Strength and conditioning programme design for combat sports

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Review

Strength and Conditioning Programme Design for Combat Sports

***Ian Lahart*[1] *and Paul Robertson*[1]**
[1]University College Birmingham, UK

Abstract

Effective strength and conditioning programmes are designed to optimally prepare athletes to meet the specific demands of their particular sport. Due to the unique and highly specific nature of each combat sport, strength and conditioning professionals are faced with a particularly complex challenge. This chapter presents an analysis of the three very different combat sports of amateur boxing, taekwondo, and judo. Each of these combat sports requires competitors to perform a diverse range of technical movements and skills, elicits a specific metabolic response during actual competition, and necessitates the possession of distinct physiological characteristics for performance at elite levels. Therefore, strength and conditioning programme design for each sport requires a different and multifaceted approach. Sports-specific skill-based high-intensity interval training, Olympic weightlifting exercises, circuit training, plyometrics, and complex training are strength and conditioning methods that can all be tailored to meet the specific technical and physiological demands of actual competition. The following chapter provides strength and conditioning professionals with a rationale for these training methods and sample sessions demonstrating how they can be applied to each of the three combat sports.

Keywords: *Judo, Taekwondo, Boxing, Complex Training, High Intensity Training, Plyometrics*

The nature of combat sport is to strike, throw or grapple with an opponent [59]. However, each combat sport is highly individualized and requires unique actions and techniques. For example, taekwondo involves only kicks and punches, while judo prohibits punching and kicks in favour of throws and grappling. In addition to this, individual combat sports have differing rules

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[1] Please address correspondence and requests for reprints to Ian M. Lahart, Sports Therapy Department, University College Birmingham, Summer Row, Birmingham, England, B3 1JB or e mail i.lahart@ucb.ac.uk.

and regulations. For example, in Greco-Roman wrestling only use of the arms and upper bodies are permitted, whereas in freestyle wrestling, athletes can use their arms, upper body, and legs and may hold opponents above or below the waist [56]. Furthermore, combat sports have different contest formats, for example, judo consists of one continuous 5-minute bout, whereas taekwondo contests consist of three 2-minute rounds [49, 113]. Therefore, due to the different actions, techniques, and contest rules and formats, each combat sports represents a unique challenge to the strength and conditioning professional.

Specifically, this chapter will examine the three combat sports of amateur boxing, taekwondo, and Judo. Along with freestyle and Greco-Roman wrestling, these three combat sports represent the five Olympic combat sports. In accordance with the law of specificity, to be effective, strength and conditioning programmes for any of these three sports must stress the physiological systems specific to that particular sport. To do this we must first understand the physiological effects elicited during and after competition in the sport. Once these effects have been analysed, a strength and conditioning programme can be designed to adequately stress the physiological systems required for competition and simulate the conditions elicited during actual competition in the training environment.

With this in mind, the first part of this chapter aims to provide strength and conditioning practioners with the latest findings from the literature in regards to the specific technical and metabolic demands that these sports place on participants. In addition to this, the physiological characteristics of elite competitors will be explored to find possible determinants of successful performance in each sport. In part two of the chapter, these findings will then be applied to the design of strength and conditioning programmes for the three combat sports. Both advanced and traditional training methods, specific to each sport and supported by scientific evidence, will be investigated.

Part I. Technical and Physiological Analysis of Combat Sports

Technical and Physiological Analysis of Amateur Boxing

Boxing is an intermittent contact sport, characterised by bouts of short duration high-intensity activity [52]. This high-intensity activity is comprised of a high punching rate and punching force, and dynamic footwork [94]. Currently, boxing in the Olympics allows only amateur participation, and consists of four 2-minute rounds, separated by 1-min rest periods, but this is due to change to three 3-min rounds in 2009. The aim of boxing is either to score more points than your opponent or stop your opponent within the contest duration. A point is scored if a punch is not blocked or guarded but lands directly with the knuckle part of the closed glove of either hand on any part of the front or sides of the head or body above the belt, but not on the arms. The outcome of a contest is either decided by the referee within its designated duration, or by 3 to 5 judges using the CSS computer scoring system if the fight goes the distance [1].

