.3% (91.3)
Maximal Oxygen Consumption	5.52 L/min
Relative Maximal Oxygen Consumption	55.2 ml/kg/min
Max Heart Rate	182 bpm
Maximal Respiration Volume	3.30 L
Maximal Respiration Frequency	56
Vo2 max Running Speed	19 km/h
Max Running Speed	21 km/h
Max Lactate Concentration	17 mmol/L

Table 15. Running intensity zones

Intensity Zones	Heart Rate
Regeneration zone	<105
Extensive aerobic training zone	105-131
Intensive aerobic training zone	131-152
VO_{2max} zone	>152

Energetical Training

The main goal of the aerobic program (Table 13) was aimed to develop higher cardio-respiratory capacity which enables the athlete to achieve high intensity of combat and recovery within and between combat sequences both at training and competition. Aerobic training is based on laboratory assessment data (VO2max treadmill exhaustion test) and determining heart frequency zones (Table 14 and 15). Basic zones of aerobic training are used as the background for choosing training methods (extensive, intensive and maximal aerobic work). Training forms were: standard continuous aerobic running (20’-30’ on 50-75% of HR max), fartlek running (20’ alternate tempo running on 12 to 16 km/h on 75-90% HRmax) and interval aerobic training (3-5 sets of 2-3’ on 90-95% of HR max). In the first 5 weeks extensive and intensive methods dominated. In the last 4 weeks (6-9) the maximal aerobic method dominated.

Recovery

Large physical and mental loads in MMA demand the use of appropriate recovery methods. A great part of MMA training provokes intensive metabolic reactions. Lactate level during training and competition reaches values of 8-22 mmol/l. Also, explosive and fast movements and overcoming great external loads have consequences in neuromuscular exhaustion. All previous facts are the main reasons for using both methods for energetical and neuromuscular restitution.

Some of the most common recovery methods are: sleep management, active recovery methods (capilarization running, stretching, limb shaking, foam rolling), adequate nutrition and rehydration strategies, nutritional ergogenic aids (isotonics, full proteins, amino acids, carbohydrates, nitrates, sulfates, vitamins and minerals), physical methods (cold bath, contrast bath, sauna, steam bath), massage and biotherapy. Each method is meant for a different type of training and a different phase of the preparation process or competition.

CONCLUSION

MMA is an extremely demanding sport from a neuromuscular, energetical end psychological point of view. Next to physical and mental demands, MMA has great health risks. Very often this sport puts fighters in real life survival situations. All of the mentioned reasons motivate fighters to establish a high level of physical preparedness. The aims of physical conditioning in MMA are: development of neuromuscular and energetical abilities and capacities, improving body composition and the health status of the athlete. All the aspects of physical conditioning are aimed to enable the fighter to show his combat skills and arts during competitions. Each fighter has his own combat style which should have a basic and specific physical background. Also, the fighter should be well prepared for different combat styles of his opponents. Every fight could be finished in a few dozen of seconds but it could also last the full time (3 – 5 sequence of 5'). That is the reason why physical conditioning specialists train their combat athletes for extreme competition demands and why the top level MMA fighters often report that "physical conditioning is the best winning technique in MMA."

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Chapter 6

STRUCTURING AND COMPARISON OF MODELS FOR DETERMINING FACTORS OF SUCCESS IN JUDO

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ABSTRACT

Competitive success in judo is determined by a number of characteristics and abilities as well as technical performance and tactical performance, both of which are realized in direct combat against an opponent. The division of judoka into several weight categories adds to its complex structure. Each of the categories is distinguished by its technical and tactical structure as well as its physiological demands and morphological characteristics. Quantitative experimental procedures for determining the correlation and impact of certain factors on success in judo are exclusively carried out by either testing subjects - judoka (model A) or by surveying judo experts (model B). Both models have their advantages and disadvantages. Model A has two basic methodological problems, the first concerning the definition of the criterion variable of the success of judoka and the second relating to the fact that all judo competitions are conducted by weight categories. In model B, the

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methodological problem is the selected system of offered importance entry on dimensions for success in the competition. In the second part of this chapter, results of a comparison of the two models for determining factors of success in judo are presented. Model A research included the testing of motor functional abilities of the best Croatian judoka in the cadet age category. Model B research involved interviewing top judo experts on the importance of motor functional abilities for the success of cadets in judo. The model A sample was composed of 71 male and female judoka (age 16±0.6 years) divided into four subgroups according to gender and weight class (22 males and 15 females in the lower weight classes; 20 males and 14 females in the heavier weight classes). The sample in model B consisted of 40 selectors and trainers from European cadet judo teams from a total of 22 European countries; all selected participants had a high level of education and successful coaching careers. In model A, nine tests were used as predictor variables to assess motor functional abilities (flexibility, agility, coordination, balance, specific judo endurance, explosive strength, muscular endurance, maximal strength, speed). The competition efficacy variable was defined on the basis of collected points that the tested judoka achieved in the criterion competitions for the current year. For the purposes of model B, a measuring instrument-questionnaire was constructed to evaluate the impact of the same motor functional abilities for success in judo in the cadet age group. The results differ with respect to the gender and weight categories in both models. Although no statistically significant correlation among factors of success was found for either model, common determinants of success irrespective of the applied model were identified.

Keywords: combat sport, weight classes, questionnaire, motor abilities, young athletes

INTRODUCTION

What factors determine success in judo and achieving top results? To what extent can these factors impact predicting future success? Answering these questions is not simple due to the complexity of judo. Competitive success is determined by a range of characteristics and abilities along with technical performance and tactical performance, both of which are realized in direct combat with an opponent. In other words, judo is a sport with great physical, technical, and tactical complexity [1]. The division of judoka into several weight categories adds to its complex structure. Each of the categories is distinguished by its technical and tactical structure as well as its physiological demands and morphological characteristics [2]. Callister et al. [3], as far back as 1991, emphasized that the factors responsible for successful performance are specific to each weight category. However, since that time, frequent changes in the rules of combat have, to some extent, caused changes in the hierarchy and the level of importance of certain dimensions for success in judo. In particular, changes that have occurred in recent years (e.g., ban on certain grips and throwing techniques, reducing the duration of combat for women) have significantly influenced the style and intensity of combat of top competitors [4, 5] and thus the change in the significance of individual factors for success in combat. The factors for success in judo, therefore, vary with years, and identifying these essential abilities is the foundation for advantageous planning and programming of the training process.

The equation specification for performance in a particular sport to the hypothetical level should define the primary dimensions (factors) of anthropological status necessary for success. It should also define the size of the impact of individual anthropological factors on that success. Petkovic [6] explained that the hypothetical setting of equation specifications for success in sport can be expressed in the form

$$Sj = adM + adCv + adMo + adC + adE + adS + adEn + adEr.$$

Hence, mathematically speaking, success in judo (Sj) is equal to the sum of the relative contribution of each dimension of anthropological status particularly propagated by weight (ad) contributions to certain factors. In the equation, (M) represents the morphological factors, (Cv) cardiovascular endurance factors, (Mo) motor factors, (C) cognitive factors, and (E) emotional factors. Other factors include sociological factors (S), environmental factors (En; location, time, trial, gym, among others), and factor (Er), representing a mistake. Defining equation specifications is primarily a hypothetical problem. Nevertheless, the final resolution and confirmation of a hypothetical model can only be sought in the experimental determination of relations and the influence of these dimensions on the application of appropriate statistical procedures.

Quantitative experimental procedures for determining the correlation and impact of certain factors for success in judo have exclusively been carried out by either testing subjects (model A) or by surveying judo experts (model B). Studies for model A are numerous, and the results generally confirm that practically all the analyzed anthropological characteristics have a significant impact on success in judo. On the other hand, only a few studies have interviewed top level judo experts (model B) to determine factors for success in judo. Nevertheless, results from both models are similar.

Basic Characteristics of the Two Research Models

a) Research by Athlete Testing

Athlete testing is the dominant form of research in sports and thus in judo. This is perhaps the greatest comparative advantage of this model as it allows researchers and trainers to compare their results with many other published findings. Numerous studies present the “model values” of top judoka and positively correlate these characteristics with success in judo combat [7-20]. However, researchers have mostly focused on one or two anthropological dimensions that were then evaluated through tests. For the results to be credible and conclusions reliable in this model of research, it is desirable to test top level judokas and particularly in each weight category; unfortunately, these individuals are not easy to coax into testing. To get a broader picture of the impact of certain abilities for success, a relatively large number of tests are needed to assess different capabilities; this will significantly prolong and complicate the measurement protocol. Furthermore, such testing should be conducted at a time when athletes are in optimal form, which is during the annual (semi-annual) competition period. The result of each subject in a particular test depends on certain factors, including the metric characteristics of the measuring instrument, the quality of the evaluators, and the motivation of the participants.

b) Research by Surveying Judo Experts

This research model of factors for success is not well represented in sports or in judo [21]. This is surprising given that the experimental procedure can be accomplished faster and more easily, and many of the problems listed for the previous model are solved by the use of a questionnaire. However, this model has flaws that can be partly removed by carefully structuring the questionnaire. The basic requirement is that the questions must be understandable, simple, and precise. The questionnaire itself must be short so that coaches -

respondents can stay motivated and concentrated when responding. For respondents to understand the posed question, it should be translated into their native language, including the adaptation of professional terminology. The basic precondition for obtaining relevant results by this method is interviewing the top experts who will "want" to convey or share their knowledge and experience with those who are collecting the data. Furthermore, if respondents do not have an adequate level of education or specific knowledge of judo, they will not be able to respond to questions adequately.

METHODOLOGICAL ISSUES OF THE TWO RESEARCH MODELS

Regardless of which model is chosen, the results need to be analyzed methodologically so that the conclusions are valid. In model A (testing athletes), it is possible to identify two basic methodological problems. The first problem concerns the definition of the criterion variable of the success of judoka [22]. It would be wrong to assess the performance of judoka on the basis of one competition because competition in judo is organized according to the model of elimination. In other words, competitors are not in the same position as other competitors, i.e., they have a different number of combats, with different opponents. Therefore, assessing their actual competitive success objectively is impossible. The solution is in the observation of competitors over a longer period or a large number of events and a large number of criterion variables, such as the number of wins and the number of successful actions. Another methodological issue is that all the competitions in judo are conducted by weight categories. It is known that competitors per weight category differ significantly in some anthropological characteristics directly related to the mass of the judoka, such as the maximum strength. Variability of those characteristics within each weight category is relatively small, and the distributions of results for all categories overlap slightly. Therefore, it is difficult to get a significant correlation between the criterion and predictor variables when all judoka (regardless of weight class) are observed together. That can lead to erroneous conclusions in the interpretation of results (Figure 1). The solution is to observe weight categories, e.g., lighter, medium, and heavier weight classes, separately. On the other hand, in some cases it is necessary to present the results in their relative values (the result of the test/weight of the subjects).

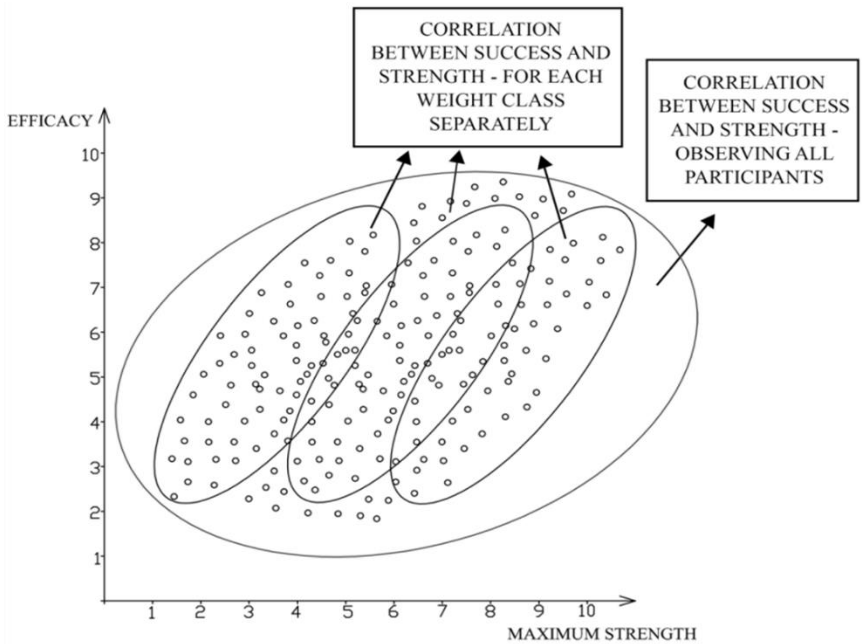


Figure 1.Hypothetical model of the correlation between maximum strength and success of judoka.

Figure 1 shows that the correlation between maximum strength and efficiency is numerically much higher when viewing the weight classes or groups separately (three small ellipses) compared to the correlation when observing all participants (large ellipse).

In model B, the methodological problem is the selected system of offered importance of entry on dimensions for success in the competition. There are three possibilities:

a) Entry of order (from most to least important) of offered dimensions. Such a system is easy to fulfill and administer but only provides information about the hierarchy of the analyzed dimensions and not about their relation. For example, it is not possible to discover how flexibility is less important for success in judo than agility. Since the results are displayed on an ordinal scale, nonparametric statistical methods are required.
b) Entry of percentage points for each dimension offered (where the sum is limited to 100%). By the application of this system, the order of influence is obtained as is the relation of offered dimensions for

success in judo. However, setting the restriction to the sum of the percentage points to 100, limits the respondents in their answers, and it often happens that the respondent corrects already entered values to meet this request.

c) Entry of percentage points for each dimension offered (where the sum does not have to be 100%). Our opinion is that this is the optimal system because it does not limit the subjects and allows complete freedom in the assessment.

LIMITATIONS OF THE TWO RESEARCH MODELS

Each experimental procedure has limitations that should be taken into account when interpreting the results. Thus, in the application of any of the models for determining factors of success, the following should not be ignored:

a) There is a phenomenon of dynamic predictors in the assessment criteria and a phenomenon of dynamic ranking of individual athletes within a predictor. In particular, it would be desirable to determine the predictive value of some anthropological characteristics when assessing the performance of the cadet, junior, and senior age. Additionally, it would be desirable to determine how these characteristics are viable (under the influence of training and/or growth and development) within a certain period.
b) When analyzing the results of the success factors, a compensatory phenomenon as a limiting factor must be taken into account. Different athletes can reach superior levels of performance in different ways because flaws in some characteristics can be compensated by other characteristics. For example, if a top level judoka has less developed maximum strength, he could compensate that with high levels of specific endurance, and adjust his fighting style to achieve dominance over opponents.

RESULTS OF RESEARCH COMPARING THE TWO MODELS

In the previous subsections, basic characteristics were listed and advantages, disadvantages, and limitations of two quantitative experimental models for determining factors for success in judo were discussed. This subsection will present a comparison of the two research models on success factors in a sample of male and female judoka at the cadet level [23]. As such, these results point at new perspectives on the topic since there have been no similar researches, so far.

The Subject Sample

In Model A, the research sample consisted of 71 male and female judokas whose parents had agreed to their participation in the study, which represents 55% of the competitor population in the cadet age group (16 ± 0.6 years) in Croatia. These participants were divided into four subsamples according to gender and weight categories (male judoka categories: 46-60 kg, lighter weight classes [LWC] and 66-90+ kg, heavier weight classes [HWC]; female judoka categories: 40-52 kg, LWC and 57-70+ kg, HWC). Thus, the sample consisted of the following: 22 male judoka of LWC and 20 of HWC; 15 female judoka of LWC and 14 of HWC. The average training experience of all subjects was 7 years (±0.9 years).

The sample in Model B consisted of 40 selectors and trainers from European cadet judo teams from a total of 22 European countries, which represents 43% of all member states of the European Judo Union and 52% of the total sent questionnaires to the available email addresses. Of these, 10 trainers had completed postgraduate studies, 6 trainers had completed graduate studies, and 24 trainers had completed undergraduate studies. The subjects ranged between 30 and 55 years of age and had coached and/or managed judo for at least 8 years. Respondents during their careers with their respective athletes had won at least one medal in World or European cups or championships.

The Sample of Variables

In model A, a set of predictor variables consisted of nine tests to assess motor functional abilities as follows: flexibility - sit and reach (FLEX in cm) [14, 22]; agility-T test (AGI in sec) [24, 25]; coordination - agility on the ground (COO in sec) [14]; balance-Stork test (BAL in sec) [26]; specific judo endurance - specific judo fitness test (SPEC in index) [2, 7, 9-11, 27, 28]; leg power - countermovement jump (POW in cm) [29]; muscular endurance-sit ups in 60 sec (END in number of repetitions) [8, 30]; maximum strength - Lat machine 1 repetition maximum (MAX in kg) [31]; and speed - running 30 m from a flying start (SPEED in sec) [18]. Tests were selected based on whether they met the following criteria: a) have satisfying metric properties confirmed in published works, b) are appropriate to the age group of subjects, c) are by structure, to some extent, similar to specific judo situations. The criterion variable of competition efficacy was defined on the basis of the placement that the judoka achieved in the criterion competitions for the current year and that were published in the registry of the Croatian Judo Federation.

For model B, a new instrument/questionnaire was constructed to evaluate the impact of motor functional abilities for cadets' success in judo. Respondents, by entering a number from 0 to 100, expressed an opinion on the impact of nine motor functional abilities (flexibility, agility, coordination, balance, specific judo endurance, power, muscular endurance, maximal strength, and speed) for success in judo according to gender and weight classes (LWC and HWC). The process of filling out the questionnaire was conducted electronically (over the Internet) and in six world languages (English, German, Russian, French, Spanish, and Italian). The questionnaire was hosted on a specialized server, which enabled password-controlled access and automatically identified the respondents when filling out the questionnaire based on their particular computer IP address and personal information. The respondents received personal invitations to participate in the research via e-mail, along with an explanation, instructions, and a link to access the survey.

Methods of Data Processing

All applied variables were subjected to standard descriptive processes for determining basic statistical parameters (mean and standard deviation). For model A, multiple regression analysis was applied to determine the impact of certain motor functional abilities on the criterion variable of success in judo and then values of standardized regression coefficients (β) were calculated. These coefficients, dependent on each variable’s rank, were observed in the absolute sense and explicitly indicated the hierarchy of each applied predictor’s impact on success in judo. For model B, trainers, using their expert assessment, ranked the impact of individual motor functional abilities for success in judo on a scale of 0–100. The inter-item correlation (IIR) was calculated to assess agreement among respondents (judo coaches). Spearman’s rank correlation coefficient (Spearman's R) provided a measure of correlation between the listed models.

RESULTS

Figures 2 and 3 show that the most important factors for success in judo in the HWC are identical for men and women according to model A.

The greatest impact on the criterion variable of success in males and females of HWC had variables that estimated MAX, COO, and POW. However, for males in the LWC, the greatest impact on the criterion variable of success had variables that assessed AGI, SPEED, and SPEC; for females in the LWC, the strongest correlation with the criterion variable was that which assessed END, SPEC, and COO. Common to all subsamples of subjects was that the variables that assessed FLEX and BAL were at the bottom of the rank for impact on success in judo of judoka in the cadet age group according to model A.

In model B, research yielded an extremely small range of results of average values for the impact of certain motor functional abilities for success in judo. Consequently, an average range for all analyzed subsamples of respondents was only 20 percentage points from least important to most important abilities for success in judo. The degree of agreement between responding judo experts is, on average, lower (in the range of 0.20 to 0.41) than the numerical results of previous research that interviewed judo coaches [21]. Although they are top quality judo experts, a larger number of variables offered, in relation to aforementioned studies, probably contributed to the increased difference in the answers given on the impact of individual abilities for success in judo. The relatively large measuring scale of the impact of certain capabilities (0-100) probably caused the large dispersion in the results, as well as the fact that respondents had to enter specific values, especially for lighter and heavier weight classes in men's and women's competitions (four issues). It is also noteworthy that SPEC was extremely important for success in judo, while FLEX was the least important for success, regardless of gender and weight categories. The results also showed that MAX was the most important for success in males and females of the HWC and the least important in males and females of the LWC. Characteristically, for both males and females of the LWC, SPEED was the most important motor functional ability.

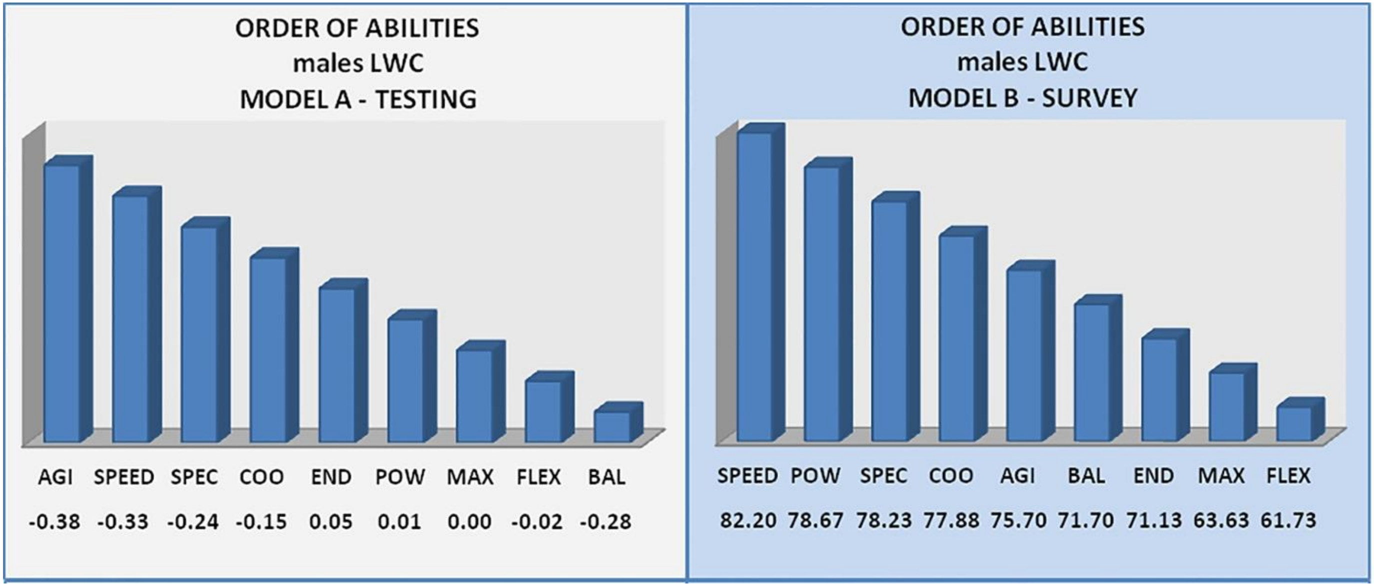


Figure 2. (Continued)

Where are: FLEX - flexibility, AGI - Agility, COO - coordination, BAL - balance, SPEC -specific judo endurance, POW - explosive power, END - muscular endurance, MAX - maximum strength and speed SPEED, figures indicate a) the value of the beta coefficients in model A (testing) and b) the average value of percentage points in the model B (survey).

Figure 2.Results of the order of motor functional abilities essential for success in judo through two models for determining factors of success in judo. The plot shows males of lighter and heavier weight classes.