For strength and conditioning programme design purposes it is important to understand the energy pathways that predominate during sports competition. The majority of combat sports require a combination of the three energy systems. Combat sports consist of the performance of intermittent high-intensity short duration bouts of activity, which is predominantly fuelled by the anaerobic pathways of ATP and creatine phosphate (PCr) hydrolysis (phosphate system) and the degradation of muscle glycogen to lactate (lactate system) [112]. However, a significant contribution from the aerobic energy system has also been shown in high-intensity exercise lasting just 6 seconds [36]. Furthermore, this aerobic contribution has been shown to increase when high-intensity, short duration activity is repeated or sustained [14, 36, 73]. In addition to this, athlete’s with a high level of aerobic fitness appear to recover faster from high-intensity activity than less aerobically fit athletes [103]. Thus, although the anaerobic energy systems predominate during boxing activities, the aerobic energy system has an important role in both the execution of and recovery from multiple high-intensity activity. The percentage contribution of the anaerobic and aerobic energy systems to boxing has been estimated as 70-80% anaerobic and 20-30% aerobic [41].

Limited research exists regarding the physiological response to boxing performance. Furthermore, the physiological impact of competition is dependent on a boxer’s style and the tactics employed throughout a contest. Khanna and Manna [52] investigated the physiological response to actual boxing rounds (3 x 2 minute rounds) during competitive trials compared to graded treadmill exercise which simulated actual boxing competition (3 x 2-min bouts of exercise performed at progressively higher intensities, separated by a 1-min rest). When comparing the actual boxing rounds to graded exercise, the authors reported that the actual boxing round elicited significantly higher maximal (183-184 bpm vs. 177-180 bpm) and recovery (161-168 bpm vs. 138-146 bpm) heart rates, and blood lactate levels (7.1-9.9 mmol/L vs. 6.5-9.7 mmol/L) for all weight categories [52]. High lactic acid concentrations highlight the intense nature of boxing competition and reflect the contribution of the lactate system to meet energy demands.

Smith [93] compared post competition blood lactate values collected after different contest formats and scoring systems using data gathered between 1987 and 2004. The highest post contest blood lactate values (13.5 mmol/L) were recorded after the current format of four 2-minute rounds using computer scoring, compared to 9.5 mmol/L after three 3-minute rounds, and 8.6 mmol/L after five 2-minute rounds using computer scoring systems. The differences in lactate values between the different contest formats may be related to changes in tactical strategy and training methods [93].

In the future format (3 x 3-min rounds) there is an emphasis on the boxer to perform more frequent repeated bursts of high-intensity punching throughout the contest, thus, increasing the physiological demand on the athletes reflected by elevated lactate levels [94]. Smith [93] reported higher lactate concentrations and maximal heart rate values (>200 bpm) during actual boxing than those found in Khanna and Manna [52]. This may be explained by the shorter bout duration of the actual boxing (4 vs. 3 rounds), and the fact that Khanna and Manna [52] recorded heart rate values at the end of each round, while Smith [94] measured heart rates continuously during each round. Therefore, as Khanna and Manna [52] were unable to detect heart rates during periods of high-intensity activity during the actual rounds, the reported heart rates would be expected to be lower than in Smith [93].

Physiological Characteristics of Elite Amateur Boxers

Unfortunately, there are few studies that have investigated the physiological characteristics of amateur boxers. Furthermore, the application of this literature is limited by the changes in contest format by the AIBA, from 3 x 3 minute rounds to 5 x 2-min rounds in 1997, in 2000 to the 2008 format of 4 x 2 minutes with 1-min rest, and again to the new format of 3 x 3-min rounds with 1-min between rounds [1, 2, 93]. As seen above these modifications in contest format have changed the physiological demands of boxing and in turn the physiological characteristics of the athletes.

Guidetti and colleagues [42] investigated whether a relationship existed between certain physiological characteristics of elite amateur boxers and their ranking as decided using AIBA ranking criteria. The 8 elite Italian national middleweight (75-81 kg) boxers in this study possessed a mean VO_2max of 57.5 ml/kg/min. The mean VO_2 at which lactate threshold (LT) occurred was 46 ml/kg/min, which equated to 78.4% of the average VO_2max. The boxers mean body fat percentage was 14.5 $\pm$ 1.5 %, the mean grip strength was 58.2 $\pm$ 6.9 kg, and the mean wrist girth was 17.6 $\pm$ 0.6 cm^2. The variables found to be most related to boxing competition ranking were the individual anaerobic threshold and the handgrip strength, while moderate relationships were reported for VO_2max and wrist girth. However, wrist girth may not be a useful parameter to identify boxing talent because increases in this measure would be an expected as an adaptation to biochemical usage [42].