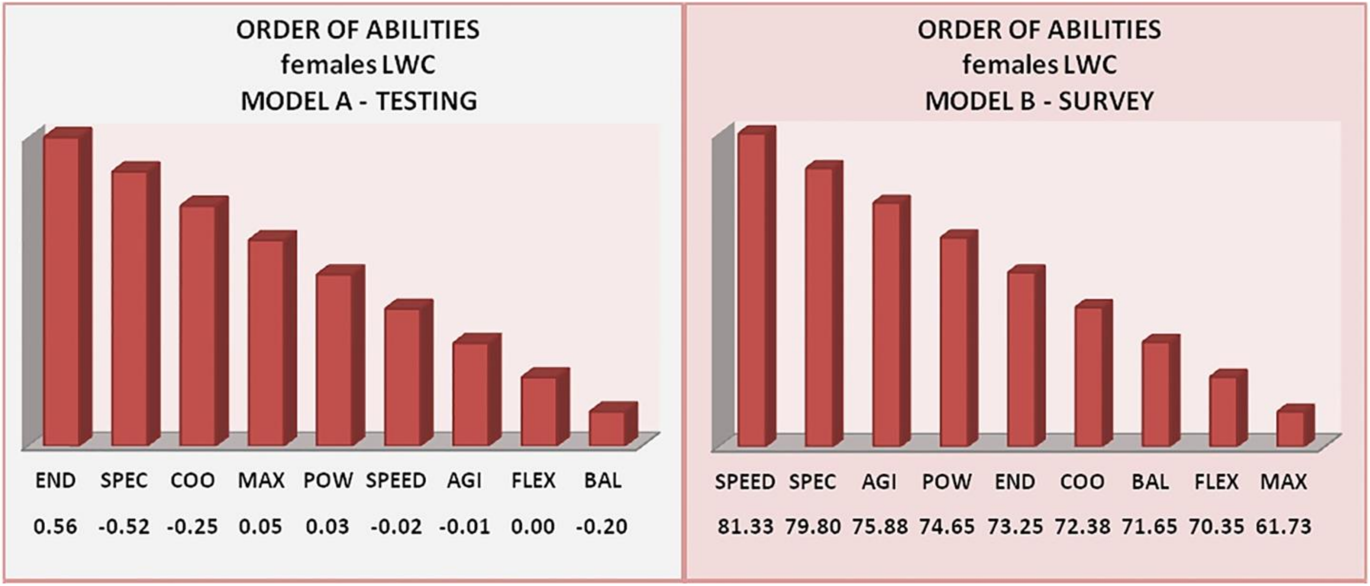
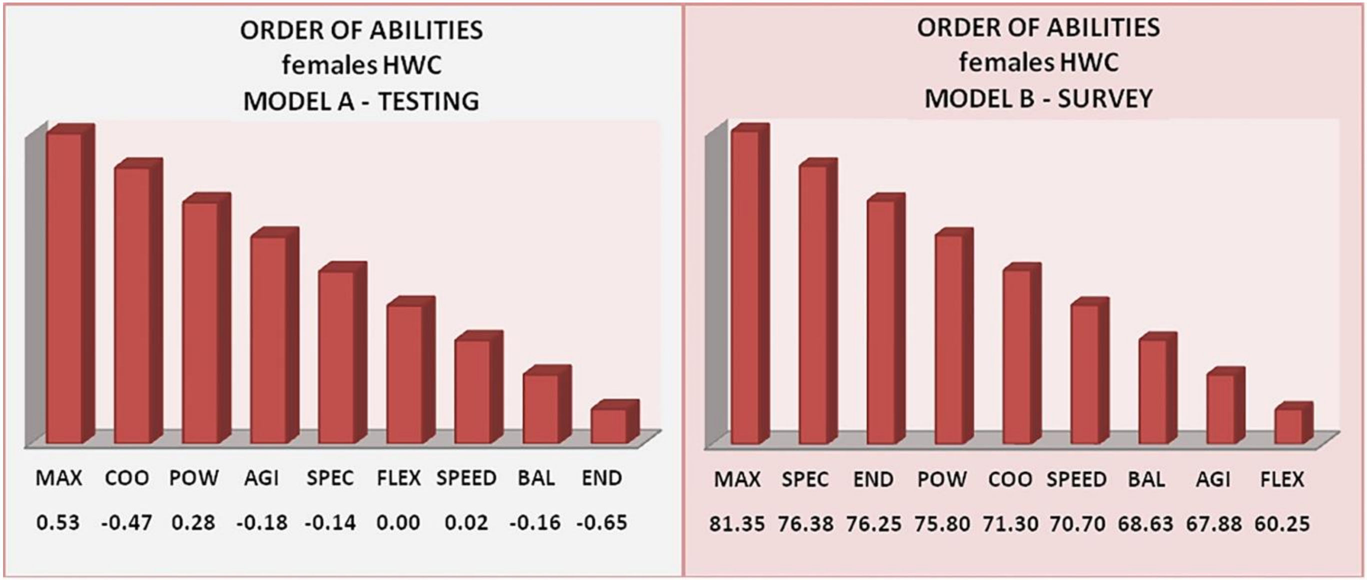


Figure 3. (Continued)



Where are: FLEX - flexibility, AGI - Agility, COO - coordination, BAL - balance, SPEC -specific judo endurance, POW - explosive power, END - muscular endurance, MAX - maximum strength and speed SPEED, figures indicate a) the value of the beta coefficients in model A (testing) and b) the average value percentage points in the model B (survey).

Figure 3.Results of the order of motor functional abilities essential for success in judo through two models of determining factors of success in judo. The plot shows females of lighter and heavier weight classes.

Table 1. Correlations of ranks between the results of two applied models

Males HWC		Males LWC		Females HWC		Females LWC	
R	p	R	p	R	p	R	p
0.35	0.35	0.60	0.08	0.31	0.40	0.20	0.60

Where are: R - Spearman's correlation coefficient, p - level of significance.

The results of the correlation analysis (Table 1) showed that there is no significant correlation in the results obtained by model A and model B for all observed subsamples of respondents (Spearman's R ranges from 0.20 to 0.60). A superficial observation of the obtained numerical values of correlation coefficients indicated that the opinions of top coaches, related to the hierarchy of abilities essential for success, were not associated with the results of testing of male and female judoka in either the LWC or HWC. However, the analysis of the problem is much more complex and needs to be viewed from several perspectives.

Certain principles are common to both applied models. Analysis of the partial results of the testing of motor functional abilities and the results of the survey reveal the most important factors for success in judo, taking into consideration gender and weight classes, are the following:

a) Speed, which ranks second in model A and first in model B, is a common determinant of success from the set of analyzed variables in males of the LWC;
b) Specific judo endurance, which places second in both models applied, is a common determinant for success from the set of analyzed variables in females of the LWC;
c) Maximum strength, which is in first place in both of the applied models, is a common determinant for success from the set of analyzed variables in males and females of the HWC.

For the other motor functional variables, greater or fewer differences are noticeable in the order with respect to the applied model. The existence of differences in the order and importance of certain motor functional parameters between the two applied models can be partly explained by their specific characteristics (i.e., shortcomings, which are discussed in more detail in previous subsections). In addition, the draft of the research itself has certain shortcomings. Although a high-quality sample of cadets was used, the sample is small and the testing could not cover the best European male and female judoka. In addition, for practical reasons, model A was applied to a collection of just nine tests, one test for assessing each latent motor dimension (ability). However, a greater number of tests per individual skills would better "define" the tested ability of the analyzed subjects. It is important to emphasize that the sample of respondents consisted only of competitors from Croatia, while the sample of coaches included 22 European countries. The relatively small range of results, from least important to most important abilities, in model B indicated a significant effect of a large number of different motor functional abilities on cadets' success in judo, according to the responses of judo experts. In other words, respondents estimated that all the offered motor functional variables have large and equal importance for success in judo. As a consequence, only a few modifications to the survey (minor changes in the number of subjects and variables) could cause a significant change in the order of motor functional factors for success in judo.

CONCLUSION

Basic characteristics, advantages, and limitations of models for determining the factors for success in judo have been described in this chapter. We showed the results of research that compared two models for a sample of male and female judokas of cadet age. The results reaffirmed the appropriateness of classification of judokas in the LWC and HWC, irrespective of the model applied, because factors of success differ with regard to weight categories. Although no statistically significant correlation between the two applied research models was found, certain common determinants of success in both models can be identified. An important predictor of success in males of the LWC is speed, while in females of the LWC, specific judo endurance is more important. For males and females of the HWC, maximum strength plays the most vital role. It is difficult to determine which of the two applied models is more reliable in identifying factors for success in judo. It is better to say that both models have their advantages and disadvantages, and it is for researchers to decide which to use in their work. It is also important to emphasize that the scientific basis of obtained results by any model is important in the daily work of judo coaches as it contributes to the quality of planning and training programs, all with the goal of achieving top results.

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Chapter 7

SPECIAL JUDO FITNESS TEST: RESULTS AND APPLICATIONS

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ABSTRACT

The Special Judo Fitness Test (SJFT) is a relatively simple and ecologically valid method of sport-specific evaluation that can be used by judo practitioners from varying demographic backgrounds and skill levels. Due to its demonstrated sensitivity, the SJFT has been used to examine the response to intervention, including utilization of ergogenic

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aids and manipulation of both acute pre-exercise procedures and long-term training programs. Published SJFT data, including the number of throws completed, heart rate response values, and the SJFT index, indicate that the testing protocol as well as age- and gender-specific performance must be considered during the evaluation process.

Keywords: judo, training, age, gender, evaluation

INTRODUCTION

Judo coaches have identified technical excellence (23.4%), psychological (20.1%), and tactical preparation (18.0%) as major contributors to competitive success; however, physical preparation (29%), consisting of body composition (14.8%) and physical fitness (14.2%), surpasses each of these factors [1]. Thus, the control of a competitor's physical preparation level is a crucial coaching activity in contemporary judo, where strength and endurance are necessary for execution of technical-tactical actions, but body build and composition are also of concern due to most tournaments being organized by weight divisions [2]. Both general and specific fitness tests are used to evaluate physical preparation in judokas. General fitness tests do not utilize judo techniques/motions and can be compared to athletes from different sports. Conversely, specific judo tests simulate intermittent efforts consistent with fragments of activity during judo competition [3-6].

A variety of specific judo tests exist and, while most present reliable and valid results, they vary in popularity due to the time and devices needed to conduct them [7]. The Special Judo Fitness Test (SJFT) provides a simple method for judo coaches to test judoka in an ecologically-valid environment on judo mats (*tatami*) in a venue dedicated to practicing judo (*dojo)*. Moreover, results obtained from the SJFT can be immediately compared to normative values constructed for performance evaluation in men [8, 9] and women [10].

Briefly, the SJFT is divided in three periods (A=15 s; B and C=30 s) with 10 s intervals between them. During each period, the athlete (tori) being evaluated throws two partners (uke A and B; separated by 6 m) as many times as possible using the one-armed shoulder throw (*Ippon-seoi-nage*). Both uke A and B should be similar in height and weight to the tori. Immediately following and one minute after the test, heart rate is measured. Stopwatches and heart rate monitors can be employed to aid in the testing procedures [8]. The SJFT index is calculated as follows:

$$SJFT\ Index = \frac{Final\ HR\ (bpm) + HR1\,\mathrm{min}(bpm)}{Throws\ (N)} \qquad \text{Eq.1}$$

where:

Final HR – heart rate registered immediately after the test.
HR1 min – heart rate obtained 1 minute after test.
Throws – number of throws completed during the test.
The test has also been presented in visual form [11].

Use of the SJFT has been advocated during scientific conferences/ symposia organized in conjunction with the International Judo Federation (IJF) World Championships since 1999. As a consequence, this test, which was originally developed to monitor adaptations to training, has become popular amongst countries involved with the IJF. Furthermore, skilled administration of the SJFT and interpretation of the results have been emphasized during coaching courses organized by the European Judo Union (EJU) at the University of Bath, Ruskin University in Cambridge, and Malaga Sport Institute. Testing results have been published in national (Brazil, Georgia, Italy, Poland, Japan, Serbia, Croatia, Spain) and international scientific journals, as well as in book chapters (Brazil, Serbia, Poland, USA), and international scientific conference proceedings: European College of Sport Sciences, Scientific Symposiums of European Judo Union, Scientific Symposiums of IJF, International Martial Arts and Combat Sports Scientific Society (IMACSS) and others.

Due to the physical effort applied during the SJFT, which mimics the temporal structure, technical movement, and physiological responses experienced during judo competition, researchers have also used the results of the test in the evaluation of various interventions and ergogenic aids. With the increasing availability of results from the SJFT from both men and women at different age and competitive levels, the aim of this chapter is two fold: (1) evaluation of population-specific SJFT data; (2) determination of the influence of varying experimental factors on SJFT performance.

METHODS

Published SJFT data from 1995 to 2015 were collected using full-text databases, including Medline, Web of Science, Scholar Google, and Sport Discus. Manual search procedures were also conducted and relevant articles included at the discretion of the authors.

Qualitative analysis was performed on studies in which any of the four dimensions of the SJFT (Total throws performed, HRfinal, HRrecovery and Index) were used as dependent variables in the evaluation of experimental factors. In addition, the physiological response to the typical judo effort performed during the SJFT was described and interpreted.

Quantitative analysis was performed on published sources presenting competitive level or age-specific SJFT data from samples of male and female athletes. We analyzed 46 relevant studies examining 630 male athletes and 15 studies examining 185 women. If results of male and female athletes were mixed, the data was not included. Furthermore, if the samples were not adequately characterized or any of the SJFT data was missing, the studies were excluded.

There after, the size, mean and standard deviation (SD) values for each of the four dimensions of the SJFT were combined using a formula proposed by Kirkendall, Gruber and Johnson [12]:

$$\text{Combined } \bar{x} = \frac{\sum(\bar{x}_i \cdot n_i)}{\sum n_i} \qquad \text{Eq.2}$$

$$\text{Combined } SD = \frac{\sum(n_i \cdot SD_i^2)}{\sum n_i} \qquad \text{Eq.3}$$

Where: $\bar{x}_i$= the mean value for a given sample, n_i = the sample size for a given sample, and SD_i = the standard deviation for a given sample. Subsequently, effect size values for the athletes belonging to the junior (U20) and senior (20+) age classifications were calculated for each of the parameters of the SJFT using Cohen's d statistic with the combined $\bar{x}$ and SD for each group. Effect sizes were interpreted as follows: 0.2 -small, 0.5 -moderate and 0.8 -large [13].

The combined average and standard deviation values for the male senior (MS; n = 510), male junior (MJ; n = 120), female senior (FS; n = 98), and female junior (FJ; n = 65) sub-groups of judo athletes were examined. Homogeneity of variance was verified using Bartlett's test for Total throws

(7.427, $p = 0.059$), HRfinal (4.246, $p = 0.236$), HRrecovery (2.518, $p = 0.472$), and Index (4.908, $p = 0.179$). Medical Bundle software was employed for systematic meta-analysis. Total throws was identified as the primary variable of interest due to it being highly correlated with the results of the Uchikomi Shuttle Run Test ($r = 0.62$, $p = 0.007$), a sport-specific modification of the popular running ability test [14]. One-way analysis of variance (ANOVA) was used to compare the SJFT data between groups. When significant differences ($p < 0.05$) were identified, effect size (η^2) was calculated and interpreted as follows: 0.02 – small, 0.06 – medium, 0.13 – large [13]. Because of unequal group sizes, pair-wise comparisons were conducted with the Games-Howell method for multiple comparisons. In addition, the results of each group were compared to the grand mean using analysis of means (ANOM) plots. The Stat graphics Centurion v. XVII software was used for the group comparisons.

RESULTS

Part One

The SJFT has been extensively used as a performance parameter in longitudinal studies involving different interventions to which judo athletes are submitted, including ergogenic aids used acutely, such as bicarbonate [15], caffeine [16, 17] and creatine [18, 19], as well as short-term nutritional interventions, such as chocolate milk ingestion after training sessions [20] and caloric restriction [21]. The effects of warm-up or recovery procedures, such as the use of postactivation potentiation [22] or active recovery [23], have also been assessed using this test. Moreover, the SJFT performance parameters have been used as dependent variables in studies investigating the effects of specific training protocols, such as different strength training periodization schemes [24], aerobic training [25], concurrent training [26], adaptation to different periodization phases [27], training quantification [28], training for children and adolescents [29] and training intensification and tapering [30]. Hence, these studies provide relevant information concerning the SJFT while reporting interventions that could benefit judo athletes’ performance. Thus, in this section, four main aspects will be presented: (1) effects of nutritional or ergogenic aids interventions on SJFT performance; (2) acute neuro-muscular procedures aimed at affecting SJFT performance; (3) effects of training protocols on SJFT performance; (4) additional factors influencing SJFT performance.

Effects of Nutritional or Ergogenic Aid Intervention on SJFT Performance

As judo is considered a high-intensity intermittent combat sport [31], researchers have investigated the potential for ergogenic aids to increase anaerobic energy release or delay the accumulation of metabolites as strategies to improve performance. However, as the measurement of physiological and performance variables during simulated judo matches is difficult, some studies have elected to use the SJFT as a performance criterion.

Artioli et al. [15] investigated the effects of sodium bicarbonate ($NaHCO_3$) on multiple SJFT performance, i.e., 3 bouts of the original SJFT interspersed by 5 min intervals. Nine judo athletes ingested either $NaHCO_3$ (0.3 g/kg of body mass) or a gelatinous capsule 2 h before the tests. To ensure the quality of the results, the authors used a double-blind crossover design. The results indicated increased number of throws in bouts 2 and 3 of the SJFT and higher blood lactate concentration 3 min after the last bout of the SJFT in the $NaHCO_3$compared to the placebo condition. Thus, induced alkalosis was effective in improving high-intensity intermittent performance and increasing H^+ efflux to the blood (as inferred from the increased blood lactate concentration), while the SJFT was sensitive to the intervention.

Several investigations have been conducted examining creatine supplementation and SJFT performance. Radovanovic et al. [18] submitted six athletes to a one-week creatine loading protocol (0.3 g/kg of body mass/day added to 20 g of dextrose per serving four times per day) followed by a one-week maintenance phase (single dose of 0.3 g/kg of body mass added to 20 g of dextrose was used), and six athletes to placebo (only dextrose). They found no significant differences between groups concerning SJFT parameters (Table 1). Notably, performance in the Wingate test was increased in the creatine group, which conflicts with the general findings that creatine supplementation increases high-intensity intermittent performance, but not single high-intensity bout performance [32].

More recently, [19] concluded that supplementation of creatine malate during 6weeks of preparatory training did not result in improved SJFT performance when compared to placebo consumption. The 6-week training program did improve Total Throws in the SJFT (26.9 ± 2.7 vs. 27.9 ± 2.4) indicating neuromuscular adaptations; however, the unchanged SJFT Index (12.28 ± 1.47 vs.12.06 ± 1.22) implies the circulatory and respiratory systems did not respond in the same manner. The authors concluded that “results obtained during the SJFT test depend not only on energy resources, but also on the exercises which improve the technique of performing typical grip-and-throw judo actions, despite the ensuing fatigue” [19].

Table 1. Special Judo Fitness Test performance in athletes submitted to two weeks of placebo or creatine supplementation (values are mean and standard deviation; Adapted from Radovanovic et al. [18])

	Creatine		Placebo	
	Before	After	Before	After
Total number of throws (rep)	23.4 ± 2.1	24.8 ± 2.8	24.2 ± 2.5	25.1 ± 2.9
Heart rate after the SJFT (bpm)	182.44 ± 8.60	180.46 ± 6.40	183.12 ± 7.80	181.52 ± 8.10
Heart rate 1 min after the SJFT (bpm)	154.66 ± 12.28	155.24 ± 11.84	156.36 ± 13.10	154.74 ± 11.42
Index	14.61 ± 2.10	13.95 ± 1.82	14.18 ± 1.96	13.52 ± 1.78

Caffeine ingestion and its effects on SJFT performance have also been investigated [16, 17]. Pereira et al. [17] used a double blind crossover design to compare caffeine (6 mg/kg of body mass) and placebo (dextrose) on the SJFT performance in young female judo athletes (n = 13, age = 17.6 ± 1.6 years old) and found no effects on the test variables (Table 2). The authors attributed the absence of improvement to the low technical level of the sample used, although they did not report how this aspect would be related to the expected effects of caffeine ingestion.

Table 2. Number of throws, heart rate and index in the Special Judo Fitness Test after caffeine or placebo consumption (values are mean and standard deviation; Adapted from Pereira et al. [17])

	Caffeine	Placebo
A (rep)	4.53 ± 0.51	4.46 ± 0.51
B (rep)	8.30 ± 0.63	8.23 ± 0.72
C (rep)	7.23 ± 0.59	7.46 ± 0.77
Total (rep)	20.07 ± 1.18	20.15 ± 1.67
Heart rate after (bpm)	190.30 ± 9.63	190.69 ± 9.19
Heart rate 1 min after (bpm)	162.07 ± 13.78	164.30 ± 9.64
Index	17.59 ± 1.40	17.75 ± 1.98

Table 3. Index in the Special Judo Fitness Test after 5% weight loss ingesting placebo or caffeine during the 4 h recovery period and in a control (baseline) condition (values are mean and standard deviation; Adapted from Lopes-Silva et al. [16])

	Control	Caffeine	Placebo
Index SJFT1	14.2 ± 1.9	14.9 ± 1.4	15.1 ± 2.2
Index SJFT 2	15.8 ± 2.5	15.1 ± 1.3	14.5 ± 1.3
Index SJFT 3	16.3 ± 2.3	15.3 ± 1.9	15.1 ± 1.5

Subsequently, Lopes-Silva et al. [16] tested the effects of caffeine (6 mg/kg of body mass) compared to placebo (cellulose) and a control condition on SJFT performance after ~5% of body mass reduction conducted over a five-day period, i.e., a typical weight loss procedure used by judo athletes. Following a 4 h recovery period with body mass still lower (~3%) than baseline values, six judo athletes performed 3 bouts of the SJFT with 5 min intervals between them. Neither Total Throws nor the SJFT Index differed between conditions (Table 3).

Despite no change in SJFT performance, increased blood lactate and lower rating of perceived exertion were observed in the caffeine condition compared to the other two conditions, suggesting that caffeine can increase glycolytic energy release and provide athletes with lower feelings of fatigue during exercise. Nonetheless, these changes did not result in performance improvements. Thus, taken together, these two studies do not indicate that SJFT performance can be affected by caffeine ingestion. This finding has two main implications: (1) physical performance in judo is not likely affected by caffeine ingestion; (2) avoidance of caffeine ingestion by athletes prior to completing the SJFT is unnecessary.

As periodization schemes typically include phases of intensified training. Papacosta et al. [20] investigated the effects of ingesting 1L of chocolate milk or 1L of water following training sessions conducted over separate 5-day periods in which 12 judo athletes were making weight to compete. The weeks analyzed were separated by a two-week interval and the SJFT, among other tests, was used to assess performance variation at days 1 and 5 of each week (Table 4).

Table 4. Special Judo Fitness Test performance at the beginning and end of one intensified training week ingesting water or chocolate milk after each training session (values are mean and standard deviation; Adapted from Papacosta et al. [20])

	Water		Chocolate milk	
	Day 1	Day 5	Day 1	Day 5
Total number of throws (rep)	25 ± 3	25 ± 3	27 ± 2*	28 ± 2*
Index	14.2 ± 1.6	13.7 ± 1.2	13.3 ± 2.1	12.4 ± 1.1* Ɨ

* Significantly different from Water condition ($p < 0.05$); Ɨsignificantly different from day 1.

Although the total number of throws in the SJFT was higher in the chocolate milk condition, this nutritional intervention did not improve the number of throws in the period analyzed. However, the SJFT index improved 6.8% in the chocolate milk condition, but not in the water ingestion condition, suggesting that this nutritional strategy was beneficial in improving judo-related performance.

Abedelmalek et al. [21] submitted 11 judo players to the SJFT at baseline and after 7 days of caloric restriction resulting in a 5% reduction in body mass and subsequent decrements in all of the SJFT variables (Table 5).

Although the authors did not discuss the performance changes, it can be inferred that the dehydration impaired the aerobic and anaerobic energy release needed to perform the throws, while a reduction in plasma volume yielded decreased stroke volume resulting in increased heart rate to maintain the cardiac output necessary to deal with the imposed exercise intensity.