Recently, Khanna and Manna [52] reported mean VO_2max values of 61.7 ml/kg/min and 54.6 ml/kg/min in senior ($\geq$ 19 year of age) and junior (< 19 years of age) Indian amateur boxers, respectively. Compared to junior boxers, the senior boxers were found to possess a mesomorphic body conformation, significantly higher body fat percentage (16.4 % vs. 12.2 %), power-to-body weight ratios (6.5 W/kg BW vs. 4.9 W/kg BW), back strength (156.5 kg vs. 125.7 kg), and both left and right grip strength (left = 50.1 kg vs. 44.9 kg; right = 62.7 kg vs. 45.6 kg). In addition to this, senior boxers were able to work at higher intensities than their junior counterparts, as evidenced by the finding of significantly higher mean maximal heart rates (191 bpm vs. 186 bpm) and peak lactate levels. Due to the performance inhibiting effects that excessive blood lactate is associated with, it can be said that the higher the intensity at which an athlete can work at without an excessive accumulation of blood lactate, the longer and harder that athlete can exercise [7]. Thus, a higher LT allows a boxer to perform at a higher intensity level during subsequent rounds, delaying the detrimental affects associated with lactic acid accumulation [52].

A recent study investigated both the physiological demands of amateur boxing and the physiological profile of senior and junior England international amateur boxers [93]. A mean total skinfold of 22.3 mm and mean body fat percentage of 9.1% was reported for the senior boxers, while the junior boxers possessed higher mean total skinfold and mean body fat percentage of 23.8 mm and 10.1 %, respectively. The mean VO_2max values of senior boxers was 63.8 ml/kg/min, which was significantly higher than the 49.8 ml/kg/min reported for the junior boxers. The boxers' mean heart rate at a blood lactate of 2 mmol/L (LT) and 4 mmol/L (onset of blood lactate accumulation or OBLA) was reported as 151 bpm and 174 bpm, respectively. The lactate threshold was reached at 68% of VO_2 max, while OBLA occurred at a mean VO_2max percentage of 86%.

Along with exhibiting dynamic footwork and high punch rates, amateur boxers require the ability to punch with a high amount of force. Smith et al. [94] demonstrated using lead and rear straight punching of a boxing dynamometer (CV = 1%) that elite boxers punched with more force than both intermediate and novice boxers, and that all levels of boxers punched with greater force with their rear compared to their lead hands. The higher punch force generated by the elite boxers was said to be related to their greater experience over the intermediate and novice, and the emphasis on the production of a forceful rear punch in elite competitions that use computer scoring [94]. Whereas, the higher rear punch force (elite = 4800 N) compared to lead hand (elite = 2847 N) reported was attributed to the force generated by the legs, increased body rotation, and the greater distance over which the long-range straight rear punch is thrown [46].

In summary, actual boxing rounds elicit maximal heart rates exceeding 200 bpm and 184 bpm was measured at when measured throughout four 2-minute rounds and at the end three 2-

minute rounds, respectively. Post contest lactate levels of 13.5 mmol/L and 9.9 mmol/L have been recorded after four 2-minute rounds and three 2-minute rounds, respectively. Currently, elite amateur boxers possess mean body fat percentages ranging from 9.1 % to 16.4 %, and show a mesomorphic body conformation. Mean VO_2max values of elite amateur boxers range between 57.5 ml/kg/min and 63.8 ml/kg/min, reflecting the need for boxers to perform at a high percentage of VO_2max. Previous studies have shown that elite amateur boxers possess high anaerobic capacities, such as mean LT between 68% and 78.4% of VO_2max, mean OBLA of 86% of VO_2max, and a high mean power-to-body weight ratio of 6.5 W/kg BW. In addition to this, elite amateur boxers require the ability to punch with mean forces of 4800 N with the rear hand and 2847 N with the lead hand.

Thus, the physiological demands of the amateur boxing require a well developed cardiovascular system, the ability to tolerate high levels of lactic acid, and the capacity to recover quickly between bouts of high-intensity activity. The aims of strength and conditioning for boxing should be to maintain a relatively low body fat percentage, attain a mesomorphic body conformation, improve the efficiency of the aerobic system, increase the capacity of the ATP-PC system, enhance lactate threshold and tolerance to lactic acid accumulation, improve recovery between intense bursts of activity, and increase the amount of force generated with each punch.