Table 5. Performance and heart rate responses to the Special Judo Fitness Test at baseline and after 7 days of caloric restriction (values are mean and standard deviation; Adapted from Abedelmalek et al. [21])

	Baseline	Caloric restriction
Total number of throws (rep)	31.00 ± 2.65	26.27 ± 2.90*
Heart rate after the SJFT (bpm)	182.3 ± 5.3	188.0 ± 8.4*
Heart rate 1 min after the SJFT (bpm)	154.0 ± 2.8	161.0 ± 3.2*
Index	10.80 ± 3.00	13.28 ± 4.00*

* Significantly different from baseline ($p < 0.05$).

Acute Neuro-Muscular Procedures Aimed at Affecting SJFT Performance

As judo athletes perform 5-6 matches in a single day [31], the recovery process between matches is an important factor for competitive success [31]. Considering these aspects, [23] used the SJFT to verify if the use of 15 min active recovery after a 5 min judo match simulation would provide a better recovery process compared to 15 min passive recovery and to a control condition. Despite more rapid blood lactate removal during active recovery compared to passive recovery, no differences were found concerning the total number of throws in the SJFT (control = 26 ± 1 throws; after passive recovery = 26 ± 3 throws; after active recovery = 27 ± 2 throws). Notably, 15 minutes was long enough to provide full recovery of performance for these athletes. Furthermore, active recovery might provide some benefit when shorter periods are provided between matches, such as in regional competitions; however, this aspect still needs to be examined.

Different pre-exercise warm-up strategies have been recommended and, in particular, the use of post-activation potentiation has gained popularity in the last decade [33]. Briefly, the post-activation potentiation procedure involves the execution of maximal or submaximal dynamic or static resistance exercise using heavy loads (called the conditioning task) followed by an brief interval (1 to 10 min) prior to the main activity, which is normally a power or sport-specific task [22, 33]. To verify the possibility of improvements in SJFT performance following post-activation potentiation, Miarka et al. [22] submitted 8 judo athletes to this test in a control condition and 3 min after a plyometric conditioning activity (10 x 3 consecutive jumps stepping off elevated surfaces – 20, 40 and 60 cm - and landing as fast as possible, using 30 s intervals), a maximum strength intervention (5 sets of 1 rep of squat exercise at 95% of one-repetition maximum and 2 min intervals) and a contrast exercise (3 sets of 2 rep of squat exercise at 90% of one-repetition maximum followed by five horizontal jumps with legs together and 2 min intervals). The main results are presented in Table 6.

The plyometric intervention resulted in a higher number of throws in period A compared to the control condition, which was likely a consequence of improved motor efficiency and increased neural stimulation required to generate muscle power during this type of exercise. Heart rate after the SJFT was higher in the plyometric condition compared to the contrast condition, which can be explained by a higher number of repetitions used in the former compared to the latter. Additionally, heart rate 1 min after the SJFT was lower in the contrast condition compared to all others, although an explanation for this result was not presented. Finally, the contrast condition resulted in a lower

SJFT index compared to the control and plyometric conditions, which was primarily influenced by the heart rate response [22].

Table 6. Performance and heart rate responses in the Special Judo Fitness Test after different warm-up procedures or a control condition (values are mean and standard deviation; Adapted from Miarka et al. [22])

	Control	Plyometrics	Maximum Strength	Contrast
A (rep)	5.7 ± 0.5	6.4 ± 0.5*	6.3 ± 0.5	5.7 ± 0.5
B (rep)	9.7 ± 0.5	9.6 ± 0.5	9.7 ± 0.5	10.1 ± 0.9
C (rep)	8.4 ± 0.5	8.4 ± 0.5	8.6 ± 0.8	8.4 ± 0.5
Total (rep)	23.7 ± 1.4	24.3 ± 1.0	24.3 ± 1.5	24.3 ± 1.7
HR after (bpm)	187 ± 11	192 ± 8†	188 ± 12	184 ± 9
HR 1 min after (bpm)	154 ± 11	159 ± 7	154 ± 5	144 ± 6§
Index	14.49 ± 1.30	14.51 ± 0.54	14.06 ± 0.77	13.58 ± 0.72‡

HR = heart rate; *Different from control condition ($p < 0.05$); †Different from contrast exercise condition ($p < 0.05$); ‡Different from control and plyometric conditions ($p < 0.005$); §Different from all other conditions ($p < 0.05$).

Effects of Training Protocols on SJFT Performance

The ability to detect changes throughout training protocols is an important aspect of any physical test. In order to serve this purpose, the SJFT has been employed as a tool to monitor the specific physical fitness of judo athletes throughout many different training protocols.

Radovanovic et al. [26] submitted 14 judo athletes to either strength or concurrent (strength and aerobic) training in addition to regular judo training for 12 weeks and used the SJFT variables as performance markers. Strength training was conducted three times per week, including three to five exercises for the major muscle groups, with intensities varying from 60% to 85% of one-repetition maximum, increasing the number of sets and decreasing the number of repetitions over the course of the study. Aerobic training was conducted twice per week, for 30 min (10 min below the aerobic threshold, 5 min between aerobic and anaerobic thresholds, 5 min above anaerobic threshold and 10 min again below aerobic threshold). The SJFT index decreased for both the strength (pre = 15.41 ± 2.08; post = 13.58 ± 1.91) and concurrent training (pre = 15.86 ± 2.32; post = 13.24 ± 1.75) groups. These results suggested that both types of training protocols added to the regular judo program were effective in improving performance in the SJFT. However, as the study presented only the SJFT index, and no control group was used, it is difficult to interpret the source of the adaptation (cardiovascular versus muscular; strength training or judo only). This information would be quite important as different types of training seem to influence different variables in the SJFT [24, 25].

Table 7. Performance and heart rate responses in the Special Judo Fitness Test before and after a combination of standard judo training and aerobic training

	Pre-training	Post-training
A (rep)	6 ± 1	6 ± 0
B (rep)	11 ± 1	10 ± 0
C (rep)	10 ± 1	10 ± 1
Total (rep)	26 ± 1	26 ± 2
Heart rate after (bpm)	184 ± 7	177 ± 15*
Heart rate 1 min after (bpm)	155 ± 15	145 ± 15*
Index	13.75 ± 0.77	12.24 ± 1.18*

* Significantly different from pre-training.

Indeed, Bonato et al. [25] demonstrated that the inclusion of aerobic training during the last 6 weeks of a 12-week judo training program resulted in improvements in the SJFT (Table 7). The aerobic training involved three sessions per week, composed of two continuous 30-min running sessions at 60% of maximal aerobic speed and one session of 15 sets of 1-min high-intensity intermittent running intervals at 90% of maximal aerobic speed interspersed with 1-min intervals at 60% of maximal aerobic speed.

The differences in the SJFT variables were significant only for heart rate measurements, reflecting a typical adjustment to aerobic training, i.e., a lower heart rate for the same absolute effort intensity and a faster heart rate recovery after a given effort, which resulted in improved index values [25]. Moreover, in only 12 weeks of training, the group progressed from a “regular” to a “good” classification according to normative data [8].

However, as in the previous study, the absence of a control group prevents the identification of specific contributions from the standard judo training, the aerobic training, or a combination of the training modalities.

Franchini et al. [24] compared the effects of 8 weeks, three sessions per week, of linear and daily undulating strength periodization added to regular judo training on SJFT performance. The linear group trained at 3-5 RM in the first two weeks, performed power exercises in weeks 3 to 5 and trained in the 15-20 RM zone in the last three weeks. The daily undulating group completed the same training sessions, but the different loading schemes were each completed on a weekly basis. Protocols involved the execution of 12 different exercises, equally distributed for both groups and training sessions. A significant increase in the number of throws in the B and C sets, and, consequently, in the total number of throws, as well as a reduction in the index, were detected for the whole group, with no significant differences between groups (Table 8).

Table 8. Special Judo Fitness Test performance before and after 8 weeks of linear or daily undulating strength training programs (values are mean and standard deviation; Adapted from Franchini et al. [24])

	Linear		Undulating	
	Pre	Post	Pre	Post
A (rep)	5 ± 1	6 ± 1	6 ± 1	6 ± 1
B (rep) †	10 ± 1	10 ± 1	10 ± 1	10 ± 1
C (rep) †	9 ± 1	9 ± 1	8 ± 1	9 ± 1
Total (rep) †	24 ± 1	25 ± 2	24 ± 2	25 ± 2
Heart rate after (bpm)	184 ± 12	188 ± 10	175 ± 15	177 ± 13
Heart rate 1 min after (bpm)	165 ± 16	166 ± 14	151 ± 20	150 ± 17
Index †	14.7 ± 1.2	13.7 ± 1.2	13.3 ± 2.1	12.4 ± 1.1

† Moment effect, difference between pre- and post-training ($p < 0.05$).

In contrast to the results reported by Bonato et al. [25] demonstrating that aerobic training influenced the heart rate-related variables, this study demonstrated that strength training increased the number of throws in the last two sets of the SJFT. Thus, as the SJFT index is a mix of aerobic and anaerobic variables, it can be improved via different training protocols.

Table 9. Special Judo Fitness Test performance before and after 4 weeks of pre-competition training in child and adolescent judo athletes (values are mean and standard deviation; Adapted from (Fukuda et al. [29])

	Children		Adolescents	
	Pre	Post	Pre	Post
Total (rep)	19.0 ± 0.7	18.6 ± 0.9	21.8 ± 0.4	22.5 ± 0.5
Heart rate after (bpm)	196 ± 7	190 ± 11	193 ± 11	190 ± 7
Heart rate 1 min after (bpm)	157 ± 17	162 ± 13	170 ± 12	164 ± 16
Index	18.78 ± 1.93	19.12 ± 2.15	16.75 ± 1.22	15.76 ± 0.86†

† Different from pre-training ($p < 0.05$).

The SJFT has also been used to monitor the final phase (last 4 weeks) of pre-competition judo training in youth athletes [29]. These authors evaluated 8 children and 12 adolescents at baseline and after four weeks of training and reported an improvement in SJFT index for only the adolescent group (Table 9).

For the adolescent group, slight non-significant changes in the total number of throws and heart rate responses combined to generate a significant change in the index, indicating that the index seems to be the most sensitive parameter of the SJFT. Thus, longer training periods seem to be needed to improve SJFT performance in children. However, the SJFT may not be as sensitive in this younger age group due to its high glycolytic requirements [34].

More recently, Agostinho et al. [28] investigated the relationship between training loads assessed via session rating of perceived exertion (session-RPE) and performance in the SJFT over a two-year training period in cadet and junior judo athletes (15.9 ± 1.3 years old). The authors reported that session RPE and standard RPE values resulted in similar accuracies when assessing training loads. Furthermore, the combination of dynamic chin-ups holding the judogi (another judo-specific test) and the number of throws in the SJFT provided the best description of performance variations across the competitive seasons evaluated. Indeed, the modeling of RPE assessed after each training session predicted 50% of the variation in this combined variable (chin-up plus throws in the SJFT), which provides support for the use of individualized training loads to enhance performance in judo athletes involved with long-term training.

The intensification and tapering phases are quite important for optimal competitive performance and monitoring these phases is a key component of the training process. Analyzing these phases, Papacosta et al. [30] submitted 11 judo athletes to 5 weeks of training composed of 1 week of normal training, 2 weeks of intensified training and 2 weeks of exponential tapering, and used the SJFT, among other tests, once per week to evaluate performance improvements. The SJFT index was utilized as the main parameter from the SJFT, but no difference was found in response to training (Figure 1); however, a trend for increases of 5.9% and 7.4% during weeks 4 and 5, respectively, was reported. Indeed, half of the athletes presented improvements in the SJFT, which, according to the authors, could indicate that judo athletes with lower technical levels would be more responsive to improvements in the SJFT than athletes with higher technical skills. However, the authors did not indicate the technical level of the athletes investigated or report information about the other SJFT variables. Thus, these aspects should be studied in future investigations.

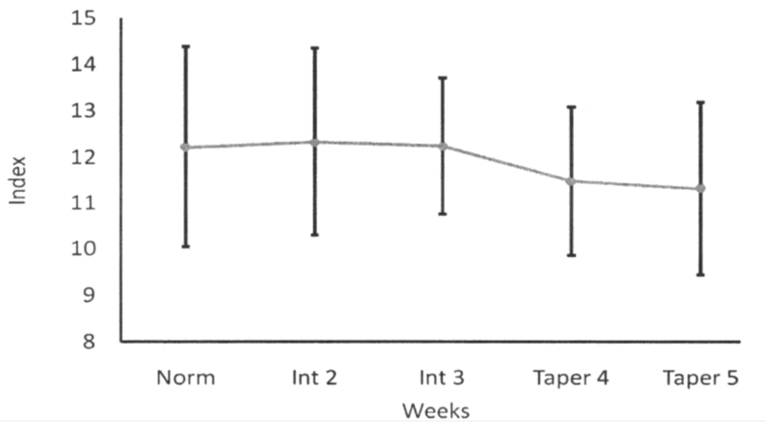

Figure 1. Special Judo Fitness Test index in 5 weeks of judo training, involving 1 week of normal (Norm), two weeks of intensified (Int 2 and Int 3) and two weeks of tapering (Taper 4 and Taper 5) (values are presented as mean and standard deviation; Adapted from Papacosta et al. [30]).

Franchini et al. [27] also used the SJFT to monitor the effects of 18 weeks of training and found no variation in the test's variables (Table 10).

The authors attributed the lack of improvement in the SJFT to decrements in lower-body aerobic power during the training period. Interestingly the training period also resulted in an increase in the anaerobic profile assessed via the Wingate test. These divergent changes likely interacted to maintain the variables from the SJFT, which has important contributions of both aerobic and anaerobic energy release [34].

Table 10. Special Judo Fitness Test performance before and after 18 weeks of training in adult judo athletes (values are mean and standard deviation; Adapted from Franchini et al. [27])

	Before	After
A (rep)	6 ± 0	6 ± 1
B (rep)	11 ± 0	11 ± 1
C (rep)	10 ± 1	9 ± 1
Total (rep)	28 ± 1	26 ± 1
Heart rate after the test (bpm)	197 ± 6	190 ± 8
Heart rate 1 min after the test (bpm)	178 ± 9	171 ± 9
Index	13.66 ± 1.04	14.03 ± 1.15

Additional Factors Influencing SJFT Performance

Differences in body build and body composition have been identified between athletes from heavier and lighter weight categories [35]. To seek knowledge about dependency of SJFT performance on weight, Sterkowicz and Franchini [36] conducted a cross-sectional study on 80 male judo competitors. The lighter category athletes (60 – 81 kg) revealed better specific fitness, whereas the heavier category athletes, specifically those in the over 100 kg category, were characterized by worse results with respect to the SJFT. The Multiple Range Test confirmed significant differences among mean values of the heaviest category and the subset of the first four weight categories ($p < 0.05$). The number of throws performed by the over 100 kg competitors was similar to the two closest weight categories (i.e., – 100 kg and –90 kg). Furthemore, the authors also identified better SJFT performance in elite judo players compared to novice athletes and concluded that the test can be used for training control and talent identification [36].

Sogabe et al. [37] examined the effects of laterality on SJFT performance and demonstrated that fewer throws were performed in period A when judo athlete's utilized their non-dominant side (5.4 ± 0.7) as compared to their dominant side (5.9 ± 0.5). Additionally, a decreasing number of throws were performed in consecutive segments of the SJFT in men using their dominant side, while a decline was not observed using their non-dominant side. Paradoxically, when using their dominant side, women performed fewer throws in period A (Ax2 = 10) than in subsequent periods (B = 11 and C = 11). While the authors attributed this discrepancy to the female sample being at a higher competitive level and possessing greater a balance of technical and tactical actions [37], the potential for priming effects of the first period positively affecting the proceeding periods cannot be excluded.

Variants of the SJFT have also been examined. Sterkowicz-Przybycień et al. [38] examined the standard SJFT and a modified SJFT in 7 national-level judo athletes during the competitive period. Both variants of performance were videotaped and the throws performed were counted. On the first testing day, the subjects performed the standard SJFT using the one-armed shoulder throw (*Ippon-seoi-nage*) during which they actually threw their partners, while on the second testing day, the same technique was utilized during shadow *Uchik*omi / solo practice (*Tandoku-renshu*; TR). During the TR tests, a significantly greater total number of throws were observed compared to the SJFT (34 ±2 reps vs 28 ± 2; difference 6.29 ± 1.38 reps, $P < 0.001$), whereas HR values immediately after the TR and SJFT (176 ± 81 vs 181± 1bpm) and after 1 minute (146 ± 8 vs 152 ± 14) were similar ($P > 0.05$). Furthermore, the index values were significantly lower (better) for the TR as compared to the SJFT (9.47 ± 0.76 vs.11.96 ± 0.82; difference -2.49 ±0.44, $P < 0.001$).

Michielon et al. [39] found that the top-10 ranked Italian judo athletes in the 60-66 kg category presented significantly better SJFT results than 10 lower-ranked athletes. The high-ranked group performed significantly more throws (26.5 vs. 23.5) with similar HR final (188.5 vs. 192.3 bpm) and significantly lower HR after 1 min (151.0 vs. 165.4 bpm). When high-ranked athletes completed the standard SJFT (using *Ippon-seoi-nage*), as well as variants using the inner thigh throw (*Uchi-mata*) and the sweeping hip throw (*Harai-goshi*), the total throws and index values were similar across techniques (all $p > 0.05$): *Ippon-seoi-nage* (26.5 and 12.85), *Uchi-mata* (25.8 and 13.0), *Harai-goshi* (27.2 and 12.45). However, the results of the lower-ranked judo athletes were significantly different using *Ippon-seoi-nage* (total throws: 23.5; index: 15.3), *Uchi-mata* (total throws: 23.4; index: 15.04), and *Harai-goshi* (total throws: 24.8; index; 14.42).

Using the assumption that the SJFT may be in appropriate for beginners due to *Ippon-seoi-nage* being a more advanced technique, Barreto et al. [40] proposed the use of the major hip throw (*O-goshi*). A sample adult males ($n = 9$), adolescent males ($n = 9$), and adolescent females ($n = 5$) performed similar Total throws using *Ippon-seoi-nage* vs *O-goshi* (21.9 ± 2.9 vs 21.7 ± 2.7; 22.0 ± 2.4 vs 23.1 ± 2.6; 21.8 ± 1.6 vs 22.0 ± 2.0 throws, respectively) which coincided with SJFT index values ranging from 15.1 to 16.2. These results indicate that alternative throwing techniques might be appropriate for less advanced judoka completing the SJFT.

Part Two

A Comparison of SJFT Results Characterizing Judo Athletes according to Age and Gender

Based on the comparison of SJFT results from published research studies, it was concluded that male and female judo athletes should be evaluated separately [10]. In the results of the analysis conducted for this chapter, no substantial difference in Total throws performed was observed between female [25.49 reps (95% CL: 24.45-26.52 reps); Figure 2] and male groups [25.49 reps (95% CL: 24.97-26.01 reps); Figure 3]. However, significant heterogeneity was found between the 15 female samples ($Q = 56.489$, $df = 14$, $p < 0.001$; considerable $I^2 = 75.02\%$, CL = 59.01-85.02%) as well between the 46 male samples ($Q = 107.307$, $df = 45$, $p < 0.001$; $I^2 = 58.06\%$, CL= 41.87-69.75%).

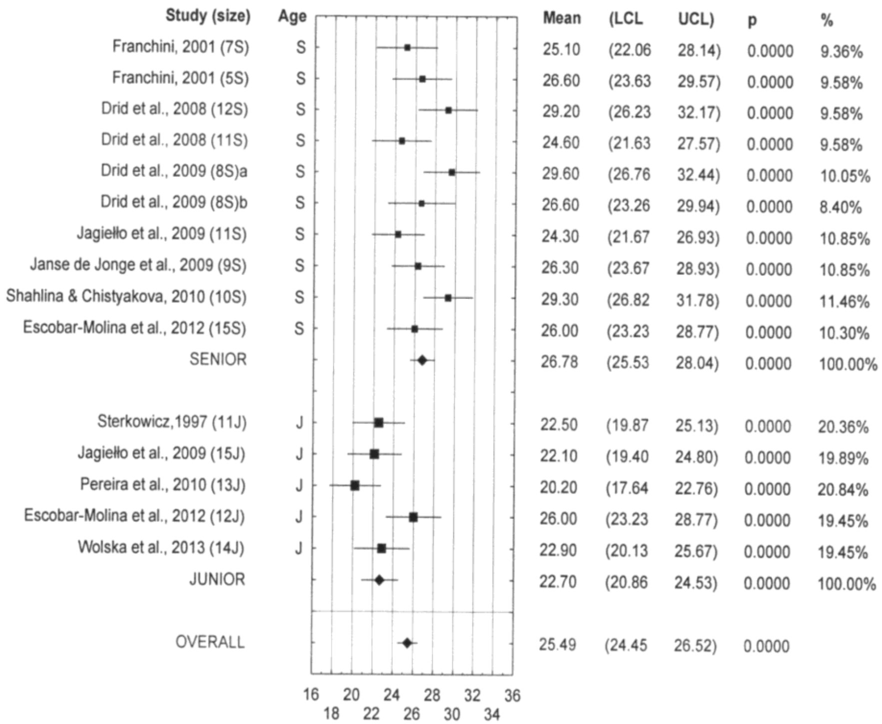

Figure 2. Meta-analysis for Total throws performed by female athletes [17, 41-49] in the SJFT (markers represent mean values and error bars representing 95% confidence intervals). Note: a-team A, b-team B.

Table 11. Results of the Special Judo Fitness Test variables in senior and junior male and female judo athletes in mean (SD)

	Female J	Female S	Male J	Male S
Total Throws (rep)	23 (2)	27 (2)	24 (2)	26 (2)
HR final (bpm)	183 (10)	180 (8)	185 (10)	181 (9)
HR 1 min recovery (bpm)	150 (13)	149 (12)	152 (12)	152 (13)
Index	14.85 (1.56)	12.45 (1.27)	14.11 (1.52)	12.94 (1.51)

Note: J – junior (U20); S–senior (20 and older).

When examined by age, the Total throws variable was significantly different between senior and junior categories for both women (Figure 2) and men (Figure3).

The forest plot displaying the female data (Figure 2) illustrates better performance in senior [26.78 reps (95% CL: 25.53-28.04)] versus junior athletes [22.70 reps (95% CL: 20.86-24.53)] and the calculated effect size between the age groups was large (Cohen's d = 2.00). The forest plot displaying the male data (Figure 3) also showed better performance in senior [26.30 reps (95% CL: 26.61-26.98)] compared to junior athletes [24.44 reps (95% CL: 23.65-25.22)] and the calculated effect size was large (Cohen's d = 0.81). Subsequently, all four SJFT variables in senior and junior female and male judo athletes were characterized (Table 11).

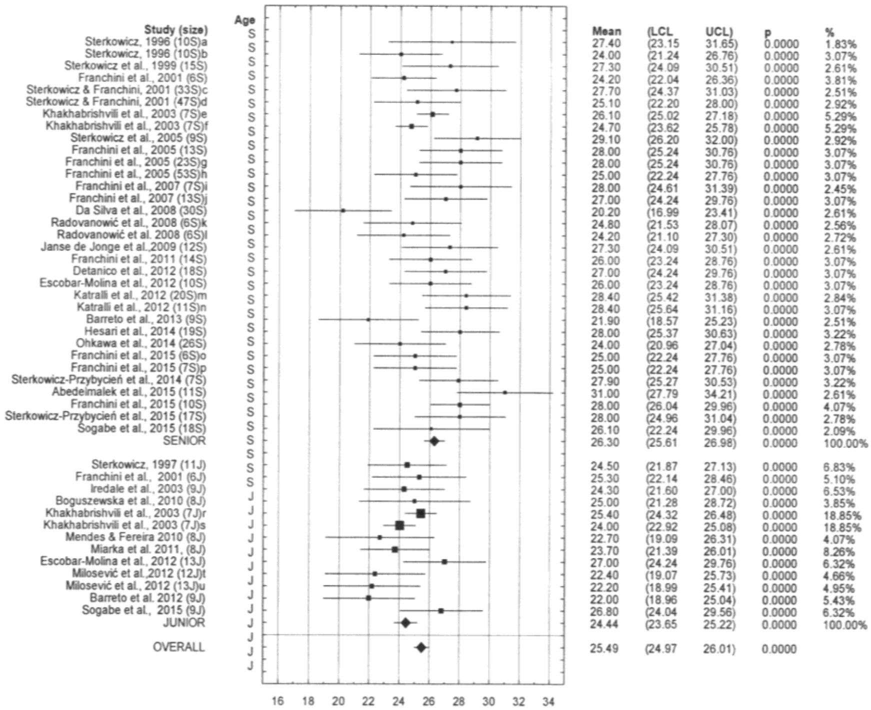

Figure 3. Meta-analysis for Total throws performed by male athletes [18, 21, 22, 24, 27, 36, 37, 38, 40, 44, 47, 48, 50-68] in the SJFT (markers represent mean values and error bars representing 95% confidence intervals). Note: a- Polish Championships medal winners, b- Polish Championships non medal winners; c- elite, d- novice; e- Georgian team, f- Polish team; g- elite, h- non elite; i- Brazilian team A, j- Brazilian team B & C; k- creatine group, l- placebo; m-to 5 years of experience; n- more than 5 years of experience; o- linear, p- undulating strength training; r- Georgian junior team, s- Polish junior team; t- junior, u- cadet.

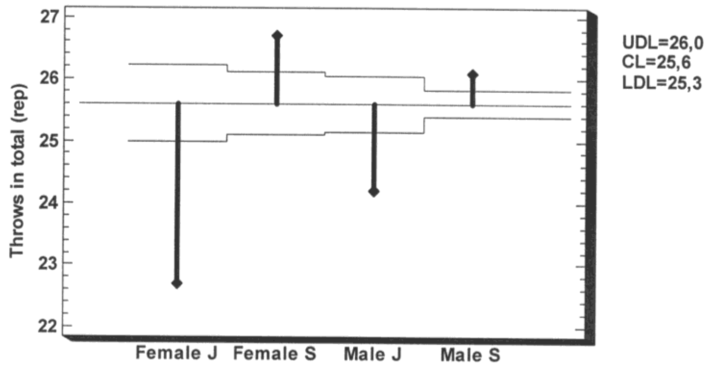

Figure 4. Analysis of mean Total throws with 95% decision limits for junior (J) and senior (S) female and male judo athletes. UDL – upper decision limits; LDL – lower decision limits, CL – central line = grand mean.

The mean values for Total throws were significantly heterogeneous between age and gender groups ($F_{3,\ 787} = 63.88$, $p < 0.001$, $\eta^2 = 0.196$ [large effect]). Multiple range test results (95% Games-Howell) demonstrated differences between Female Junior and Female Senior (-4.0 $\pm$ 0.821 reps), Female Junior and Male Junior (-1.5 $\pm$ 0.676 reps), Female Junior and Male Senior (-3.4, 0.828 reps), Female Senior and Male Junior (2.5 $\pm$ 0.612 reps), and Male Junior and Male Senior groups (-1.9 $\pm$ 0.622 reps). However, similar values were found for Female Senior and Male Senior groups (0.6 $\pm$ 0.777 reps). The ANOM plot shown in Figure 4 shows the difference in Total throws for the age and gender groups in reference to the grand mean (Figure 4).

When compared to the grand mean, the senior groups revealed significantly greater [above the upper decision limit (UDL)] and the junior groups significantly fewer [below the lower decision limit (LDL)] Total throws. These findings confirm the necessity of separate evaluation of junior and senior athletes within gender groups.

HRfinal, measured directly after the SJFT, was significantly different between groups ($F_{3,\ 787} = 8.94$, $p < 0.001$, $\eta^2 = 0.033$, [small]). Multiple range test results showed significant differences between the Female Junior and Female Senior (3.2 $\pm$ 2.435 bpm), Female Senior and Male Junior (-5.4 $\pm$ 3.437 bpm), and Male Junior and Male Senior groups (4.5 $\pm$ 3.976 bpm). HR final in the Female Senior, Male Senior, and Female Junior groups, as well in the Female Junior and Male Junior groups, were similar. The ANOM plot shown in Figure 5 illustrates that HR final in the Male Junior group was significantly higher than the grand mean.

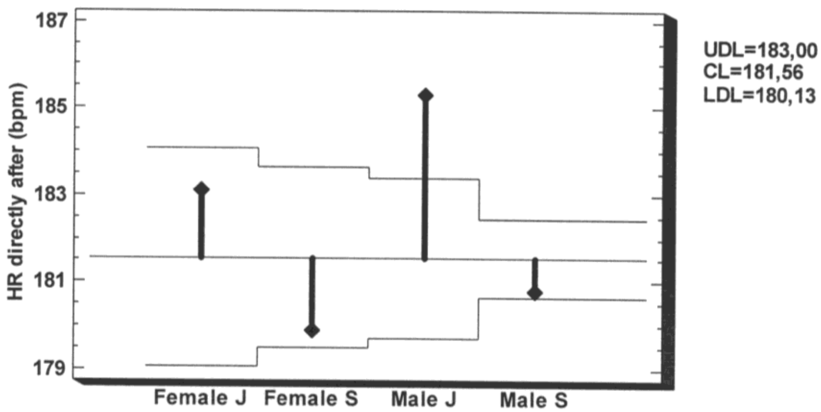

Figure 5. Analysis of mean HR final with 95% decision limits for junior (J) and senior (S) female and male judo athletes. UDL – upper decision limits; LDL – lower decision limits, CL – central line = grand mean.

The mean HR 1 min after the SJFT were not significantly different between groups ($F_{3,\ 787} = 1.65$, $p = 0.177$, $\eta^2 = 0.006$ [negligible]). The difference between pairs of groups ranged from -3.2 to 1.8 bpm. The ANOM plot shown in Figure 6 displays the lack of differences between each group and the grand mean.

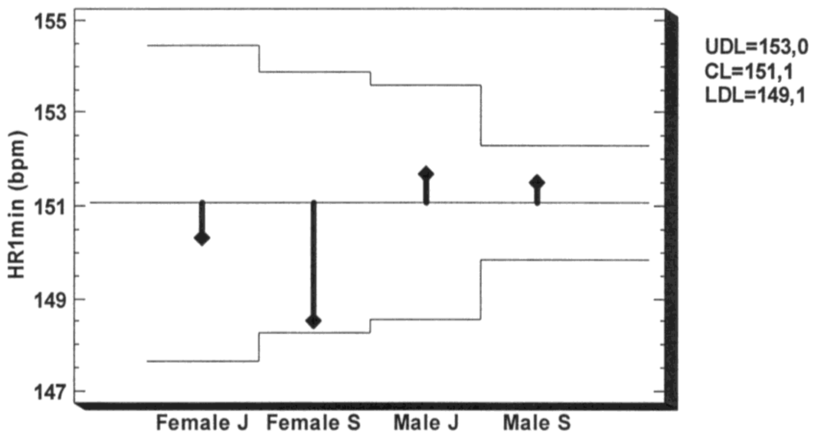

Figure 6. Analysis of mean HR 1 min after with 95% decision limits for junior (J) and senior (S) female and male judo athletes. UDL – upper decision limits; LDL – lower decision limits, CL – central line = grand mean.

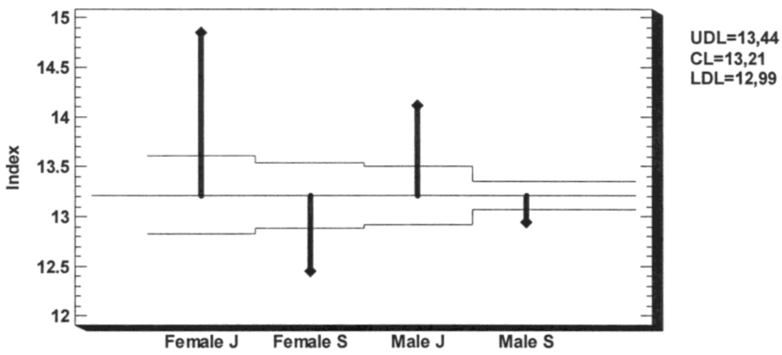

Figure 7. Analysis of mean Index values with 95% decision limits for junior (J) and senior (S) female and male judo athletes. UDL – upper decision limits; LDL – lower decision limits, CL – central line = grand mean.

The SJFT index was significantly different between groups ($F_{3,\ 787}$ = 54.83, $p < 0.001$, $\eta^2 = 0.173$ [large]). The multiple range tests (95% Games-Howell) identified significant differences between the Female Junior and Female Senior (2.40 $\pm$ 0.379), Female Junior and Male Junior (0.74 $\pm$ 0.492), Female Junior and Male Senior (1.91 $\pm$ 0.607), Female Senior and Male Junior (-1.66 $\pm$ 0.400), and Male Junior and Male Senior groups (1.17 $\pm$ 0.619). No difference between the Female Senior and Male Senior groups (-0.49 $\pm$ 0.537) was identified because this interval included "0". Differences for all groups compared to the grand mean are clearly exhibited on ANOM plot shown in Figure 7.

CONCLUSION

The intention of writing this chapter was to synthesize the available literature using the SJFT as both an experimental measure and a training tool. Due to possible redundancy, some results presented in previous reviews [8, 69] (were omitted or reinterpreted). The main practical conclusion is the need for standardization of conditions when administering the SJFT, including the warm-up, selection of testing partners from the same weight category, consumption of ergogenic aids, time of day, and other environmental factors. Furthermore, the need for the development and use of age and gender-specific normative values in the evaluation of judo athletes has been clearly demonstrated. In the last seven years, classificatory tables for males and females [8, 10] have become available. Although these tables can be used to evaluate judo athletes, weight category-based tables for each sex are lacking. The understanding of the best moment to apply the SJFT in a typical judo training week is also relevant and should be tested systematically. Nonetheless, due to its relative simplicity, ecological validity, and sensitivity to intervention, the SJFT presents a unique method of sport-specific evaluation that can be used by judo practitioners from varying demographic backgrounds and skill levels.

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Chapter 8

INJURY PREVALENCE IN JUDO: AN UPDATE

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ABSTRACT

In terms of judo science and practice, injury could be defined as "damage that affects a part of the body and results in an inability to practice or compete normally". Injury risk in elite judo athletes is average when compared to the other Olympic sports. However, concerning time loss injuries, judo is ranked second among combat sports at the previous two Olympic Games. Regarding the body region, injuries occur mostly in the upper and lower extremities, with the highest percentage of shoulder and hand/finger injuries in the upper, and knee injuries in the lower extremities. Head and neck injuries have a low incidence in judo compared to lower and upper limb injuries. Despite the low number of occurrences, these are potentially the most harmful injuries. Injury prevalence in judo, through review of published data, indicates that it is necessary to establish a long-term injury surveillance system in order to minimize injury incidence and time loss injuries. Knowledge about injury risk, severity, localization, type, and mechanism of injuries during training and competition is the first step towards adequate injury prevention and specific educational and preventive measures. Moreover, technical development, rule change, change in technique and tactics, and improvement of sports equipment can decrease potential injury risk.

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Keywords: injury, injury risk, time loss injuries, injury prevention

INTRODUCTION

Injury is commonly defined as "hurt, damage or loss sustained" [1]. In sports there is a lack of consensus about injury definition and injury grade, so it was not possible to adopt a standardized definition [2]. The main doubt is whether injury includes any request for medical assistance or those situations that result in withdrawal from training or competition. From our point of view the most suitable definition is "damage that affects a part of the body and results in an inability to practice or compete normally" [3]. Regardless of injury definition problems, long-term surveillance of injuries will help to create injury prevention programs and protect the athletes' health [4].

In the field of combat sports, the aim is symbolic destruction of your opponent. Judo is a martial art and combat sport in which you defeat your opponent by throwing him on the ground or by utilizing some of the control techniques (pin, choke, or arm lock). When we take into consideration that injury rates are higher in sports that include body contact [5], it is very important to reveal the injury mechanism and suggest prevention methods and/or rules change. Modern sport rules are designed to make competitors safe and to minimize the possibility of sustaining an injury. The Medical Commission of the International Judo Federation has prohibited the number of original judo techniques (*kawazu gake*, *kani basami*, *do jime*) and other actions (any action that may endanger or injure the opponent, especially the opponent's neck or spinal vertebrae) that expose contestants to the risk of being injured. All these actions are penalized with *hansoku make* – the direct disqualification– because they may cause severe injuries to contestants. There are also slight infringements of rules that are related to injury prevention, for example: to put a hand, arm, foot, or leg directly on the opponent's face; to apply leg scissors to the opponent's trunk (*Do jime*), neck, or head; and to bend back the opponent's finger(s) in order to break his grip. These actions are penalized with a shido (warning) because they cannot cause severe injuries. A competitor is allowed to receive three *shido* penalties during the fight. A fourth *shido* results in disqualification [6].

Injury risk in elite judo athletes is average when compared to the other Olympic sports (11.75% in judo, 11.25% in all sports). When we consider only the combat sports at the previous two Olympic Games, taekwondo had the highest percentage of injured athletes (33.05%), followed by boxing (12.05%), judo (11.75%), and wrestling (10.7%). These data imply that striking sports had a higher percentage of registered injuries than grappling sports. The ranking by sport concerning time loss injuries is slightly different, putting judo in the second place among combat sports at the Olympics (taekwondo 12.1%, judo 7.6%, boxing 5.85%, and wrestling 5.5%) [7, 8]. In contrast, judo is ranked highly among the most dangerous sports at Youth Olympic Festivals: ranked 1st at the 2nd Summer Youth Olympic Games (2014) in Nanjing (China) and 4th at the European Youth Olympic Festival 2013 in Utrecht (the Netherlands) [9, 10]. Also, relatively high injury risk (15.5%) was found in 2012 Paralympics, which ranked judo 7th among 21 sports [11].

Knowledge about injury risk, severity, localization, and type of injuries during training and competition is the first step towards adequate injury prevention. The next most important step is to reveal the injury mechanism. By knowing the injury mechanism we can create sport specific educational and preventive measures. Factors such as technical development, rule change, change in technique and tactics, and improvement of sports equipment (tatami, judogi, etc.) can influence potential injury risk. It is necessary to establish a long-term injury surveillance system because of the evolving nature of sports.

INJURY LOCATION

Regarding the body region, we can see that injuries occur mostly in the upper and lower extremities (body) (Table 1), with the highest percentage of shoulder and hand/finger injuries in the upper, and knee injuries in the lower extremities. From retrospective studies that followed injury location in adult judokas, it is clear that the biggest share of injuries occur in the knees (up to 26.36%), shoulders (up to 25.53%), and fingers (up to 21.83%) [3, 12]. Knee and shoulder injuries are usually sustained while executing or receiving a throw [3, 13]. It seems that Seoinage technique puts a judoka at high risk of getting injured, acquiring a knee sprain while executing the throw and different shoulder injuries while receiving the throw [2].

One of the main goals of a judo fight is to throw your opponent, so main attention should be paid to these potential risk situations. On average there are 6-7 quality throw attempts during a fight. In these situations *tori* puts *uke* totally out of balance [14-16]**.** This is the reason why beginners should not engage in randori (training fight) or competition before they properly learn *ukemi* in order to minimize injury risk. Finger injuries are associated with grip fighting as a potential injury mechanism [17, 18]. Grip fighting is an important part of the fight since the judoka with better kumikata has an advantage during both offensive and defensive maneuvers. High level senior competitors spend more time on kumikata fighting compared to beginners [19] and youths [16]**.** Finger injuries usually affect competitors from lower weight categories and the expected recovery time is less than seven days [20]**.**

Statistically significant differences between men and women in the number of injuries were not reported [5, 12, 20]. In children, knee injury was ranked 6th overall, which is encouraging when we consider complications that are associated with this type of injury. At this age measures should be taken to prevent shoulder/upper arm, foot/ankle, and elbow/lower arm injuries [21].

In a study based on Finland's national sports injury insurance registry data, it was found that around 70% of injuries occurred during training [5], which was in accordance with the results of [12]. As opposed to these data, there were studies claiming competition injuries are more common in judo (ranging from 49% up to 59%) [22, 23]. Findings differ due to a variety of procedures used for data collecting (questionnaires, hospital records, insurance claims, etc.). While questionnaires are affected by memory bias, hospital records and insurance registries usually exclude soft (minor) injuries.

Table 1. Injury location

	Keun-Suh Kim et al. 2015 [20]	**José A. Pérez-Turpínet al. 2013 [3]**	**Barsottini et al. 2006 [12]**	**Souza et al. 2006 [23]**
Head	/	/	1.00	0.91
Neck	5.6	/	/	/
Trunk	23.4	6.39	12.00	4.55
Shoulder	10.2	25.53	16.00	21.82
Elbow	7.5	10.64	3.00	/
Hand/fingers	10.7	8.51	14.00	21.83
Thigh	7.0	6.38		5.45
Knee	9.7	23.40	23.00	26.36
Ankle	8.4	14.89	14.00	10.00
Foot	5.6	4.26	12.00	3.64
Other	12.9	/	5.00	5.46

TIME LOSS INJURIES

Time loss injuries are defined as injuries that produce absence from training or competition for at least one day. Judo is not in a group of high risk sports for sustaining time loss injury at the Olympic Games [7, 8], thus there were 6.4 and 8.9% of judokas with time loss injuries at the Beijing and London Olympics [2]. Likewise, no gender differences were found [7, 8, 24]. Over 2/3 of injuries occurred during competition [5, 7, 8, 22], while only one study found that 70% of injuries happened during training [12]. In some studies it was not clearly pointed out [5, 21], but judging by the method of data collection (insurance and hospital records), we assume that the injuries were time loss.

Injury risk for 1000 athletes' exposures is often used in the literature. Different data were found for time loss injuries: 18.9/1000 A-Es male, 10.3/1000 A-Es female ([24]); 4.85/1000 A-Es male and 13.70/1000 A-Es female [25]. Concerning age, the highest injury risk was found for the age between 20 and 24 [5]. This is the period when a judoka starts the senior career and when the intensity of training and competition usually increases. It seems that a judoka's level manifested by the color of his belt does not influence injury risk [24]. More studies are needed to confirm this hypothesis.

Knee injuries had the highest share of time loss injuries, followed by shoulder injuries [5, 12, 22]. Mean absence from training and competition ranges from 1-7 days at the Olympics (5.7% of competitors received an injury with this level of severity) to 21-29 days during national level competitions [2].

SEVERE HEAD AND NECK INJURIES

Incidence

Head and neck injuries have a low incidence in judo (from 0 up to 6% of all injuries) compared to lower and upper limb injuries [3, 20, 26]. Despite the low incidence, these are potentially the most harmful injuries. There is a lack of precise estimation of the number of catastrophic injuries in judo. Most of the cases reported come from Japan, the homeland of judo, with approximately 200,000 registered judokas [27-29]. In the period between 2003 and 2010, 49 severe head and neck injuries were reported to All Japan Judo Federation through the System for Compensation for Loss or Damage. Incidence of head injuries varied from 0.98 per 100,000 athletes per year in 2004 and 2006, to 3.21 per 100,000 athletes per year in 2009. On average there were 1.96 severe head injuries per 100,000 athletes per year. A lower incidence was registered for severe neck injuries. The highest incidence was reported in 2007 (3.02 per 100,000 athletes), while in 2010 there were no reported cases. On average there were 1.20 severe neck injuries per 100,000 athletes per year. The fatal outcome was registered in 15 cases. Only 4 (13%) athletes with a head injury and 5(26%) with a neck injury fully recovered [29].

Head Injuries (Acute Subdural Hematoma)

Acute subdural hematoma is the leading cause of death and severe morbidity in judo [28-31], boxing [32, 33], and American football [34, 35]. It is "a hematoma that occurs between the dura mater and arachnoid in the subdural space and that may apply neurologically significant pressure to the cerebral cortex" [36]. The main cause of acute subdural hematoma in judo is the rupture of a bridging vein due to impact of the athlete's head against the mat (*tatami*) [28]. Important signs of a possible acute subdural hematoma are loss of consciousness, headache, visual disturbance, and convulsive seizures [35]. Being thrown is the most common injury mechanism (90%), whereby a particularly dangerous situation was receiving the *osoto gari* throw with 42.86%, followed by *seoi nage* (14.29%), *ouchi gari*, *tai otoshi*, and *harai goshi* with 9.52%. It is important to highlight the fact that 90% of the athletes were under 20 years old, among whom 60% were novice judo players with a white belt, currently in their first year of junior high school or first year of high school [29].

Mastering *ukemi*, the art of safe falls, seems to be the most important part of preventing severe head injuries. Novice judo players must learn proper *ukemi* before engaging in a *randori*. The fact that upper limb contact with *tatami* greatly influences deceleration during the fall should be emphasized by the coach [37]. The data on proposed under-mat installation in order to reduce the impact forces to the head during the throw [27] still remain unclear [30], so it cannot be recommended.

Neck Injuries

The probability of sustaining a neck injury during a judo fight is relatively low (as mentioned above, in Japan there are 1.20 severe neck injuries per 100,000 athletes per year). There are prospective and retrospective studies that did not register any neck injuries [12, 23]. Still, the severity and consequences of neck injuries demand a more detailed insight into the mechanism and type of neck injuries. In the study based on accident reports submitted to the All Japan Judo Federation there were a total of 19 severe neck injuries registered between 2003 and 2010 [29].The outcome was complete paralysis in 7 cases (37%) and incomplete paralysis in 7 (37%).

As opposed to head injuries, most neck injuries were sustained by *tori* during an execution of a throw attempt (12 cases, 63%). In other 7 cases (37%) *uke* was injured while being thrown on the *tatami*, from which 3 cases included the *seoi nage* throw. In addition, while head injuries are more prominent in young novice judo players, severe neck injuries seem to occur in more experienced judo players. Caution is needed while executing the *uchi mata* throw, because it was the most common injury mechanism (37%) [29]. We speculate that hyperflexion of the cervical spine occurs when the *uchi mata* throw is poorly executed due to a technical error of *tori* or *uke's* defensive movements.

SHIME WAZA AND UDE KANSETSU WAZA CONCERNS

The win in a judo match can be obtained by applying the *shime waza* (chocking techniques). Following the strict rules, the choke is applied on the side of the neck or trachea of the opponent. It is important that during the pressure on the neck there is no displacement of the spine, which could lead to a serious injury. By pressuring the neck *tori* applies the pressure to the carotid sinus, which slows down the heart rate to that the point where the blood pressure cannot supply the brain with a sufficient amount of blood. This mechanism makes *uke* become unconscious. When *tori* stops the pressure, the heart rate increases and *uke* wakes up [38]. *Uke* usually submits before losing consciousness. No deaths have been reported in national or international tournaments. In general, caution is needed because prolonged pressure and interruption of the blood flow could lead to brain damage or even death. There are no data showing chronic brain damage resulting from choking throughout the judokas career [2].

Ude kansetsu waza is an elbow joint lock group of techniques. By producing hyper extension in the elbow joint and/or by wrenching it, *tori* forces *uke* to surrender and ultimately gains the win by *ippon* [39]. Judo had a highest number (6) of elbow injuries at the previous Olympic Games in London 2012. Injuries accrued during the application of an arm lock, causing severe valgus stress and significant injury to the Ulnar Collateral Ligament [40]. We hypothesize that the importance of the event influenced judokas to try to withstand the pain that joint lock produces, which ultimately led to an injury. When we take into consideration that there were 383 athletes competing in the Olympic judo tournament and that one of the main ways of achieving victory is through an arm lock, the number of elbow injuries is not alarming. Nevertheless, athletes should be informed about higher injury risk prior to an important competition.