Technical and Physiological Analysis of Taekwondo

Taekwondo is a Korean martial art that was introduced as an Olympic sport in the 2000 Sydney Olympics. Olympic taekwondo bouts consist of three 2-min rounds (reduced from 3 x 3-min rounds in 2005), and depending on their weight category competitors may fight several times during the same day [113]. Points are scored by kicks to the torso and head or by punches to the head only, with sufficient force to displace the body segment [116]. Matches are either won by knock-out or points. Typically most points are scored from kicks, with very few points coming from punches and penalties [51].

Analysis of taekwondo competitive bouts in the 2000 Olympic Games revealed that kicking accounted for 98% of all techniques used to score, whilst offensive techniques were more commonly used to score than defensive techniques (275 vs. 204 for men, and 273 vs. 242 for women) [51]. Interestingly, non-winners scored a higher percentage of their points with offensive techniques than male winners (63% vs. 57%), while male winners scored considerably more with defensive techniques than their unsuccessful counterparts (46% vs. 38%). Similarly, another study discovered that 43% of all head blows were inflicted by an opponent's counter-attack [55]. This suggests that although an offensive technique gains a higher amount of points the ability to score with defensive techniques may differentiate between winners and non-winners.

In addition to this, Koh and Watkinson [54] investigated video analysis of 35 incidents of head blows in 48 matches in the 1999 world taekwondo championships, and reported that shorter opponents received head blows (47%) more often than taller (26%) or similar stature opponents (26%). Of these head, 66% were received in a closed sparring stance where the body is protected, which results in the head becoming the main target. No evasive manoeuvres were performed, which may be due to athletes overly concentrating on offence, poor anticipation, or greater training in kicking skills rather than blocking skills [54].

Evidence of the effectiveness and prevalence of kicking techniques can be provided by studies investigating the frequency of head blows and time-loss injury during taekwondo competition. In a previous study, roundhouse kicks followed by spinning kicks have been shown to inflict most time-loss injuries in both male and female taekwondo athletes, due to the greater velocities generated with these kicks [10, 78]. Koh and Watkinson [54] reported that head and face blows were most frequently inflicted by axe or roundhouse kicks (axe = 70%; roundhouse = 20%) involving the leading or front foot (57%). While, Beis and colleagues [10] reported that roundhouse kicks and axe kicks were responsible 50% and 33% of head blows, respectively.

Elite taekwondo athletes require the ability to kick and punch with repeatedly with great speed and force throughout a competitive contest. Chiu et al. [21] researching a new measurement system for taekwondo athletes, reported speeds of 80.2 to 90.9 km/h for roundhouse kicks and 78.9 to 85.7 km/h for back kicks. The device also measured roundhouse and back kick force values of 78.9 to 92.5 kgf and 72.1 to 85.7 kgf, respectively. Serina and Lieu [89] noted that roundhouse kicks travel at great speed (15 m/s) and have a high potential for inflicting soft-tissue injury, while back and side kicks can generate large chest compressions.

Heller and colleagues [43] analysis of two 2-min rounds of competitive taekwondo fighting revealed that typical bouts consisted of repeated 3 to 5 s of high-intensity activity alternated with periods of low-intensity. In addition to this, the authors observed heart rates of 100% of maximal heart rate and lactate concentrations of 11.4 mmol/L during competitive taekwondo. Bouhel and colleagues [17] reported that simulated taekwondo competition, consisting of a three 3-min rounds, with 1-min rest periods between each round, elicited heart rate and lactate values of 197 bpm and 10.2 mmol/L, respectively. The lactate levels in this study were only slightly higher than that found by Heller et al. [43] after two shorter rounds of 2-min duration (10.2 mmol/L vs. 9.9 mmol/L). Unfortunately, no studies to date have examined the actual physiological effects of the new three 2-min round contest format.

Physiological Characteristics of Elite Taekwondo Athletes

Due to the change in taekwondo contest format from 3-min rounds to 2-min rounds, caution is advised when interpreting data pre-2005, as it may reflect as accurately the changed physiological demands of the sport. Markovic and colleagues [65] reported that successful female taekwondo champions possessed somewhat lower body fat percentages (by 2.3%) and were slightly taller (by 5.8 cm) than less successful ones. In agreement with this, Kazemi et al. [51] although not significant found that winning taekwondo athletes tended to be younger in age, taller, and possess slightly lower BMI than their weight category average. The authors suggested that taller competitors had an advantage over opponents of lesser stature due to a longer reach, leaner body, and longer lever, which helps them cover larger distances expending less energy.