ANTERIOR CRUCIATE LIGAMENT INJURY

According to the Medical Subject Headings (MeSH), Anterior Cruciate Ligament (ACL) is defined as "[a] strong ligament of the knee that originates from the posteromedial portion of the lateral condyle of the femur, passes anteriorly and inferiorly between the condyles, and attaches to the depression in front of the intercondylar eminence of the tibia". ACL has a decisive role in knee stabilization, so ACL deficiency will cause knee instability. Prolonged deficiency and avoidance of rebuilding the anterior cruciate ligament to restore functional stability of the knee can even lead to cartilage lesions and meniscal tears [41]. If surgery is necessary, it is recommended to undergo an ACL reconstruction one month after the injury [42], but only in case that the patient is mentally prepared and that full range of motion is restored while effusion and pain are kept to a minimum [41].

Out of all cases of ACL rupture injuries, 77.68% occur during sports activities, 8.82% occur in everyday accidents, 4.66% in traffic accidents, and 8.84% occur due to other factors. A retrospective study based on institutional documents detected 4,355 cases in the period between 1993 and 2007. In the athlete group, judo (n=589) was ranked third with 12% of the share, after football (18.51%) and basketball (18%) [43]. One retrospective study based on questionnaires where the sample consisted of 260 German judokas showed that 60.8% of the judokas suffered at least one serious knee injury in their career [44].

Table 2. Caution

Caution!
Kenkayotsu grip style
Being attacked with osotogari, kosotogari (gake), haraigoshi, kouchigari (gake)
Attempting tai otoshi
Being countered with uranage, kosotogari (gake)

Around 79% of ACL injuries in judo were caused by direct contact with the opponent. It is claimed that competitors engaged in *kenka yotsu kumikata* are more likely to suffer ACL rupture compared to those in *ai yotsu* [45]. These findings are expected, because the kenkayoutsu gripping style is far more often used during fights [15], almost twice as often in heavyweights (43.72% *kenka yotsu*, 22.11% *ai yotsu*) [14].

Being attacked is potentially the most dangerous situation (67%), especially if the opponent is attacking with *osoto gari*, *kosoto gari* (*gake*), *kouchi gari* (*gake)*, or *harai goshi*. The first three techniques are classified as leg techniques, while *harai goshi* belongs to hip techniques [46]. They all share a common principle. *Tori* uses his body movement and good gripping to apply force and burden the supporting leg of *uke*. Execution is made by sweeping out the supporting leg [39]. Caution is needed when the adversary uses *ura nage* and *kosoto gari* (*gake*) to counter your offensive move (Table 2). It is also recommended to avoid full or almost full leg stretch during your own *tai otoshi* attack because it puts your leg in a highly vulnerable position [45]. This is in accordance with the results of Prill et al. [44]. They claimed that *tai otoshi* could be the most dangerous technique, considering the number of situations where *tai otoshi* is used. They also pointed out *uchi mata* as a risk factor for ACL rupture. Thus, the authors recommend to judokas with a propensity for knee injuries to avoid these techniques and specialize in hip techniques, which are much safer.

Prevention of ACL injury

The first step is to create a judo specific ACL injury awareness programme. This programme may help to improve the knowledge of coaches and athletes to recognize and avoid potential situations of high risk of ACL injury in judo. This kind of programme has already had positive influence on reducing ACL injury occurrence in highly skilled alpine skiers [47].

Tamalet and Rochcongar [48] suggest considering the following principles for prevention:

- increase strength of hamstrings;
- improve neuromuscular control by a suitable warm-up for increasing neuromuscular activation;
- avoid fatigue alteration of control capabilities;
- correct positioning of the lower limb (the attention will be particularly focused on the quality of movement).

They recommend a multi-component programme that will include plyometrics, neuromuscular programming (quality dynamic stability, body awareness, anticipation of movement, core-training), and stretching and strengthening of the hamstrings. Such injury prevention routine was created by an international group of experts and named FIFA 11+. The aim was to reduce injuries among male and female football players aged 14 and older. Scientific evidence [49-51] showed significantly lower injury incidence in the teams that performed the routine as a standard warm-up at the start of the training session at least twice a week.

In judo, a possible lower limb primary injury prevention programme “Judo 9+” was proposed by Malliaropoulos, Callan and Johnson [52]. It is a warm up routine consisting of 9 sport-specific exercises aimed at improving balance, core stability, and dynamic stabilization. It is necessary to conduct the Randomized Control Trials to gain scientific evidence in order to recommend the programme implementation.

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Chapter 9

ANAEROBIC CAPACITIES FOR ELITE PERFORMANCE IN TAEKWONDO

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ABSTRACT

Taekwondo is from a global perspective one of the most popular sports in the world, judging by the number of practicing athletes. The conclusion of numerous research studies that have been conducted is that the high level of motor and functional skills, with emphasis on speed and anaerobic capacities, is essential for success. Despite their great popularity, scientific databases rarely contain articles dealing with validated specific measuring instruments for detecting the level of anaerobic capacity in the domain of taekwondo; rather they utilize non-specific tests for this purpose, which we will review in this chapter, among other topics. In practical use, the tests implementing the diagnostics of energy capacities are divided in the following manner: with regard to the place of testing – into laboratory and field tests, and with regard to their type – into specific and non-specific. With regard to the type of stress, they are divided into fixed and progressive stress tests, and

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with regard to the manner of execution into continuous and discontinuous tests. Anaerobic energy capacity-endurance is the ability to resist fatigue during dynamic activities of submaximal or maximum intensity. Anaerobic energy capacities can be divided into anaerobic-alactate and anaerobic-lactate capacity. In order to develop specific endurance of taekwondoathletes, two methods can be utilized: intensive interval method and maximum interval method. Considering the planning and dimensioning methodology of the fitness training process in the light of improvement of specific anaerobic capacities of taekwondo athletes, it is important to pay attention to the basic, specific and situational preparation period of taekwondo athletes, as well as to the endurance training plan during the microcycle. The choice of diagnostic tests and methods to be applied is left to the coaches who need to take into account numerous factors when making their choice, such as age and number of athletes, financial capabilities, level of fitness, the timing of testing in the annual curriculum, as well as the level of informedness of the members of the coaching staff. The presented set of tests is certainly not a definitive list of tests used, because a list of all tests is neither possible nor necessary to make, seeing as the idea of this paper was to inform us of the possibilities we have at our disposal for the diagnosis and improvement of anaerobic capacities of taekwondo athletes.

Keywords: functional diagnostics, endurance, functional training, fatigue, martial art, combat sport, taekwondo

INTRODUCTION

Kinesiology as a science that studies, among other things, the principles governing the process of exercise and the consequences for the human body resulting from these, should provide answers to many questions that may be helpful in understanding the dominant principles of a particular sport [1]. Connection of sports activity and success in sports with certain human characteristics is of particular interest to kinesiology. This applies especially to motor and functional abilities and morphological characteristics, since they are largely responsible for the proper mastering and implementation of various movement structures [2]. To achieve top results in a sport, it is necessary to have at one’s disposal scientific knowledge about the character of the sport itself, as well as the influence of certain factors on success in that sport. Scientific approach entails thorough and successive monitoring and verification of athletes’ complete anthropological status through all the stages of their sports career. The most commonly tested segments of anthropological status are motor and functional abilities and morphological characteristics of an athlete.

This is because the measuring instruments for evaluation of these characteristics have satisfactory metric characteristics, so the results obtained are also exact and interpretable, and are of great importance for success in almost every sport [3]. Combat sports are, globally, one of the most popular and fastest growing groups of sports in the world and striking combat sports hold a significant position within that group [4]. Out of the total of 25 permanent "core" sports included in the program of the Summer Olympic Games, four are combat sports, two out of which belong to the family of striking combat sports (taekwondo and boxing) [5]. Approximately 25% of all medals in the Summer Olympics go to athletes in combat sports. In addition to the striking combat sports included in the Olympic Games program (taekwondo and boxing), the “non-olympic” sports of karate and kickboxing are widespread and globally popular sports and serious candidates for inclusion in the Olympic Games program (karate, 2020) which unite a large number of athletes from all continents within their umbrella World Federations [6]. The World taekwondo Federation is one of the biggest organizations in the world according to the number of members, with as many as 207 member countries. Many conducted studies concluded that a high level of motor and functional abilities, with emphasis on speed and anaerobic capacities, is essential for success in karate [7-10], taekwondo [11, 12, 13], as well as kickboxing [15, 16, 17].

Despite great popularity of combat sports, primarily thanks to the amateur approach together with modest cash outlays for scientific research, as well as the complexity of their implementation, we agree with the conclusions that the implementation of high-quality studies of the connection and influence of anthropological characteristics on performance is more of an exception than a rule in the field of striking combat sports, and therefore we were unable to find papers in which specific measuring instruments for detecting the level of anaerobic capacity in the field of striking combat sports were constructed and validated in the relevant scientific databases, so various *non-specific* tests, which we will, among others, address in this text, are used for that purpose instead [18, 19, 20]. The limitation in the application of these tests for the purpose of detection of the level of anaerobic capacities in the field of striking combat sports including taekwondo is found in the diversity and non-specificity of movement structures such as running or jumping, which are significantly different from the movement structures characteristic of striking combat sports.

The second but no less important limitation is the lack of results of metric characteristics verification on the sample of examinees practicing striking combat sports stratified by sport, sex and age, as well as the reference tables with the results sorted by age, sex and weight category.

Diagnostics represent a series of procedures which determine individual characteristics of an examinee by testing key abilities and qualities, with the aim of evaluating distinctive morphological characteristics, the state of motor and functional abilities and the level of specific characteristics of an individual.

In order to develop sports diagnostic systems and measuring instruments for evaluation of anaerobic capacities essential for achievement of top results in taekwondo, it is necessary to have at one’s disposal scientific knowledge about the character of the sport itself, as well as the influence of certain factors on success in that sport.

FUNCTIONAL ANALYSIS OF TAEKWONDO

Movement structures involving the use of foot and hand techniques, feinting, hopping in a fighting position (guard), linear and lateral movement in the arena, and moving in a circle [18], as well as the dynamics and ratios of rest and fight durations are the characteristics which, with minor deviations, connect and characterize striking combat sports [21, 22]. Taekwondo is a polystructural acyclic sport dominated by swift techniques of kicks to the body and head of the opponent. The duration of a fight is 3 x 2 minutes with 30 seconds’ rest between rounds. At a competition, the most successful taekwondo athletes find themselves participating in 5 or more fights a day. Next to basic aerobic endurance, anaerobic endurance represents the dominant type of endurance essential for achievement of successful results in taekwondo. We can divide anaerobic endurance into glycolytic and phosphagen types. In both cases, energy is obtained without the presence of oxygen.

Due to the limited supply of ATP in the organism, the phosphagen component uses ATP and has a short duration (up to 15 sec) and the glycolytic one (30-120 sec) includes glycogen breakdown and muscle acidification. In a taekwondo fight, there are no constant activities lasting 30 seconds or longer; however, due to frequent intervals featuring high-intensity activities, the fight takes place in the glycolytic zone, but at the same time the glycolysis is not deep.

We need general and specific anaerobic endurance to get through the fight without losing speed and reaction time. Recent research indicates that the lactate level during the activity does not exceed 12-14 mmol/l. An analysis of recorded fights has shown that taekwondo is characterized by the exchange of intervals of high-intensity activity lasting 3-5 seconds and low-intensity periods at a ratio of 1:3 to 1:4.

DIAGNOSTICS OF ENDURANCE OR ENERGY CAPACITIES

Endurance diagnostics is performed as an initial, transitive and final measurement during the training process with the aim of determining the efficiency of aerobic and anaerobic functional mechanisms or controlling the effects achieved through programmed training.

It is an essential part of the integral conditioning system which includes diagnosis, prognosis, analysis and control of the state of a taekwondo athlete's fitness level in the annual work cycle as well as throughout their long sports career. In practice, there is a large number of standardized tests to evaluate fitness and endurance of athletes, and an even larger number of variations of those tests. The tests can be divided into more expensive and precise laboratory tests and the cheaper field tests. Each test has its advantages and disadvantages, and therefore we should always determine which of the tests at our disposal is adequate and suitable at a particular time for a particular individual and/or group of athletes. It is also vitally important that every test has an exactly defined testing procedure and good metric characteristics (reliability, sensitivity, pragmatic and factorial validity), so that the results could be compared to the previous results either of the same athlete or other athletes.

Requirements for the development of energy capacities (aerobic and anaerobic) are known to differ between athletes in different sports, but energy capacities of athletes in the same sports also vary.

Development of individual energy capacities requires specific training operators and individually defined intensities and necessary intervals of work and recovery, defined using precise data on the current state of functional parameters.

In order to provide relevant information on the fitness level of each individual's energy capacities for the coaching staff, modern sports science achievements, and therefore the specific diagnostics of athletes' fitness, must be observed and applied.

TYPES OF DIAGNOSTIC PROCEDURES

In practical use, the tests implementing the diagnostics of energy capacities are divided in the following manner: with regard to the testing location – into laboratory and field tests, and with regard to their type – into specific and non-specific. With regard to the type of stress, they are divided into fixed and progressive stress tests and with regard to the manner of execution into continuous (without breaks between individual stress levels) or discontinuous (with breaks between individual stress levels) tests. Advances in sports diagnostic technology enable easier, cheaper and more precise laboratory and field measurements of aerobic and anaerobic energy capacities responsible for the energy supply of the body during a sports activity. Accordingly, in practice there is an increasing number of tests based on the use of technological aids such as heart rate meters, GPS systems, systems for measuring energy consumption, etc.

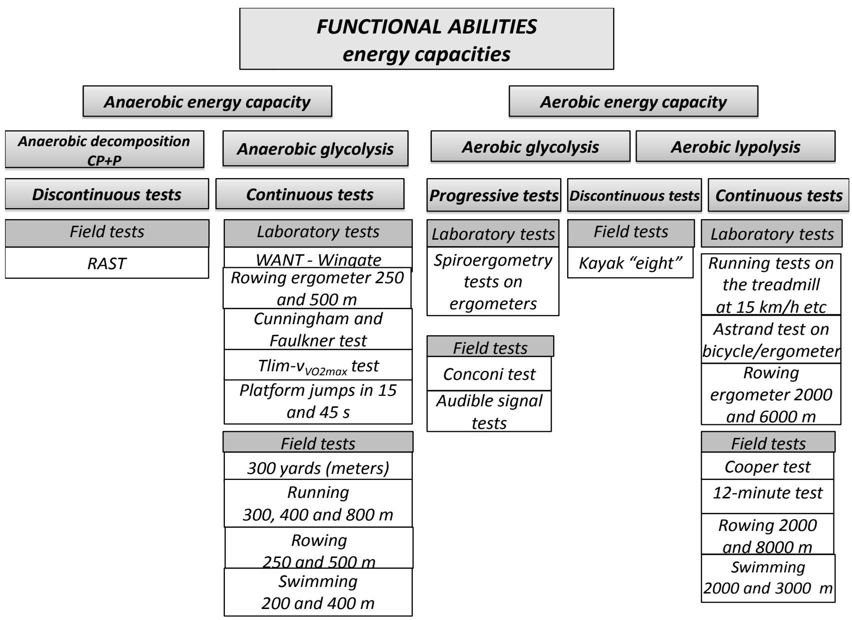


Figure 1. One of the ways of displaying energy capacity evaluation tests.

The question of the advantages and disadvantages of laboratory and field testing has been the subject of many studies and it is extremely important to be familiar with them when choosing a set of tests and performing them.

Spiroergometry Testson Ergometers

Table 1. Overview of advantages and disadvantages of laboratory and field testing

Distinctive features of testing	Field tests	Laboratory tests
Performance location	possibility of performing the tests on a sports field (+) possibility of performing the majority of tests in a hall and in an outdoor field (+) variable fields (bases) (-)	performing tests exclusively in a laboratory (+/-) always the same conditions, fields and bases for testing (+)
Time of testing	at the time of the chosen testing appointment (+/-) within the training process (the training itself) (+)	at the time of the chosen testing appointment (+/-)
Special features of testing	specific situational conditions (+)	non-specific laboratory conditions (+/-)
Standardization of testing conditions	non-standardized, variable meteorological (humidity, temperature, air pressure) conditions (-)	standardized, non-variable, meteorological (humidity, temperature, air pressure) conditions (+)
Type of measuring equipment	in most cases, no possibility of using sophisticated measuring equipment (-)	possibility of using sophisticated measuring equipment (+)
Stress dosage	variable dosage (+/-)	precise dosage (ergometers) (+)
Price of testing	depends on the type and complexity of the testing and the travel expenses and equipment transport expenses (+/-)	fixed price (+/-)

Table 1. (Continued)

Distinctive features of testing	Field tests	Laboratory tests
Duration of testing	depends on the type and number of tests the entire set of tests (anthropometry, motor skills and evaluation of aerobic capacity (e.g., “Conconi” or “Beep test”) for the entire team - one day $^{(+/-)}$	depends on the type and number of tests the entire set of tests (anthropometry, motor skills and precise evaluation of aerobic capacity (spiroergometry) for the entire team - two days $^{(+/-)}$

LEGEND:(+) - advantage; (-) - disadvantage; (+/-) - can be an advantage in some situations, a disadvantage in testing.

ANAEROBIC ENERGY CAPACITY EVALUATION TESTS

Anaerobic energy capacity (general anaerobic endurance) represents the ability to resist fatigue during dynamic activities of a sub-maximum or maximum intensity (e.g., 200, 400, 600, 800 m run). But what sets it apart from aerobic capacity is that anaerobic energy processes include the production of energy processes without the use of oxygen. Muscle glycogen and phosphocreatine are used as energy sources, and lactic acid (lactate) which, due to its high acidity lowers the blood pH and disrupts muscle function, is created as a byproduct of anaerobic (glycolytic) metabolism.

The anaerobic energy capacity is defined by the total amount of energy available for the performance of work (capacity of the organism) and maximum intensity energy release (energy rate). Anaerobic energy capacities can be divided into anaerobic-alactate capacity and anaerobic-lactate capacity.

When we talk about anaerobic capacity diagnostics, we talk about maximum stresses. They are characterized by the production of a large oxygen debt and a high concentration of blood lactate. The level of general anaerobic endurance depends primarily on the amount of anaerobic energy sources (ATP, CP and muscle glycogen), their efficient breakdown (enzyme efficiency) and buffer capacity. Aerobic capacity (the oxygen transport system) has no significant influence on general anaerobic endurance, although we can conclude that a higher aerobic capacity ensures longer periods of anaerobic stress because lactic acid decomposes with the help of oxygen (1 g of lactic acid requires about 50 ml O_2)[24].

a). Laboratory Tests for Evaluation of Anaerobic Energy Capacity, i.e., Anaerobic Endurance

Anaerobic energy capacity is defined by the total amount of energy available for performance of work (capacity of the organism) and maximum intensity energy release (energy rate). Measurement of anaerobic capacity is limited by many methodological and technical factors. Laboratory stress tests are most often conducted on a bicycle ergometer or using specific field tests and, recently, on a treadmill. There are numerous methods of evaluating anaerobic capacity, and the ones used most frequently are the so-called *critical power* method [25], MAOD – *maximal accumulated oxygen deficit* [26], measuring oxygen debt and the so-called EPOC (*'excess postexercise oxygen consumption'*). However, all of these methods require expensive equipment and specific tests so they are not often used in practice. The two laboratory tests used most often are the Wingate test and the platform jumps lasting 15 to 60 seconds.

The *Wingate test* is the best-known and the most frequently used laboratory test for measuring anaerobic capacity (anaerobic endurance).

Table 2. List of most frequently used laboratory tests for evaluation of anaerobic energy capacity

No.	Test name	Measuring unit
1	Wingate test - WANT	W
2	Jumping on a platform (Ergo jump tests lasting 15-60 s)	cm; W/kg
3	Anaerobic zone endurance in the KF1 test - meters run	m
4	Rowing on a rowing ergometer, 250 and 500 m	s
5	Treadmill running endurance time at v_{VO2max} - Tlim	s
6	Measurement of maximum oxygen debt and deficit	VO_2

The test is performed by an examinee pedalling at maximum capacity (the greatest number of rotations possible) on a bicycle ergometer with constant resistance, for a duration of 30 seconds.

The resistance (impeding force) must be strong enough for the examinee to be unable to maintain the initial maximum power (rotation speed) for longer than a few seconds. The performance on the test is quantified by the number of rotations achieved, and maximum and average power, as well as the decrease in power [27], are assessed.

The *15, 45 or 60 s jump* test, performed either on a platform or a contact mat (e.g., "Quattro jump", Kistler), evaluates anaerobic endurance and anaerobic strength during jumps [23].

An athlete performs the jumps continuously within a set time at maximum intensity, with every jump being performed from a semi-squat from the same place, with hands fixed on the hips. The result is expressed as average jump height (cm) and mechanical strength in 15, 45 or 60 s divided by athlete's body mass (W/kg).

Specific 250 and 500 m rowing tests, 300, 400 or 800 m running, 200 or 400 m swimming, 500 m kayaking or riding a bicycle on a set short route or for a set amount of time can also be performed in a laboratory on specific ergometers and/or on a field in specific conditions. The goal of all these tests is crossing the set distance in the shortest time possible, and the result is most often expressed in seconds.

As additional information for the evaluation of anaerobic capacity, maximum blood lactate concentration is measured after the test (after 1, 3 and 5 minutes of recovery). Maximum blood lactate concentration is an indirect measure of anaerobic capacity.

Anaerobic capacity can also be evaluated based on the difference between the stress intensity at the anaerobic threshold and the maximum stress reached in the progressive tests on ergometers. In that case, we are discussing anaerobic zone endurance, and the value of meters run, rowed or cycled from the moment of crossing the threshold to the moment of test termination, or the last completed stress level in a progressive test is used as a measure of anaerobic capacity.

The *T-lim* test is a test to evaluate anaerobic capacity performed only after running speed is evaluated in the progressive stress test (or another type of locomotion, rowing, cycling etc.) where an athlete reaches VO_{2max} (v_{VO2max}). After definining v_{VO2max}, the T-lim test is performed, where the athlete has to run (or row or cycle) for as long as possible at set speed and the result is expressed in running (or other type of locomotion) endurance time at v_{VO2max}.

Table 3. List of most frequently used field tests for evaluation of anaerobic energy capacity

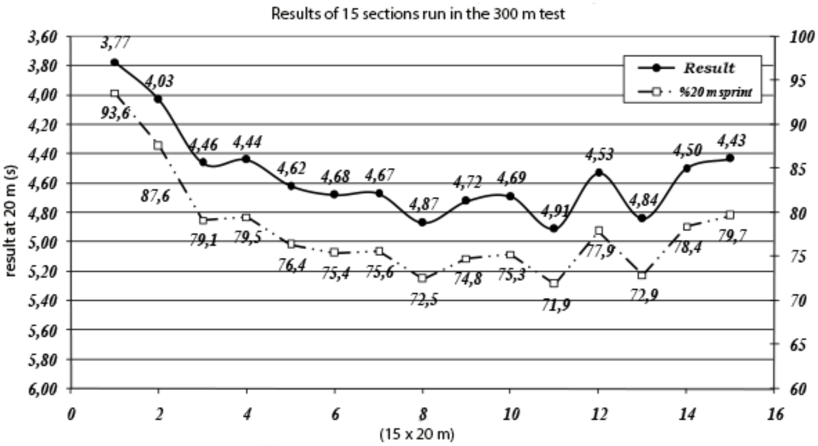
No.	Name	Measuring unit
1	300 yard (12x22,87m) or 300 m (15x20m)	sec
2	Interval sprint test (RAST)	sec
3	250 and/or 500 m rowing and kayaking test	sec
4	300, 400 or 800 m running test	sec
5	200 and/or 400 m swimming test	sec

b). Field Tests for Evaluation of Anaerobic Energy Capacity, i.e., Anaerobic Endurance

Continuous maximum field tests for evaluation of anaerobic capacity, such as the 250 and 500 m rowing and kayaking test, the 200 to 800 m running test or the 200 or 400 m swimming test, were mentioned and explained in the previous chapter. The same tests can be performed on ergometers in laboratory conditions or in gyms or in specific conditions (water, at an athletic stadium etc).

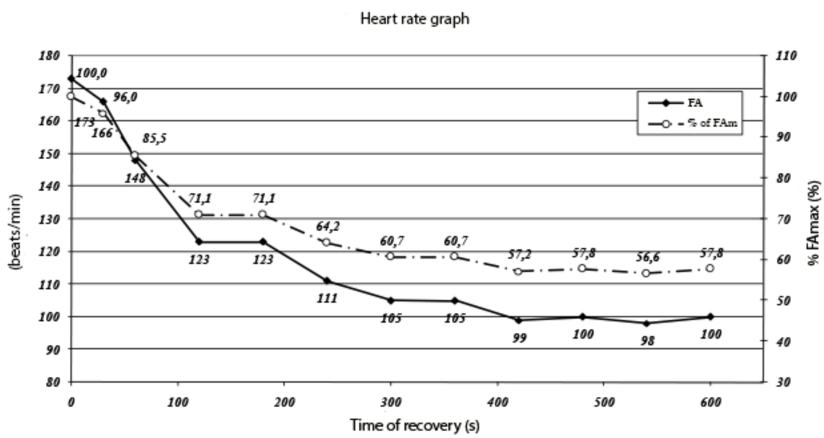
However, various modifications of *interval or continuous sprint tests* are also applied when analyzing athletes' energy capacity (speed endurance). In the most famous interval sprint test, the *RAST test* (*„Running anaerobic sprint test“*), an athlete sprints for 35 meters five to six times with a 10-second break, and the test is used to evaluate anaerobic acyclic endurance. The best and average sprint times are analyzed, as well as the decline in results through sections. The decline is a consequence of fatigue, and the lesser the decline, the better the regeneration ability. Depending on modifications (whether the sections are 10 m or 35 m long) the test lasts between 45 seconds and 1.5 minutes. During the 10 m sprint, phosphagen reserves are consumed, and the slower those reserves are consumed, the lesser the possibility of a decline in the sprint. An athlete needs a good ability of renewing phosphate reserves, and the better the renewal, the better the result.

One of the best-known tests for evaluating anaerobic capacity or speed endurance is certainly the 300 yard test and/or the European version, the 300 m test. These are tests in which the examinees run 20 m (in the 300 m test with 15 sections of 20 m each) or 22.87 m (in the 300 yard test with 12 sections of 25 yards or 22.87 m) sections consecutively, without breaks.



Legend: Results of 15 sections in the 300-m test and % of results in 20-m sprint, Results of 20-m sections (s) Sections (15 x 20 m) % of 20-m sprint (%).

Graph 1. Display of results of 15 sections run in the 300 m test and display of % of maximum result at 20 m for each section.



Legend: FA in recovery, FA (beats/min), Time of recovery (s), % famax (%).

Graph 2. Graphic display of heart rate and % of FAmax during 10 minutes recovery after the 300 m running test.

Measuring lap times is recommended for later analysis of speed declines through the section and analysis of the % of the maximum speed at 20 m run in a separate 20 m sprint test (Graph 1).During these tests, examinees bring their organism into a state of total exhaustion due to the accumulation of large amounts of lactic acid. Since players are not placed in such a situation in the game itself, this test should be applied when testing maximum anaerobic capacity and maximum blood lactate concentration and as a way of mentally strengthening the players. If a "pulse meter" is placed on an athlete during the test, stress during the test and speed of recovery after the test can also be measured (Graph 2).

DEVELOPMENT OF SPECIFIC ANAEROBIC ENDURANCE OR CAPACITY IN TAEKWONDO

It should be noted that anaerobic endurance crucial for achieving top taekwondo results cannot be developed in a short period of time and without fulfilling other health and medical conditions. It takes time for the organism to produce the desired reactions. Endurance should be developed from an early age. It is often necessary to be patient and try to increase the taekwondo athlete's endurance with a *step back*, by emphasizing the basic endurance training for increasing anaerobic capacities. In relation to achieving results fast, coaches may see it as *wasting precious time and a step back*, but an insufficiently developed anaerobic endurance level represents an obstacle we will always come up against until we overcome it. In the short term, coaches will observe that in this way we lose out on tactical or other forms of training which may decrease our fitness, but in the long term, we will encounter this problem, and it will, as we have already mentioned, limit us. Therefore it is crucial to solve the problem of the insufficiently developed specific anaerobic endurance before the taekwondo athletes' adulthood, so that, as seniors, they could focus on achieving top sports results.

A taekwondo fight requires a level of endurance which will secure a high level of speed and reaction throughout the entire individual fight as well as the entire competition. When planning and modelling the training process, we must be aware of the fact that a taekwondo competition consists of a series of fights taking place in one day. The stresses should be planned to resemble the stresses in the fight as much as possible. An athlete must reach a high level of fatigue without a decrease in ability or with the lowest possible decline of ability. A quality design of a training process must include planning of an appropriate rest period, so that the following series or round could be at the same level, without a decline in task performance speed. If excessive fatigue not fulfilling the above-mentioned conditions is noticed, the plan does not match athlete's abilities and we need to compare and revise the set goals against the realistic ones. When tired, an athlete loses coordination (one of the factors of speed) and speed (the reserves of phosphocreatine and glycogen, necessary for muscle contractions, are spent). Excessive endurance training leads to redistribution of characteristics of white and red muscle fibers which do not match the needs of developing speed, and this leads us into the area of deep glycolysis, which, according to available research, has not been noted in taekwondo fights.

a). Methods for Developing Specific Anaerobic Endurance in Taekwondo

In order to develop specific endurance of taekwondoathletes, two methods can be utilized: intensive interval method and maximum interval method [18].

Considering the planning and dimensioning methodology of the fitness training process in the light of improvement of specific anaerobic capacities of taekwondoathletes, it is important to pay attention to the following:

Table 4. Methods for developing anaerobic capacities

	Intensive interval method	Maximum interval method
Exercise tempo	Fast	Explosive
Stress intensity (%) 1. force (external resistance) 2. performance speed	no stress or up to 10% submaximum intensity	no stress or up to 10% maximum intensity
Duration - repeats (sec)	15-20	3-6
Work - rest ratio within series	1:2 to 1:3	1:4 to 1:5
Number of repeats	3-5	6-8
Rest intervals between series (min)	2 min	2 min
Number of series	3-4	5-8
Number of trainings per week	2	2

b). The Basic Period of a Taekwondo Athlete's Preparation

This period is suitable for developing general and specific endurance. When training top athletes, general contents are used most often to develop specific endurance. As has been mentioned, the intensity and the extensity of various specific and nonspecific conditioning exercises which should meet the specific requirements of taekwondo training and competition are planned.

In the basic period, endurance can be influenced with easier taekwondo training. The body is not ready for great stress yet, but taekwondo kicks need to be integrated into the training. We can compromise by setting tasks with a greater number of hits and repeats, but with an easier tempo which suits athletes' current condition. The set number of hits and coordination complexity will elevate the pulse to a level which ensures the development of endurance even without high intensity.

c). The Specific Period of a Taekwondo Athlete's Preparation

The emphasis on specific taekwondo endurance begins when an athlete enters the specific phase of the preparatory period. Conditional training and taekwondo training are integrated, i.e., athlete's abilities are developed using specific training contents. To program the training in this period correctly, we should pay attention to all important factors related to stress planning in the endurance training. It is important for the stress to be as close as possible to the stress during competition. Specific stress consists of the intensity and the extensity of work and rest.

Sometimes so-called *excessive stress* needs to be applied to push the boundaries, but that definitely must be planned, especially in the specific period which is part of the preparatory development period. Several excessive training sessions, generally speaking, will not set the athlete back, but the type, intensity and the characteristics of the following training, as well as our expectations of the athlete, should be taken into account when planning. Training is dominated by high intensity, and the extensity should be evaluated based on athlete's condition and gradually developed. It is to be expected that, in the course of training, the intensity will decline and occasionally vary (one round will be better, another one worse). This is normal and acceptable up to a certain point, and where that point is depends on the coach's estimate. When the kicks and movements lose speed, the rest period should be increased, the athlete should switch to a different type of activity or terminate the training completely. For example, 10 rounds might be scheduled in the training plan, but if the athlete is exhausted after 6 rounds, we should accept that fact. Given the complexity and intensity of the stress on the muscle and nervous systems, as well as transport and vegetative systems, coaches should know that this type of training is the most stressful for athlete's organism.

When training to develop specific anaerobic capacities, it is recommended to use tasks performed at a high intensity and consisting of hitting the focuser while alternating the exercise and rest times. That type of training is mostly used to develop abilities which will, in the competition period, be performed in variable conditions.

d). The Situation Period of a Taekwondo Athlete's Preparation

Achieved abilities of the energy mechanism and physical qualities are further developed through contents and forms of training which increasingly reflect the character of competition. They are characterized by high variability and the demand for solving situational problems at an automatic level. Both conditional training and tactical training are integrated. This is achieved by modeling tactical tasks with the intensity and the duration suitable for sports taekwondo fights. After the preparatory period is over, anaerobic endurance is merely maintained. Applying excessive stress is not recommended in further work. The occasional specific training can be included exceptionally in microcycle planning to prevent a premature decline in ability.

e). Endurance of a Taekwondo Athlete during the Microcycle

Within a weekly microcycle, two endurance training sessions are recommended, but this does not have to be the rule. When discussing endurance in taekwondo, we assume that it is speed endurance. As mentioned previously, by all accounts this is the most stressful type of training. It causes maximum stress on the transport and vegetative system and high stress on the muscle and nervous system, which adds up to maximum training stress. Therefore, the time of compensation for this type of training is 48-72 hours. Activity of the same type should not be repeated in this period. When that period is included in the number of days and hours of training in the microcycle, we can see why it is usually repeated only twice a week. However, if needed, an intensive microcycle with more than two training sessions can be performed, but then the maximum exhaustion of taekwondo athletes should be taken into account and a way of avoiding it should be anticipated.

f). Examples

Table 5. Specific training 1

Introductory part	warm-up 5 min, stretching 5 min
Preparatory part	4 marines (squat, push-up, squat, jump), 5 m sprint, 2 x preparation for double knee, backwards moving stance x 4 continuous repeats x 4 series, 1.5 minutes rest
Main part	3-4 rounds of sparring, Crazy Joe - the person performing the exercise hits he object set by the holder x 8 series, up to 2 minutes rest between series (pulse at rest below 120) 4-5 minutes rest between series 4 and 5, task length - attack 10 m, counter 10 m, attack 10 m, counter 10 m, other side x 2
Final part	Running or relaxed kicks to soften the muscles, stretching

Table 6. Specific training 2

Introductory part	Warm-up 5 min, stretching 5 min
Preparatory part	jumping from one foot to another diagonally across the arena, preparation width double, high skip diagonal, width 2 knees left leg, 2 knees right leg x 2 repeats x 3 series, 1.5 minutes rest
Main part	3-4 rounds of sparring, 8 rounds interval variable on the focuser, 2 minutes round, 2 minutes rest (while the other side is working or the pulse is at 120) 5-7 s roundhouse kick attack, roundhouse kick counter - 20 s movement and one sudden counter 5-7 s front leg roundhouse kick, counter roundhouse kick - 20 s movement and one sudden counter

Table 6. (Continued)

	5-7 s counter roundhouse kick, double roundhouse attack - 20 s movement and one sudden counter 5-7 s front leg counter roundhouse kick, front leg attack to the head - 20 s movement and one sudden counter
Final part	Relaxing stretching

Table 7. Specific training for children

Introductory part	Warm-up 5 min, stretching 5 min
Preparatory part	Athletic methodology - 8 exercises, variable running - running the diagonal of the school gym quickly, the width slowly 6x, repeat in 2 series, polygon barriers - 10 barriers (forward somersault, backward somersault, wriggling, leaping, slalom...), the polygon is performed for 3 minutes without stopping, 1 minute rest x 2, stretching
Main part	Taekwondo training; armor, focusers, technique, tactics on demand
Final part	Relaxing and stretching

CONCLUSION

The application of modern sports science achievements, and therefore also of modern diagnostic procedures for the analysis of any segment of athlete's fitness mentioned in this chapter, can provide coaches with precise and reliable information on the current level of athletes' aerobic and anaerobic energy capacities in various sports. Given that, unfortunately, we have not yet encountered specific measuring instruments (tests) in the domain of taekwondo that can accurately describe the level of anaerobic capacities of taekwondo athletes in accordance with the requirements of taekwondo fights, the task of future researchers furthering this field is to construct and validate a specific field measuring instrument, with satisfactory metric characteristics, which will specify the level of specific anaerobic capacities in taekwondo in a quality manner and have a high degree of applicability. In the meantime, the choice of diagnostic tests and methods to be applied is left to the coaches who need to take into account numerous factors when making their choice, such as the age and number of athletes, financial capabilities, level of fitness, the timing of testing in the annual curriculum, as well as the level of informedness of the members of the coaching staff or the coach. The presented set of tests is certainly not a definitive list of tests used in the sports world, because a list of all tests is neither possible nor necessary to make, seeing as the idea of this paper was to inform us of the possibilities we have at our disposal for the diagnosis and improvement of anaerobic capacities of taekwondo athletes. The most important thing for every coach or coaching staff is to be able to choose from a large database of tests and methods the ones that will enable them to accurately and reliably plan and program, as well as to control and improve the fitness level of aerobic and anaerobic energy capacity of each individual taekwondo athlete.

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Chapter 10

SUCCESS FACTORS FOR COMPETITIVE KARATE: KATA VS. KUMITE

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ABSTRACT

Competitive karate activity involves a number of factors that affect performance in this sport. The differences in competitive kata and kumite requirements inevitably lead to narrow specialization and influence the athletes to choose between the two disciplines. Furthermore, the two groups of athletes differ anthropometrically and physiologically, as well as in their basic and specific physical abilities. Low levels of body fat are preferable in both competitive disciplines, while greater skeletal longitudinality is more desirable in kumite athletes. All basic physical abilities should be at the optimal level in order to achieve significant results in sports karate. The basic abilities of explosive power and speed are highlighted for both kata and kumite whereas lower limb flexibility is required in kata competitors as much as agility is in kumite competitors.

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Regarding technique performance, kata competitors need to achieve a high level of strength and static balance in standard positions (stances) at the end of the techniques. On the other hand, a significant success factor for kumite competitors is the ability to establish the correct distance for the delivery of scoring techniques. Further factors that largely determine success in combat sports are general mobility and the ability to vary the rhythm and link the techniques. Technique effectiveness is directly dependent on the ability to perform a movement following a successive kinematic model. The development of both aerobic and anaerobic systems is required for performance achievement in both competitive disciplines. With the appropriate knowledge of individual characteristics and the implementation of training methods based on relevant success factors, coaches should be able to enhance the athletes' competition performance. However, for top competitive achievements in karate, it is essential to reach the balance between all the factors mentioned above.

Keywords: sports performance, competitive disciplines, combat sports, karate

INTRODUCTION

Nowadays, karate is one of the most widespread individual martial non-Olympic sports featuring two competitive events: kata (forms) and kumite (sports fight) [1, 2]. The popularity and growth of karate sport require a more modern, scientifically based approach with carefully chosen content and training procedures. In the early development of karate as a sport, the demands for kata and kumite did not differ as to the basic criteria for evaluating competitive performance and the training methods. Consequently, the participants often used to compete successfully in both disciplines. However, the change to the competition rules, especially in kumite (e.g., restricting contacts, or introducing a multi-point scoring system and higher scores for leg techniques) led to prominent differences between kata and kumite, and specializations in terms of the training process and competition requirements [3, 4]. Nowadays, the techniques used in kata and kumite are almost completely separated and only occasionally, young participants still compete in both disciplines [1].

The differences between competitive disciplines of kata and kumite justify their distinct training program approaches. Kata consists of a defined sequence of significantly formal defensive and offensive techniques, performed in a well-established order [5]. Kumite consists of a series of coupled techniques that require constant movement of the whole body while executing freely chosen defensive and offensive techniques against the opponent [6]. Given this, it could be stated that kumite has the characteristics of an open model of motoric representation, with the direct contact with an opponent. On the other hand, kata implies a closed model of motoric representation consisting of schematized movements, without direct contact with the opponent.

High-level performance and top sports results in both competitive disciplines are conditioned by not only superior technical performance or exceptional motor and functional abilities but also by mental stability and favorable anthropometrics [7, 8, 9]. In order to achieve this goal, it is necessary to understand which dominant success factors contribute to a particular sports discipline as well as how they can be improved. Therefore, this chapter will elaborate on the factors that can be influenced by training and are important for sports performance and achievements in karate sport. It will also discuss particular factors that are presumed to have a large impact on sports performance, as could be found in the available scientific research in this area related to karate kata and kumite.

The US National Library of Medicine (Pub Med), MEDLINE, Web of Science and Google Scholar databases were used to search for original studies relevant to karate success factors. The specific search terms included *karate, kumite, kata, physiological and functional abilities, motor abilities,* and *morphological and anthropometric characteristics*. The retrieved studies were further selected upon their purpose, methodology, as well as the number and characteristics of karate athletes investigated. The literature search covered the period from 1990 to April 2016. In some cases, the articles cited in the investigations retrieved in the search were also included when they were considered useful for the topic.

KUMITE

Kumite is defined as a sports discipline employing multi-structural acyclic movements, aimed at the symbolic defeat of the opponent [10]. It requires a high level of technical skills and fine motion control in static and dynamic conditions in order to perform the dominant technical action (e.g., striking, blocking, feinting, sweeping and moving) in the shortest time possible [11, 12, 13, 14, 15]. The main goal of kumite is for athletes to win points by executing defensive and offensive strategies with controlled scoring techniques, while moving freely within the contest area [5, 16].

Kumite competition rules prescribe kicks and punches as scoring techniques. Several studies indicate the dominance of hand over leg techniques [17, 18, 19, 20], while a similar relationship can also be observed in scoring attempts [21]. Kumite represents the synergy of physical and mental activity, in which the athletes must display dominance of physical strength and control in contact with the opponent, identify and predict the opponent's intentions, make a decision and perform a motor activity in good rhythm and timing. Kumite is characterized by the dynamics in movement particularly highlighted in the actions of attack and defense, while the static situations during the match are very rare.

Many characteristic movements are executed during a match, especially punching techniques that are strictly defined and performed at maximum speed and precision. Only then can the techniques be scored by the judges, which can eventually lead athletes to victory. As an individual sport, kumite is defined as a form of confrontation of two competitors in the manifestation of learned skills (techniques and tactics) compliant with the rules that specify match duration, scoring criteria, and sportsmanship (observing permitted and prohibited actions). The duration of the kumite match is 3 minutes for men's seniors and 2 minutes for women's seniors and juniors, with an extended duration for the final medal matches (men's seniors - 4 min; women's seniors and juniors - 3 min). Depending on the competition and the number of the registered participants of the draw, the athletes might have up to 6 fights in one day, in each of which they need to give their best to win and fight for a medal. Therefore, the total duration of competitive matches may amount to 25 minutes with extra time, imposing high demands on the competitors. Beneke et al., [16] reported that on average, matches lasted 267 ± 61 sec with 9-18 ± 2.1 min pause between matches, with the effort-to-pause ratio of ~2:1 in simulated matches, while another group of authors [22] established that the durations of the shortest and longest defensive/offensive techniques were 0.3 and 0.8 sec, respectively. Kumite competitors should be prepared for such timeframe and intensity of the match. The active phase of the match contains 16.3 ± 5.1 high intensity actions per match, each lasting 1-3 sec, which results in an average of 3.4 ± 2.0 high intensity actions per minute [16]. The presented data indicate that kumite requires a high metabolic rate.

Scoring points in kumite are Ippon, Waza-Ari, and Yuko, worth three, two, and one point, respectively. The criteria for the evaluation of scoring techniques are good form; sporting attitude; vigorous application of techniques; awareness; good timing; and, correct distance for the best possible performance [23]. Furthermore, kumite recognizes different weight categories (men's seniors: -60 kg, -67 kg, -75 kg, -84 kg, +84 kg; women’s seniors: -50 kg, -55 kg, -61 kg, -68 kg, +68 kg), in which the athletes are in the same weight class so that the crucial element for dominance on the mat is physical and technical/tactical preparation. During the match, elite karatekas demonstrate exceptional speed and power of attack. To meet such match requirements, it is necessary that the athletes develop their perceptive abilities (karate-specific and non-specific basic sensory functions) to improve the speed of reaction during the fight [15]. Most karatekas try to apply the fastest and most efficient techniques that make it difficult for the opponent to counter, while the choice and efficiency of a technique depend mostly on the athletes’ morphological characteristics [1]. Kumite competitions can be individual or in teams, with the men’s team of 5 competitors (+ 2 as reserves), and the women’s team of 3 competitors (+ 1 reserve) [23].

KATA

Karate kata belongs to the group of conventional sports in which movement structures are aesthetically designed and performed in a choreographed pattern. It consists of basic karate technique sequences related to attack and defense, executed according to strictly defined rules of the competition. In addition to punches, strikes, kicks and blocks, kata includes lunging, stepping, jumping, turning, and sliding movements as well. Kata also contains a number of jujutsu techniques such as levers, throws and swipes, which increase the self-defense aspect. Regular kata training has been proved to positively affect explosive strength and improve balance and agility [24]. It is often defined as a hypothetical combat against one or more opponents in a technically complex form. Most of its technical elements do not apply to kumite, wherefore kata is a more demanding discipline regarding structural complexity.

Speed, timing and duration of each kata vary upon its difficulty. The basic elements of proper kata technique include Kime (a short isometric muscle contraction performed when a technique is concluded), expressiveness, and rhythm. Competitive kata activity is presented at individual and team competitions, divided by gender and age. The team consists of three athletes that need to demonstrate the application of a chosen kata in the final matches (Bunkai). Considering duration, a team competition in the finals (kata performance + Bunkai) can last between 80 and 300 seconds. The performance of kata includes numerous technical varieties [25]. The dominant anthropometric characteristic is skeletal longitudinality, whereas specific motor abilities play a significant role in determining the response level in all forms through optimally executed karate techniques. The motor skills involved in kata are speed, coordination, strength, flexibility, accuracy, balance and endurance. Although all aspects of speed are involved in kata, the most important one is the alternative movement speed. Another precondition for good performance in kata is a high level of specific coordination.

There are two major aspects of strength in kata: explosive strength (manifested through its impact and bounce forms) and maximum strength (manifested through the contraction of all relevant body muscles at the end of the technique). Well-developed flexibility allows for optimum mobility in the joints that participate in the delivery of the techniques with the greatest range of motion. High specific flexibility and precision are particularly noticeable in complex kicks, often executed above head level. Many kata involve balancing positions and one leg endurance, indicating the necessity for the development of special coordination abilities, especially balance and agility. Given the kata duration and intensity, it can be said that this discipline belongs to the group of aerobic-anaerobic activities [25].

Anthropometric Characteristics

Anthropometric characteristics play an important part in defining the profile of the elite karate athlete [9, 26]. The knowledge of these characteristics can provide insight into the most suitable predispositions for this sport. Interestingly, research into this area is scarce despite the fact that karate is very popular worldwide, and there is a need for knowledge on body composition and somatotypes in kumite and kata athletes [26, 27].