Goa [38] observed that 30 elite Chinese male Taekwondo athletes predominantly possessed an ecto-mesomorph somatotypes, well developed muscles, and low subcutaneous fat. Analysis of male and female elite taekwondo athletes from the Czech national team revealed that the athletes possessed body fat percentages 8.2% and 15.4% for male and female athletes, respectively [44]. These body fat percentages were lower than that found in Taiwanese Taekwondo athletes (male = 13.2%; female = 19.4%) [61], and in male Tunisian national team Taekwondo athletes (11.8%) [17]. Overall successful taekwondo athletes tend to possess, with lower body fat percentage, increased muscle mass and taller, leaner bodies [37, 44, 51]. Gao et al. [37] suggested that lower body fat percentages and higher lean body mass are needed to gain the highest aerobic capacity.

To enable relatively fast recovery between rounds and fights, and also during and after training sessions, it is vital taekwondo athletes possess an adequate aerobic capacity. Rapid recovery allows an athlete reduce the amount of recovery time required between the performance of high-intensity exercise, and is especially relevant in sports such as taekwondo that demands many repetitions of a sport-specific skill [65]. A study of Czech national taekwondo athletes reported VO_2max values of 54.6 ml/kg/min [44], which was lower than the value of 56.22 ml/kg/min reported in Tunisian national team elite male taekwondo athletes [17].

Due to the explosive high-intensity nature of the sport, taekwondo athletes require high anaerobic power and anaerobic capacity [44]. Markovic et al. [65] reported that successful female taekwondo athletes achieved ventilatory threshold (VT) at significantly higher speeds and lower heart rate, possessed significantly greater explosive power, anaerobic alactic power, and lateral agility than less successful competitors.

Lin and colleagues [61] investigated the anaerobic capacity of elite male Taiwanese taekwondo athletes preparing for 2004 Olympics. The Taiwanese taekwondo athletes achieved peak power (Wpeak) and mean power (Wmean) values of 8.42 W/kg and 6.56 W/kg, respectively. These Wpeak values were considerably lower than the 14.7 W/kg BW reported in Czech national Taekwondo athletes [44], elite American senior taekwondo athletes (11.8 W/kg) [76], Tunisian national team taekwondo athletes (12.1 W/kg) [17], and elite kickboxers (18.8 W/kg) [115]. The average power of the Taiwanese taekwondo athletes was also significantly lower than that of the elite American senior taekwondo athletes (9.2 W/kg) [76] and elite kickboxers (10.5 W/kg) [115].

In summary, taekwondo athletes' score most frequently from kicks, whilst adopting offensive techniques or by counter attacking. The emphasis on kicking may mean that opponents are more vulnerable to punching techniques and may not have proper defensive techniques to counter. Therefore, taekwondo athletes should work on punching techniques in addition to kicking techniques. Taekwondo is a sport which requires great kicking speed and force. Roundhouse kicks generate the highest kick speed and force, while axe, roundhouse, and spinning kicks inflict the most blows to the head and face. While, shorter athletes, a closed stance, and a lack of offensive action with an absence of blocking skills is associated with an increased risk of head and face blows. Thus, taekwondo athletes should place more emphasis on blocking kicks and perhaps adopting evasive strategies used in other sports, such as ducking in boxing.

Taekwondo competition consists of repeated bouts of 3-5 s high-intensity activity alternated with periods of low intensity. Competitive taekwondo bouts of three 3-min rounds, separated by 1-min rest intervals elicit maximal heart rates of 197 bpm and lactate concentrations of 10.2 mmol/L. Therefore, taekwondo performance mainly consists of repeated bursts of sudden, fast and powerful kicks that require a significant contribution from the phosphate and lactate systems, while the aerobic energy system aids recovery between high-intensity activity and increasingly contributes to energy expenditure as the bout continue.

Successful male taekwondo athletes tend to possess an ecto-mesomorphic somatotype, be taller than the weight category average, and possess low body fat percentages (8% to 13.2%). Taekwondo athletes have moderately high VO_2max values of 54.6 ml/kg/min to 56.22 ml/kg/min, highlighting the importance of aerobic conditioning in the recovery between rounds and fights. The importance of the phosphate system is reflected by the high Wpeak scores of 8.42 W/kg to 14.7 W/kg achieved by taekwondo athletes. In addition to this, taekwondo athletes possess high anaerobic capacity values of 6.56 W/kg to 9.2 W/kg for taekwondo athletes. Thus, Taekwondo require lean bodies with low percentages of body fat, high anaerobic power and capacity, and moderately high aerobic capacity.