According to Sterkowicz [28], karate athletes are characterized by harmonious body build and low percent of body fat. In this study, the percentage fat mass (FM) in 13 Kyokushin karate athletes was 12.16 ± 2.31%, while the percentage of fat free mass (FFM) was 87.84 ± 2.22%. Similar results were confirmed by other research [29], in which the subject sample was extended to other combat sports (e.g., judo, wrestling, boxing, fencing and jujutsu). Additional research followed [30] with 22 pencak silat athletes of both gender, in which FM and subcutaneous measurements were investigated. The results showed that karate athletes had lower values of subcutaneous tissue. In Amusa and Onyewadume's research [8], the authors compared body composition with somatotypes in 17 karate athletes from Botswana, and they found that male karate athletes had lower FM accompanied by lower body mass index (BMI) compared to female athletes. A recent analysis of anthropometric characteristics and sports performance of 31 male athletes, members of Serbian national team (kata n = 12 and kumite n = 19) showed no statistically significant differences in body composition between kata and kumite competitors (BMI kumite 23.5 ± 2.1 kg/m^2 and BMI kata 23.2 ± 1.8 kg/m^2) [1]. However, it was noticed that kumite athletes were more robust with larger body dimensions. Comparing different competitive levels, the research by Giampietro et al., [31] showed no differences in body composition in mid- and high-level competitors, even though the FM percentage was significantly lower in elite athletes. The authors did not offer explanation to these findings.

In their review article, Chaabène et al., [27] highlighted the favorable low ballast FM% in regard to weight categories. However, FM percentage varies in karate athletes of various nationalities through different studies. For example, it was reported that Japanese karate athletes had 7.5% of body fat [32], whereas Polish athletes had 16.8% of FM [33].

A number of studies have dealt with body composition and somatotypes in karate [31, 33, 34, 35, 36]. Thus, Sterkowicz-Przybycień [33] concluded in her research that the Polish karatekas who preferred hand techniques (i.e., the competitors' "specialties") belonged to the mesomorphic profile, while the karatekas whose specialties involved dominant leg techniques were more endomorphic. Furthermore, the physical structure of the Polish karate athletes was mainly endomorphic and mesomorphic, while the value for the ectomorphic body type was lower. According to Fritzsche and Raschka [36], in the research investigating if continuous karate training caused changes to body composition, superior karatekas possessed a more distinct athletic body and lower body weight than recreational karatekas. In addition, kata athletes seemed to be more endomorphic than their recreational counterparts were, while kumite athletes were more ectomorphic. Several more studies [31, 35] highlighted that the dominant anthropometric characteristic in elite karate athletes was vertical skeletal development as opposed to a robust and muscular one. Skeletal longitudinality in top karatekas was explained as the average somatotype (mesomorphic-ectomorphic), which was also confirmed by Pieter et al., [37]. A vertically developed skeleton accompanied by a low FM percentage played a major role in sports performance [38].

Recent research by Vujkov [39] showed significant differences between the competitive disciplines in anthropometric characteristics and body composition. Kumite athletes showed higher average values in body height, body mass, length of forearms and lower legs as well as the metabolic rate at rest, whereas kata athletes showed greater FM and bone mass (BM). These differences in body features represent important knowledge that can be used in the selection process by directing young athletes towards the appropriate competitive karate discipline. With respect to competitive requirements, greater skeletal length is preferable in kumite since the scoring technique can be delivered from various distances, thus allowing the competitor to reach the opponent earlier, especially with interception actions. On the other hand, pre-determined and schematized movements in kata require stable stances and low center of gravity followed by rapid and explosive transitions through stances. Therefore, shorter skeletal length and increased bone mass could contribute to a more effective implementation of the required techniques. Monitoring the parameters of body weight and FM is particularly important in karate, especially in kumite athletes who compete in predefined weight categories. Any body weight increase due to fat accumulation can lead to poorer sports performance in both disciplines. For this reason, knowledge of the competitor's body build is of importance, because its values and composition (i.e., two-component model of FM and FFM) may be subject to change as a result of training, dietary intake and regular activity. Previous authors highlighted the importance of monitoring the body fat percentage, with the FM% measured in Serbian male karate athletes in both competitive disciplines being in the middle range of values in relation to available research results (Table 1).

According to the data available, only one recent study focused on the relationship between FM and sports achievements [51], indicating that although FM does not seem to be a crucial determinant of success in karate, a greater amount of FM can represent ballast and could have a negative impact on sports achievement. However, physical dimensions do affect the deliverance of strength and power, which is of importance for karate success and plays a significant role in the athlete's selection for a particular competition discipline [52, 53]. Furthermore, the mean values of BMI obtained in Vujkov's study [39] were much lower, not only compared to the mean values obtained in a similar research by Koropanovski [54] (22.68 and 23.21 kg / m^2 vs. 24.66 and 24.46 kg / m^2, respectively), but also in comparison with other international studies [26, 33, 55]. In contrast to the content of body fat mass, the studies into the content of body muscle mass (MM) in the body structure have been relatively scarce. The values of MM obtained for both competitive modalities expressed in percentage exceeded 40% (42.46 ± 4.84% and 43.39 ± 3.10% in the group of kata and kumite, respectively) [39]. Only Francescato et al., [42] in their study with eight karate seniors displayed the mean MM of 41.87 kg. As these values were not displayed in percentages, there are limits to the comparison of the data obtained.

Table 1. Available reasearch on fat mass (%) in male karate athletes

Reference	Country	Athlete level (number)	Weight (kg) M ± SD	FM (%) M ± SD
Ravier et al., 2003 [40] Ravier et al., 2004 [41]	France	Junior international (10) Junior national (12)	71.3 ± 11.9 69.2 ± 10.4	13.1 ± 4.4 13.4 ± 3.8
Francescato et al., 1995 [42]	Italy	Amateur (8)	72.25 ± 6.36	11.49 ± 4.15
Imamura et al., 1997 [32]	Japan	Elite (6) Novice (8)	66.8 ± 8.9 59.9 ± 7.3	7.5 ± 1.6 10.1 ± 4.4
Ravier et al., 2006 [43]	France	International (10) National (8)	71.9 ± 11.4 70.7 ± 12.2	13.7 ± 4.1 13.6 ± 4.5
Rodrigues et al., 2010 [44]	Portugal	International (10)	71.13 ± 9.35	14.1 ± 3.46
Steven Baker et al., 2006 [45]	GB	International (11)	78.8 ± 10.3	16.5 ± 4.6
Imamura et al., 1998 [5]	Japan	Elite (7) Novice (9)	66.3 ± 8.2 60.1 ± 6.9	10.7 ± 2 12.6 ± 4.5
Amusa et al., 2001 [8]	Botswana	National (10)	68.2 ± 8.9	12.2 ± 4.6
Sterkowicz-Przybycien, 2010 [33]	Poland	International (14) National (16)	86.1 ± 8.25 81.4 ± 11.9	16.8 ± 2.51 15.8 ± 1.93
Giampietro et al., 2003 [31]	Italy	Elite (14) Amateur (21) Elite (14) Amateur (21)	72.4 ± 8.7 69.2 ± 8.9 72.4 ± 8.7 69.2 ± 8.9	8.1 ± 2.4 8.9 ± 3.3 9.8 ± 1.6 11.2 ± 3.7
Shaw and Deutsch, 1982 [46]	USA	4 white belt, 2 blue, 2 brown and 1 DAN (9)	72.8 ± 7.8	12.4 ± 6.4
Rossi et al., 2007 [47]	Brasil	University athletes (12)	68.0 ± 11.1	10.5 ± 3.0
Imamura et al., 1996 [48]	Japan	National (6)	65.0 ± 5.9	12.8 ± 6.0
Lutoslawska et al., 1996 [49]	Poland	Elite (12)	79.1 ± 9.6	12.6 ± 3.3
Gloc et al., 2012 [26]	Poland	Advanced (9)	72.7 ± 8.9	11.7 ± 4.15
Sánchez-Puccini et al., 2014 [50]	Colombia	Elite (19)	65.4 ± 12.0	14.7 ± 4.3
Tabben et al., 2015 [20]	Tunisia	Elite (10)	71.2 ± 9.0	8.2 ±1.3
Vujkov, 2016 [39]	Serbia	Kata (33) Kumite (39)	68.7 ± 6.8 74.7 ± 8.1	14.8 ± 4.9 12.8 ± 2.6

FM - Fat mass %; M - Mean values; SD - Standard deviation.

In general, it could be assumed that superior muscularity with smaller fat proportion in the body composition could certainly be an advantage in specific karate activities, especially in kumite, where weight classes exist. In the light of all factors known to determine success in karate sport, anthropometric characteristics and body composition could be highlighted as important. It could be concluded that even though these characteristics are not crucial for athlete selection, they certainly represent a necessary precondition for selection and further specialization in one of the competitive karate disciplines.

BASIC PHYSICAL ABILITIES

Basic physical abilities of karate athletes have a significant informational value for several reasons. Above all, it is almost impossible to develop specific physical abilities without the development of basic physical abilities [56]. Secondly, basic abilities are important in the early selection as well as in the subsequent choosing of a particular competitive discipline. Later on, these abilities play an important part in constructing the modeling characteristics in karate, and finally, their relatively simple testing procedures are suitable for monitoring sports fitness levels.

Unlike some other areas, basic physical abilities have been well researched in karate. For example, Ravier et al., [41, 43] studied the relations between motor ability tests and anaerobic metabolism blood markers in order to find a valid test suited for kumite specialists among athletes of different levels. They found that the data for strength and speed, obtained through treadmill test and vertical jump, could be sensitive enough to identify differences between athletes of various levels. Furthermore, tests such as one repetition maximum (1RM) for evaluating maximal strength and power through bench press and back squat, back squat jump and chest jerk with a 30% load were sensitive enough for competitive success evaluation [51]. In addition, it was shown that upper and lower body maximal dynamic strength positively correlated to punch acceleration and maximal dynamic strength (1RM) in both bench press and squat-machine exercises [57].

Another group of authors [56] tried to identify the relevant competitive kumite motor structure, finding three major factors to be dominant: coordination, explosive strength and movement frequency. These factors were associated with motor structures in kumite that involve speed and power control in addition to specific coordination.

Several research studies have looked into the asymmetry problem between dominant and non-dominant limb in karate. This certainly represents an interesting topic because muscle asymmetry is very often linked to an increased risk of injury [58]. Isokinetic testing can provide valuable information in combat sports regarding the strength of certain muscle groups and detection of an imbalance between them [59]. Athletes can develop significant muscle asymmetry as a product of daily training and the demanding sport-specific activities that put them at risk of injury. In karate, there was research into muscle symmetry of the lower extremities affected by the performance of specific techniques [60] and the possibility of injury of the ankle, the hip joint, and the knee [13, 61]. In a study of muscular efficiency estimation in the dominant and non-dominant extremity, Scattone-Silva et al., [60] found that the imbalance between agonist and antagonist muscles (the knee and elbow joints) was less than 10%. This led to the conclusion that daily karate practice did not result in bilateral asymmetry of either lower or upper extremities, which earlier had been associated with the increased risk of injuries. Furthermore, the inclusion of isokinetic dynamometry to regular training, in addition to the implementation of new training elements and modalities for improved performance and the prevention of injuries due to lateral and unilateral asymmetry, was proposed as well [58, 59].

Probst et al., [61] investigated the flexibility and balance strength of the lower extremities (agonists and antagonists), along with the knee stability in performing karate-specific leg techniques. The authors assumed negative effects on leg muscles and joint loads in the performance of specific karate stances, movements and leg techniques as well as increased risk of knee injury. In contrast, they found that karate training led to an increase in quadriceps strength and to shortening of the activation time without risk of knee injury. They also recommended that certain aspects of karate training, such as direct front kick (Mae-geri), could be implemented in other sports activities, especially the ones with necessary quadriceps strength and short time of activation. The results of this study indicate that in karate, all four extremities are equally represented in the technique application. The results of flexibility tests in karate and control groups, which evaluated the knee, hip, and ankle flexion and extension, as well as their rotation concluded in favor of flexibility as an important component of many sports, including karate (due to the movement amplitude in high leg kicks aimed at the head). Surprisingly, the same survey found that in other flexibility tests of lower extremities, especially hamstrings, the obtained parameters were worse than in the control group. Flexibility represents the determinant of the current condition of the muscle-joint system that can be repaired substantially through the training process [39].

Table 2. Available research on maximum strength (1RM) in karate athletes

Reference	Country	Athlete characteristics (N)	Weight lifted (kg) M ± SD
Roschel et al., 2009. [51]	Brasil	Winners (N=14) Defeated	BP = 76.3 ± 16.8 BS = 113.3 ± 15.1 BP = 70.3 ± 11.5 BS = 128.6 ± 20.5
Imamura et al., 1998. [5]	Japan	Elite (7) Novice (9)	BP = 87.1 ± 12.5 BS = 137.5 ± 12.5 BP = 74.4 ± 7.3 BS = 120 ± 13.2
Koropanovski, 2012. [54]	Serbia	Kata (16) Kumite (19)	BP = 89.92 ± 16.26 (BPrel = 1.24 ± 0.21) BS = 145.68 ± 14.02 (BSrel = 2.02 ± 0.23) BP = 95.06 ± 12.76 (BPrel = 1.21 ± 0.12) BS = 158.72 ± 24.44 (BSrel = 2.01 ± 0.25)
Loturco et al., 2014. [57]	Brasil	Men (9) Women (10)	BP = 89 ± 19 (BPrel = 1.16 ± 0.17) BS = 201 ± 31 (BSrel = 2.65 ± 0.32) BP = 44 ± 5 (BPrel = 0.76 ± 0.14) BS = 151 ± 17 (BSrel = 2.58 ± 0.38)
Vujkov, 2016. [39]	Serbia	Kata (33) Kumite (39)	BP = 74.1 ± 19.2 (BPrel = 1.1 ± 0.2) BS = 123.5 ± 24.6 (BSrel = 1.8 ± 0.3) BP = 78.3 ± 17.8 (BPrel = 1.0 ± 0.2) BS = 124.8 ± 25.2 (BSrel = 1.7 ± 0.3)

BP - Bench press; BS - Back squat;M - Mean; SD - Standard deviation.

One repetition maximum (1RM) is the most widespread form of dynamic power assessment, but research on this subject in karate is scarcely available. Imamura et al., [5], and later, Rosch et al., [51] investigated the differences in the maximum absolute value of 1RM bench press and back squat between elite and novice karate athletes, as well as between more and less successful competitors. The authors concluded that these two tests could identify top-level athletes taking into consideration the speed of muscular contraction. Further investigation [39, 54] showed no statistically significant differences in 1RM bench press and back squat between kata and kumite competitors (Table 2).

According to the available research, 1RM dynamic leg strength of the back squat in the elite male competitors should be between 2 and 2.5 times higher, while values of 1RM bench press should be between 1.25 and 1.5 times higher in relation to body weight. Karate disciplines rely more on explosive strength and horizontal movement, which are needed to move the body weight as quickly as possible through specific stances (kata) and movement (kumite), rather than on heavy lifting and absolute power.

In the research of muscular strength, Ravier et al., [40] compared the explosive and maximum strength in athletes of different competitive levels, with better results on the cycle ergometer shown by the competitors at the international level. This led to the conclusion that maximum speed and explosive power represented the major determinant factor for mechanical muscles involved in performing karate techniques. Another study [51] maintained that the success in performing karate techniques relied on muscle strength at lower loads, because the study did not demonstrate a statistically significant difference between successful and unsuccessful karate athletes at higher loads.

A few studies that investigated explosive strength through vertical jumps [1, 9, 25, 39, 41, 50, 51, 54] are presented in Table 3. When results for kata and kumite athletes of both genders were compared [25], no significant differences were found in any of the tests applied (squat jump (SJ) and counter-movement jump (CMJ) tests). Similar results were found by Koropanovski et al., [1] in male elite senior athletes. However, significant differences in favor of kumite athletes were found in tests that assessed the ability to accelerate the whole body. Superior leg flexibility in kata compared to kumite competitors was confirmed in a survey conducted by Vujkov [39], while kumite athletes had better indicators of absolute power jumps. Koropanovski [54] also confirmed improved flexibility in kata competitors, but unlike previous studies, here kata competitors had better indicators for absolute power through jumps. It has also been found that explosive strength and coordination have a major influence on success in karate; above-average abilities that are largely innate, or genetically predetermined, such as explosive muscle strength, speed, and coordination, are required in order to achieve top results [9].

Vertical jump represents a movement that requires complex motor coordination between the upper and lower segments of the body, in which movement coordination along with explosive strength has been recognized as the dominant variable for athletic performance [9, 56]. These play an important part in successful technique execution in both competitive disciplines: to perform demanding and difficult jumps in kata, and to deliver the technique and exit the attack in kumite. The information obtained from vertical jumps may indicate the impact of training on the development of this segment in karate. For kata in particular, the jump from static position (SJ) is especially interesting, because it often occurs in kata. It is also worth noting that the momentum of arm swing in vertical jump can contribute to the improvement of traditional CMJ height by 10-20%, which indicates good coordination [62].

Overall, explosive strength is of high importance for both competitive disciplines, and it is desirable to be at the highest level possible. There is noticeable heterogeneity in the results obtained for the same or very similar populations. Generally, the reasons for this could be found in the test timing relative to the competition season. The results obtained at the end of the preliminary period and in the early stages of the competition period are expected to be higher than during competitions. There has been a greater reduction in the explosive strength assessed through standardized tests in the later stages of the competition period in kumite athletes than in kata competitors. The reasons for this could be found in the competitive requirements for kumite athletes that involve a certain level of explosive strength for the timely, accurate and controlled technique to meet the criteria for scoring. On the other hand, in kata, as a strictly defined motor model, the competitor with a higher level of explosive strength than the opponent has greater benefit than either of two kumite competitors does. These differences should therefore be taken into account when planning the competition training process.

Table 3. Available research data on explosive leg strength

Reference	Study	Athletes (N)	Jump hight M ± SD
Ravier et al., 2004. [41]	France	Juniors int. (10) Juniors nat. (12)	CMJ = 44.9 ± 5.9 SJ = 42.3 ± 4.8 CMJ = 40 ± 3.8 SJ = 37 ± 3.6
Doria et al., 2009. [25]	Italy	Elite kata (3) Elite kumite (3)	CMJ = 42.7 ± 4.4 SJ = 38.9 ± 1.1 CMJ = 42.8 ± 4.2 SJ = 40.1 ± 3.2
Roschel et al., 2009. [51]	Brasil	Winners (NR) Defeated	CMJ = 48.8 ± 3.4 CMJ = 50.8 ± 2.6
Koropanovski et al., 2011. [1]	Serbia	Kumite (19) Kata (12)	CMJ = 46.1 ± 4.4 CMJ = 48.6 ± 8.1
Koropanovski, 2012. [54]	Serbia	Kumite (16) Kata (19)	CMJ = 42.01 ± 6.82 SJ = 37.90 ± 5.21 VJ = 48.73 ± 6.56 CMJ = 47.76 ± 6.15 SJ = 41.94 ± 5.76 VJ = 55.37 ± 7.78
Sanchez-Puccini et al., 2014. [50]	Colombia	Elite (19)	VJ = 32.0 ± 8.7
Loturco et al., 2014. [57]	Brasil	Men (9) Women (10)	CMJ = 43.2 ± 5.3 SJ = 40.6 ± 5.6 CMJ = 31.9 ± 4.2 SJ = 30.5 ± 3.2
Vujkov, 2016. [39]	Serbia	Kumite (33) Kata (39)	CMJ = 46.6 ± 5.1 SJ = 44.1 ± 4.1 VJ = 55.8 ± 5.8 CMJ = 45.1 ± 6.9 SJ = 42.4 ± 6.8 VJ = 52.5 ± 9.4

CMJ – Counter-movement jump; SJ - Squat jump; VJ - Vertical jump; M - Mean; SD - Standard deviation; NR - Not reported.

Karate movements occur in certain amplitudes that require flexibility, particularly of the lower extremities. Accordingly, karate training should include the athlete's adaptation to a specific environment in which to realize powerful movements during extended stances [61]. In addition, it was shown that optimal joint flexibility reduced the risk of injury [63, 64] and increased the possibility of application of sport-specific techniques in karate, such as high kicks delivered in the full range of motion at high speeds. Flexibility is an important predictor of the successful execution of situational-motor tests [15, 40, 61]. It is worth mentioning that dynamic rather than static flexibility is required in the realization of high leg techniques, especially in kumite.

Previous studies showed that athletes in kata dominated in all tests of flexibility in comparison to kumite athletes. The results from a recent study by Vujkov [39] were consistent with the findings by Koropanovski [54], in which kata athletes showed significantly better results in all tests of flexibility than the kumite group. In other research by Koropanovski et al., [1] there was no significant difference in tests between kata and kumite groups, although kata athletes generally had 6 - 7% better flexibility. The explanation for these results could be found in kata-specific techniques and stances that need to be done in low positions. In kata training, special attention is paid to increasing mobility, especially of the lower extremities [1, 24], so that this ability could be greatly improved [65, 66].

Agility represents the ability of the athlete to change the body position or the direction of movement as quickly as possible within the given physical limits [67] and is one of the important components for success in karate. A comparison between the available agility results between kata and kumite athletes showed that the differences were negligible, although the competitors in kata achieved slightly better results than kumite competitors [1, 39, 54]. Considering competitive demands, both disciplines require a rapid change in the horizontal position of the body. In kumite this is even more pronounced because the success in executing techniques is largely dependent on agility, while in kata this rapid change in body position is delivered from low positions of the stances.

It can be concluded from the above mentioned that basic physical abilities are important for competitive success in both disciplines. While it is essential that they be at the optimal level in order to achieve significant sports results in karate, an attempt to increase these abilities beyond a certain limit would not result in a significant impact on the improvement in technical and tactical characteristics of the competitors. However, well-developed basic abilities certainly provide a good basis for further sport-specific skill development.

SPECIFIC PHYSICAL ABILITIES

The diversity of technical elements that characterizes karate sport is the reason for different research approaches to specific physical abilities. The structure of karate techniques represents the basis for the analysis of competitive and training activity [68]. In kumite, the competition rules prescribe only punches and kicks as scoring techniques, whereas in kata these techniques are significant components of the overall technique structure. Recent investigation by Tabben et al., [69] showed that high-level karate athletes preferred upper to lower limb techniques with most of the blows directed to the head, and that all high-intensity actions had a tendency towards the greater efficiency of attack and defense. Investigation into competitive kumite activity has indicated that Gyako-tsuki (a direct reverse punch) and Mawashi-geri (a roundhouse kick) are most commonly used for scoring techniques [17, 18, 19, 69, 70], and scoring attempts [21]. It has been shown that these techniques best minimize the risk of the opponent's counteraction, especially with interception and counterattack [21], indicating that Gyako-tsuki takes central place in competition and training so that it can be observed as a representative karate technique. Corresponding results have been found in the investigation of kung fu strikes and punches, in which a similar punching technique showed greatest efficacy in throwing the opponent off balance [71].

As mentioned before, kumite competition rules demand controlled contact with the opponent in order to perform a technique, while kata techniques require maximum strength. Technique efficacy implies the achievement of ground reaction force that is transferred through the lower body segments to the final body segment that performs the technique; at the same time, the involvement of as much body mass as possible is desirable [72]. This implies that intramuscular coordination is of special importance for the technique performance based on successive kinematic model as a direct result of specific motor control strategies in karate [54, 73]. Thus, the sagittal-plane techniques involving muscular mechanisms of agonist/antagonist elbow and knee flexors and extensors can be regarded as indicators of the achieved mastery level in karate [74]. The training activity should take place with an aim to improve movement efficiency, not only for maximum agonist inclusion in motion but also for complete antagonist relaxation [14]. A study by McGill et al., [75] clarified the punching mechanism through "double peak" muscle activation during punches and strikes. The first peak occurs at the beginning of the technique in order to provide support for the initial body movement, whereas the second peak occurs at the end of the technique, providing more effective body mass to support the technique and increase the power of impact. Between contraction phases, muscles relax, creating a contraction-relaxation-contraction relationship that can be an important segment in explaining the efficiency of striking and punching techniques. Finally, the ability to develop and control speed and strength represents the main feature of karate sport and it could serve as an indicator of competitive efficiency [56].

Kinematic characteristics represent a measure of human movement and positions through both space and time. These characteristics are recognized as spatial, temporal and spatio-temporal factors. Research results by Sforza et al., [76] suggested that repetition of punches had the lowest consistency with the observed movement trajectory of the technique (e.g., back and forth). They concluded that karate athletes performed a simple Choku-tsuki punch with minor fluctuations in comparison to an Oi-tsuki punch, which required the involvement of a larger number of body segments. They also found that more experienced karate athletes had a more stable technique than less experienced ones [77]. Somewhat different results were obtained in the comparison of repeatability of punches in kata and kumite competitors [54]. Kata competitors showed greater deviations in a simple Choku-tsuki punch, whereas punches that were more complex yielded no differences. The schematic of the interrelationship between individual body segments involved, or the kinematic motion model, gives important information that may provide answers about the level of efficiency in the techniques practiced. Quinze et al., [78] concluded that differences existed in intra-limb coordination in performing karate kicking techniques relative to whether the technique was performed towards a target. The data obtained during the execution of the techniques without a target suggested motor control system efficiency. However, shorter duration of the technique represents an important factor that distinguishes successful competitors [79]. Furthermore, kata athletes deliver a faster hand movement at the beginning of the punch compared to kumite athletes [54], but kumite athletes show greater hand speed at the end of the technique. Therefore, punching technique efficacy could be observed through its dynamic characteristics relative to contact surface. High-level karate athletes should possess higher upper limb velocity and greater punching impulse, which reflects on a larger body segment displacement in technique application [80]. The best punching performance is obtained with correct distance, and the most successful competitors are distinguished by higher hand acceleration related to peak force and effective mass [57]. The efficacy of punching performance is significantly determined by the ability of the athlete to achieve the greatest possible relaxation phase between two contractions [75]. Overall, lower limb power and strength as well as upper limb velocity represent the major factors for reaching high punching force [72]. Regardless of the differences in competitive demands between kata and kumite, elite competitors in both disciplines show similar dynamic characteristics in punching techniques [54]. There was an attempt to explain the data by the fact that both groups of contestants have done single process training at the time, delivering the technique without contact at the other end. Furthermore, unlike kata athletes, kumite contestants do not have the requirements for the application of striking techniques using great force.

By examining several parameters in two punching techniques using a punching bag, Cesari and Bertucci [80] concluded that elite karatekas were more efficient in stability control. This was also confirmed by Filingeri et al., [81] through their analysis of several investigations related to postural control in karate. The main finding referred to a positive effect of exercise in achieving long-term postural control.

The factors critical to success in kata are static balance control, explosive power and motor coordination. In contrast, success in kumite underlines dynamic balance control, explosive power and stamina, reaction time, strategy and tactics. It is recommended that the training sessions be more focused on lumbar stability in order for ground reaction forces to be efficiently transmitted from lower to upper body just before the end of impact [72]. Greater involvement of body mass in combination with speed in specific motor tasks that involve control represents the basis of all combat sports, and at the same time makes a major distinction between combat athletes and non-athletes [82, 83]. Training effects for the competitors in striking-based combat sports are noticeable when the base of support and center of gravity are mastered so as to enable greater stability and create adequate conditions for the effective technique execution, additionally helping accumulate the impact effects [80, 84].

It was pointed out by Katic et al., [10] that sporting success was largely determined by the integration of defense and attack actions, including the ability for executing a series of combination techniques, and that combat effectiveness was largely defined by specific skills of speed and agility. The investigation into specific motor abilities in the research by Blazevic et al., [56] revealed that karate techniques were largely determined by explosive strength and coordination. The level of specific motor skills relevant to combat effectiveness could be evaluated by a specific agility test (multidirectional movement test); specific speed could be tested by the performance of Gedan-barai blocking techniques and the frequency of Mawashi-geri technique.

It has already been indicated that a number of factors significantly affect specific motor abilities in competitive karate, with some specificities in kata and kumite techniques. Regarding technique application, kata competitors need to achieve a high level of strength and static balance in standard positions (stances) at the end of the techniques. On the other hand, a significant success factor for kumite competitors is the ability to establish the correct distance for delivering scoring techniques. Further factors that largely determine success in combat sports are general mobility and the ability to vary the rhythm and link the techniques. However, regardless of different performance techniques in kata and kumite, the biomechanical pattern is identical in both disciplines. This includes exercising appropriate stances in which movement is realized from the lower segments of body (legs) to the final body segments that realize the technique (arms/legs). Technique effectiveness is directly dependent on the ability to perform a movement through a successive kinematic model, i.e., on the ability to timely start and stop each body segment that participates in the movement. At the same time, it is necessary that the deviation from the ideal path in technique performance is the least possible, and that the joint angles are in such a range that ensures the delivery of the maximum power movement.

Physiological Characteristics

Knowledge on how to assess physiological status in athletes is relevant from several points of view. It is particularly important to determine the degree of utilization of the energy system to facilitate sports participation, the evaluation of sports success components, and competitive discipline profiling [85]. All parameters included in this section relate to the attributes necessary to profile the athletes’ responses to karate-specific exercise (e.g., time-motion analysis, followed by an aerobic and anaerobic profile) that were obtained from the available research.

In the past few decades, training and physiological testing have progressively adjusted to the characteristics of competitive sports disciplines. The diagnostics of functional abilities represents the key to obtaining necessary information on cardio-respiratory functions in athletes. However, in order to use such information properly, it is necessary to understand physiological demands and energetic requirements for both competitive karate disciplines. The structural differences between the competition requirements for kata and kumite roughly divided the existing research into the energetic requirements for kata [42, 86], kumite [16], and their comparison [25, 39, 87]. A number of studies were done in profiling of aerobic [1, 5, 25, 40, 42, 43], as well as anaerobic capacities of karate athletes [16, 42, 88]. Researchers from the end of the last century were of the opinion that anaerobic metabolism is the dominant energy source for kumite [7, 89], and thus characterized karate as a high-intensity activity. However, more recent studies have shown that the overall metabolic kumite profile is, in fact, aerobic dominant [16, 25, 90], and the structure of a kumite bout seems to support this fact. Acyclic movements and multidirectional bouncing alternate with bursts of high demanding explosive techniques accompanied by short interruptions by the judges (for awarding points, or issuing warnings and penalties). Energetic performance in karate indicates the participation of the aerobic component of approximately 70%, the alactate aerobic component of approximately 20%, and the lactate component of approximately 10% in kumite athletes [16]. On the other hand, kata competitors use almost the same proportion of aerobic and anaerobic energy production sources, with the difference that the total share of alactate components in overall energy structure is almost two times higher than in kumite athletes [25]. To a considerable extent, these differences occur as a result of the different duration of the kumite match (effectively 240 s) compared to kata (about 80-140 s), in addition to a large number of techniques that kata competitors perform in shorter time.

To the authors' knowledge, there have been only three scientific studies that analyzed the karate match [16, 22, 90]. Beneke et al., [16] reported that a simulated karate competition had 18 ± 6 efforts per 9 ± 6 seconds of recovery pattern (i.e., effort:pause ratio of 2:1), with the activity phases containing 16.3 ± 5.1 high-intensity actions per fight lasting 1 to 3 seconds each, and resulting in 3.4 ± 2.0 high-intensity actions per minute. In Chaaben et al., [90], the results showed that high-level karate athletes executed 17 ± 7 high-intensity actions per fight (~6 high intensity actions per minute). The action-to-rest ratio was about 1:1.5, but in the high-intensity-action-to-rest ratio, it increased to ~1:10, characterizing the intermittent nature of official karate combat. The study by Ilde et al., [22] examined the duration of a series of offensive and defensive actions through simulated matches lasting 2 and 3 minutes. They established that the duration of the longest offensive/defensive action sequence lasted 2.1 ± 1.0 for 2 minutes and 1.8 ± 0.4 seconds to 3 minutes of the simulated match. Furthermore, the mean total time of fighting actions was 19.4 ± 5.5s during the 3-minute karate combat simulation [22], which differed from Chaabene et al., study [90], in which the mean total time of fighting activity was 30.4 ± 9.9s during simulated combat; however, it was similar to the results in Iide et al., [22] of 20.9 ± 8.1s during the official karate combat. The longer time interval found within official conditions compared to simulated matches was explained with the motivation for athletes to be engaged only in the attack activities with the highest chance of success during official matches [84]. The mentioned results indicate that in top-level karate performance, the development of the athletes' anaerobic alactic system is important in order to perform attack/defense techniques with high-speed movement.

Since high intensity of kumite matches is an indication of predominantly anaerobic work, anaerobic capacity is important for kumite athletes in terms of the status of adenosine tri-phosphate (ATP), creatine phosphate (CP), glycolytic capacity, and others. Phosphagen releases the energy that is required for about 10 - 20 seconds' activity, while the extended activity of the following 60 - 90 seconds is obtained from additional breakdown of glycogen. Anaerobic energy capacity represents the total amount of energy obtained from sarcoplasma, or the energy that an individual can release through phosphagen and glycolytic processes. In karate, an oxygen deficit is created due to the use of energy from anaerobic sources at the beginning of the match [43]. Maximum oxygen deficit is an indicator of the size of anaerobic energy capacity, which in elite kumite athletes can reach up to 20 liters. Only one-third of the energy demands during the match are met from anaerobic sources, while further energy processes take place using the aerobic capacity.

In kata competitions, depending on the number of entries, athletes have to perform 2 - 7 different katas in a short period, thus imposing high demands on athletes. Athletes who reach the finals must complete a compulsory kata (Shitei) and one free kata (Tokui) within 60 - 80 seconds; otherwise, penalties are issued for exceeding the time limit. Comparing the aerobic capacity requirements in kumite and kata, a greater aerobic source is found in kumite (74%) than in kata (50%), while there is a greater contribution from dominant anaerobic capacity in kata [25]. The authors hypothesized that this could be caused by the engagement of different muscle groups during activities, in addition to the differing time duration of the actual competitive activity. Other research [86] investigated metabolic cost and fractional energy supply of basic karate kata (Heian Nidan, Shotokan style) with the duration of about 30s. The results showed that on average, the percentages of the energy supply for performing one Heian Nidan kata coming from anaerobic alactic, anaerobic lactic, and aerobic metabolisms were 52%, 25% and 23%, respectively. For two sequentially executed Heian Nidan kata, thus nearly doubling the duration, the calculated percentages were 33%, 25% and 42%, respectively. It was concluded that high-energy phosphates played a key role in the karate-specific rapid movements in kata. Furthermore, with longer duration and number of movements in kata, energy requirements were increasingly regulated through aerobic metabolism, which was essential even in the activities that lasted from 30 - 80 seconds. These findings were also confirmed in the study by Chaaben et al., [4].

One of the most important factors governing the athletes' performance is their level of cardio-respiratory endurance. Cardio-respiratory endurance involves the ability to sustain prolonged exercise involving both the cardiovascular and respiratory systems. Maximal oxygen consumption (VO_{2max}) is widely used by researchers to indicate an athlete's level of cardio-vascular functional capacity. Furthermore, it is considered as a valid indicator of the cooperative function of respiratory, cardiovascular and muscular systems. VO_{2max} is defined as the largest amount of oxygen that an individual can utilize during an exercise of increasing intensity [ACSM], and provides indirect information on speed of energy provided through aerobic metabolism, which is considered dominant in kumite. VO_{2max} is also considered a key determinant of an individual's current level of cardio-respiratory fitness that can be improved in time to a certain extent with the use of adequate training stimulus duration [41]. There are a number of indirect methods of assessing this parameter (e.g., field tests, shuttle run, Cooper test, etc.), as well as direct ones (laboratory tests, the treadmill or cycle ergometer). For activities such as kumite, in which body mass is used to classify athletes in weight categories, oxygen uptake is measured relative to body mass in ml/kg/min. Athletes with superior aerobic capacity could have an advantage in the performance for both competitive disciplines. Generally, higher VO_{2max} values indicate a higher level of general endurance and create a possibility for the athlete to impose a higher pace throughout the match than the competitor with inferior VO_{2max} values. In addition, aerobically superior competitors could probably recover more quickly between matches, especially when the athlete has up to 8 matches to the finals in the course of the competition. On the other hand, kata competitors could benefit from superior aerobic capacity in terms of faster and more effective recovery between competition bouts. For both competitive disciplines, a high level of physical fitness is required from elimination matches to the finals. The values of VO_{2max} from the available data for karate athletes range from 47.8 ± 4.4 to 61.4 ± 2.6 ml/kg/min (Table 4). Generally, the pauses between two rounds of performance are not sufficient for recovery, and the competitors with superior aerobic capacity will certainly have an advantage over others.

Table 4. Research of aerobic capacities in male karate athletes tested on treadmill

Reference	Country	Subjects (N)	VO_{2max} (ml/kg/min) M ± SD
Imamura et al., 1997. [32]	Japan	Elite (6) Novice (8)	59 ± 6,6 57.5 ± 5.2
Ravier et al., 2009. [88]	France	National and international level EG (9) and CG (8)	EG before: 58.7 ± 3.1 EG after: 61.4 ± 2.6 KG before: 58.2 ± 3.1 KG after: 58.1 ± 4.4
Imamura et al., 1998. [5]	Japan	Elite (7) Novice (9)	57.5 ± 5.2 57.2 ± 4.9
Shaw and Deutsch, 1982. [46]	USA	4 white belts, 2 blue, 2 brown and 1 DAN (9)	56.1 ± 5.4
Keshishian, 2013. [24]	Australia	Elite (11) Novice (9)	46.97 ± 7.7 42.74 ± 12.7
Imamura et al., 1999. [91]	Japan	Practitioners (9)	58.6 ± 6.8
Iide et al., 2008. [22]	Japan	Black belt (12)	51.2 ± 4.3
Sanchez-Puccini et al., 2014. [50]	Colombia	Elite (19)	44.8 ± 7.1
Vujkov et al., 2015. [87]	Serbia	Kata (9) Kumite (15)	47.05 ± 4.14 48.74 ± 3.66
Vujkov, 2016. [39]	Serbia	Kata (33) Kumite (39)	41,51 ± 6,23 45,90 ± 5,37

M -Mean values; SD - Standard deviation.

Even though individual punches and kicks are predominantly anaerobic alactatic and depend on muscle strength, the repetition of these motor actions that occur during a kumite bout indicate the participation of the aerobic metabolism of 77.8% ± 5.8%, while the anaerobic alactatic participation is 16.4 ± 4.6% of total energy produced during the match [16]. Thus, anaerobic alactatic contribution represents about 16% of the time of high intensity actions during the match. However, the recovery from these high-intensity actions is credited to aerobic metabolism, which may explain a large contribution of aerobic energy pathways to the total energy used during matches. These results were also confirmed by the latest time-motion analysis in karate [4]. Kumite performance mainly depends on aerobic metabolism, whereas the energy for decisive actions is provided from the anaerobic system, with anaerobic lactic metabolism possibly also contributing to the total energy used during the match [41]. This contribution can be assessed by monitoring blood lactate levels (La) before and after the match. Francescato et al., [42] showed increased values of La (5.9 ± 1.6 mmol • l-1) after one kumite match (from 1.7 to 7.6 mmol • l-1). Their results were confirmed by Lehmann and Jedliczka [7], suggesting a contribution of glycolytic metabolism to the total energy consumption during a kumite match. Available research on blood lactate values in official and simulated competitions are presented in Table 5. Due to the diversity of the results resulting from different methodologies used, their interpretation and comparison might not be appropriate. However, it can be seen (Table 5) that La^{-1} values induced varying metabolic responses in different competitive disciplines, also depending on whether the competition was official or simulated. Lower values of La^{-1} present in kata highlight a relatively low contribution of the glycolytic system. In contrast, it may seem controvertible to interpret the values obtained for kumite, because they mostly could depend on the tactics applied in the match, an individual response to lactate tolerance, or different adaptation to the training process.

An additional marker in defining functional abilities of cardiovascular parameters in athletes is the heart rate (HR) [92]. It is most readily available and easy to measure, especially in determining the intensity of an activity (HR increases proportionally to the training load). The direct relationship between HR and VO_{2max} is particularly interesting because of the possibility to calculate the individual training intensity zones as a good marker for the training process [93]. The available research showed that the average HR values in kumite athletes were above 90% of HR_{max} (91.70% in the official and 91.14% in simulated competition) [90]. Similar results (~92-100% HR_{max}) were confirmed in simulated competition for both disciplines [14, 25, 39]. These values confirm the high cardiovascular demands that occur in both competitive kata and kumite. Another cost-effective marker that has recently been adopted as a valid tool for quantifying a karate training session is the rate of perceived exertion (RPE) [94, 95], which is usually monitored in terms of additional information in the effort assessment (e.g., La^{-1}, HR). Feedback from athletes, especially on local RPE for determining exertion in a particular muscle group in karate [90], could constitute relevant information for coaches towards optimizing a specific training program so that it could be aimed at developing local endurance and improving sports performance.

Table 5. Research available on blood lactate levels at official and simulated kumite and kata competitions

Reference	Subjects (N)	Match duration (sec)	[La] mmol/l
Kumite - simulated competition			
Beneke et al., 2004. [16]	Elite (10)	267 ± 61[a]	7.7 ± 1.9 $\Delta La = 4.2 \pm 1.9$
Doria et al., 2009. [25]	Elite (3)	240[b]	7.5 ± 2.4
Iide et al., 2008. [22]	Black belt (13)	120 [b] 180[b]	3.1 ± 1 3.4 ± 1
Roschel et al., 2009. [51]	Elite (14) Winners Defeated	180 [b]	$La_{pre} = 2.3 \pm 0.4$ $La_{pos\ t} = 5.1 \pm 1.2$ $La_{pre} = 1.8 \pm 0.6$ $La_{post} = 5.2 \pm 2.2$
Tabben et al., 2014. [69]	Elite (10)	180 [b]	$La_{post} = 13.0 \pm 1.8$
Chaabène et al., 2014. [70]	Elite (10)	180 [b]	$La_{post} = 7.80 \pm 2.66$
Vujkov et al., 2015. [87]	Elite (15)	240 [b]	warm-up 2.05 ± .41 3 min 7.25 ±3.92 6 min 5.92 ± 1.69 9 min 5.35 ± 1.56
Kumite - Official competition			
Ariazza, 2009. [96]	WC participants (20)	NR	11.1 [8.7 - 12.7]
Tabben et al., 2013. [2]	Elite (4)	180 [b]	M1 $La_{post} = 8.8 \pm 0.9$ M2 $La_{post} = 9.1 \pm 3.0$ M3 $La_{post} = 8.4 \pm 2.1$
Chaabène et al., 2013. [90]	Elite (10)	180 [b]	$La_{post} = 11.14 \pm 1.82$
Chaabène et al., 2014. [70]	Elite (14)	180 [b]	$La_{pre} = 1.73 \pm 0.54$ $La_{post} = 11.18 \pm 2.21$
Kata			
Reference	Subjects (N)	Kata (style)	[La] mmol/l
Bussweiler and Hartmann, 2012. [86]	Different levels (6)	*Heian II, Shotokan* Once (t = 31.9 ± 2.9s) Twice (t = 63.6 ± 6.9s)	4.6 ± 1.1 (1st session) 4.5 ± 0.2 (2nd session) 6.9 ± 1.1
Doria et al., 2009. [25]	Elite (3)	*Unsu, Shotokan* (t = 138±4)	$\Delta La = 6.5 \pm 1.3$
Arriaza, 2009. [96]	World championship participants (9)	NR	8.79 [6.8 - 10.6]

Reference	Subjects (N)	Match duration (sec)	[La] mmol/l
Imamura et al., 1999. [91]	Black belts (7)	Different katas in 20 min	1.4 ± 0.4
Zehr and Sale, 1993. [12]	Black belts (4)	*Seisan, Shito ryu* Normal (8-10 min) Fast (8-10 min)	0.75 ± 0.3 1.43 ± 0.29
Vujkov et al., 2015. [87]	Elite (9)	Unsu, NR	warm-up 2.15 ± .29 3 min 7.11 ±3.29 6 min 4.65 ± .86 9 min 5.07 ± 2.14

[La] - Blood lactate concentration; La_{pre} - BLC before match; La_{post} - BLC after match; [a] - Referee stoppage taken into account; [b] - Referee stoppage not taken into account; NR - Not reported; ΔLa - Difference between highest lactate values after and before match; t - Duration of kata in sec.

To summarize, the aerobic system is the main source of energy independently of the competitive discipline (kata and kumite). Researchers are unanimous in the opinion that the aerobic capacity is necessary to prevent the occurrence of fatigue during work and to expedite recovery between matches and rounds [6, 16]. It is necessary to develop both aerobic and anaerobic systems in order to achieve best performance in both competitive disciplines.

CONCLUSION

This chapter evaluates success factors for competitive karate found in available research, which have been systematized according to anthropometric characteristics, basic and specific physical abilities, and physiological characteristics. From the presented sections, the following parameters have been singled out as important for competitive success in karate disciplines.

As regards anthropometric characteristics, smaller proportion of fat in body structure is advantageous to both competitive disciplines, while a vertically developed skeleton and greater longitudinal dimensions play a major role in sports performance of kumite athletes. Explosive power and speed are important basic abilities for both kata and kumite, whereas flexibility in kata and agility in kumite competitors are highlighted. Certainly, in order to achieve significant results in karate sport, it is essential for all basic physical abilities to be at optimum levels, as this will provide a good basis for further development of sport-specific skills. Technique effectiveness is directly dependent on the ability to achieve movement through a successive kinematic model, that is, on the ability to timely start and stop each body segment that participates in the movement. At the same time, it is necessary that the deviation from the ideal path in technique performance is the least possible, and that the joint angles are in such a range that ensures the delivery of the maximum power movement. The speed of muscle contraction and speed of muscle relaxation are equally important. Kata competitors should achieve strong static balance at the end of the technique, whereas kumite competitors should have the ability to establish proper distance for the realization of scoring techniques. Besides exceptional technique, kumite athletes should have well-developed motor skills (primarily speed, explosive strength, coordination, flexibility and accuracy) and functional abilities for high sports achievements.

With respect to physiology, it appears that the aerobic system provides most of energy needed in either competitive discipline. In kumite, the ATP-PCr system is equally determinant, since it provides energy during decisive actions (i.e., attack and/or defense). Considering anaerobic glycolysis, it should be noted that its contribution cannot be neglected, but it seems to be lower than that of aerobic and ATP-PCr energy systems. During kata, major energy production seems to be provided through the ATP-PCr system. Since this aerobic contribution is related to kata duration (the participation of aerobic energy system rises with increased kata duration), it can be considered as the main source of energy responsible for its regulation. Therefore, special attention should be given to the development of aerobic capacities for top sports performance in both competitive disciplines.

With the appropriate knowledge of individual characteristics and the implementation of training methods based on relevant success factors, coaches should be able to enhance the athletes' competition performance. However, for top competitive achievements in karate, it is essential to reach the balance between all of the factors mentioned above.

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About the Editor

Patrik Drid

- 2005 PhD University of Novi Sad, Novi Sad / Major Field of Study: Sport Sciences
- Member of several international juries for scientific conferences.
- Reviewer of several international scientific journals.
- Published in more than 200 papers in international and national journals and conferences (*Medicine and Science in Sports and Exercise, Nutrients, European Journal of Nutrition, Nutrition, Applied Physiology Nutrition and Metabolism, Journal of Strength and Conditioning Research, Science & Sport, Collegium Antropologicum, Kinesiology, Archives of Budo, Journal of Human Kinetics, Medicina dello Sport, HealtMed, TTEM*...)
- 6th DAN in Judo; International A category Referee;
- Chairman of International Sambo Federation (FIAS): Students Commission
- Chairman of European Sambo Federation (ESF): Youth and Students Commission;
- Members of executive Committee ESF
- Technical Delegate – Sambo, International University Sports Federation (FISU)

His research is focused on physiological responses to maximal and sub maximal exercise in judo. Besides, in last couple of years HE is focused on molecular hydrogen administration on biomarkers of acid-base homeostasis and post-exercise recovery in judo athletes as well as on effects of oral guanidinoacetic acid in human nutrition.

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