Technical and Physiological Analysis of Judo

Judo is a predominantly anaerobic, intermittent combat sport [35] requiring strength [58], quickness, balance, and explosiveness [60]. In addition to the physical demands, the sport has a large technical component and as athletes wear a *gi* (jacket type garment secured with a belt) when competing it has been suggested that judo is more technical than other grappling type sports such as wrestling [4].

Judokas (judo athletes) utilise throwing techniques to force an opponent to the ground, and once on the ground, groundwork to pin an opponent or force them into submission. Similar to boxers and taekwondo athletes, *Judokas* are split into weight categories and at senior level bouts are scheduled for 5-min real-time (i.e., clock is paused when bout is paused e.g., for injury). The *judoka* accumulating the most fractional points during this period will win the bout. However, if an *ippon* (a full point) is achieved by a judoka before this period ends, the bout will cease and that player will be awarded the victory. An *ippon* can be achieved in several ways, such as by accumulating sufficient fractional points, by throwing an opponent directly onto their back, by pinning an opponent on their back for 25 s, or by forcing an opponent to submit utilising a chokehold or joint lock [49].

If scores are level at the end of the 5-min period then the first judoka to score any form of point will win the contest during a subsequent 5-min "golden score" period. If no point is scored during this period then the three judges will indicate who they believe was the most aggressive and dominant judoka throughout the bout and award them the victory. Therefore, being able to achieve *ippon* and ending the bout as quickly as possible is beneficial as *judokas* may compete several times a day with as little as 15 mins separating contests [35].

The physiological demands of judo competition can vary due to the variety of tactics and techniques available to the *judoka*. *Tachi-waza* (standing combat) predominates over *ne-waza* (groundwork combat) in simulated combat with twelve sequences of *tachi-waza* lasting on average 21 s compared to six sequences of *ne-waza* lasting on average 11 s [34], furthermore in elite judo competition *judokas* utilise *ashi-waza* (leg techniques) in preference to *te-waza* (arm techniques) possibly due to *ashi-waza* inducing less O_2 uptake than *te-waza* [34]. Furthermore, Franchini and colleagues [34] found that use of *te-waza* was positively correlated with post-bout blood lactate concentrations.

Almansba et al. [3] highlighted that judokas of different statures may adopt different approaches with lighter *judokas* (< 66kg) adopting more arm techniques such as *seoi nage* (one-arm shoulder throw) as their stature allows them to perform throws at a quicker rate and with less effort. However, Blais and colleagues [12] in their 3-dimensional analysis of the *morote seoi nage* (two-arm shoulder throw) technique identified that the main driving moments and greatest energy expenditure in this so-called arm technique come from the lower limbs and trunk through all phases of the throw. Therefore perceived demands may not necessarily match actual demands for certain techniques.

In addition to the demands of throwing actions upon the *judoka*, being thrown and avoiding conceding an *ippon* places significant stress upon the cervical region of the spine [5, 53]. The *o goshi* (hip toss) technique is executed in an average time of 0.29 s and has been found to subject the body and head to forces similar to those observed in road traffic accidents [53]. Furthermore, Kochhar and colleagues [53] observed that in elite *judokas* impact with the floor resulted in a mean posterior translation of the head of 6.2cm from a starting position of 4-5cm anterior translation, followed by mean anterior translation of 4-5cm, suggesting a significant risk of cervical injury that may be exacerbated by poor technique and inexperience. Additionally, when thrown *judokas* will often attempt to "post" on their head in order to avoid conceding an *ippon* (landing wholly on their back) further increasing the risk of cervical spine injury [5].

The high-intensity nature of judo combat is reflected by the short durations of high-intensity combat (10 to 30 s) and rest periods (10 s), in addition to the work-to-rest (W: R) ratios of 1.5 and 3: 1 reported in the literature [35, 33]. Average heart rate values of 92% of age-predicted maximum heart rate have been measured during 5-min of simulated judo combat [27], while similar heart rate values of 181 bpm (91.4% of maximum heart rate) have been reported during actual judo competition [15].

The anaerobic nature of judo combat is demonstrated by post-bout blood lactate concentrations of 10 (± 2.1) mmol/L found in male national and international Brazilian *judokas* (mass < 100kg) [35]. These findings highlight the contribution of anaerobic glycolysis to energy production, and are similar to other post-bout blood lactate concentrations found in *judokas* across weight categories and competitive levels [27, 34, 35].

However, whilst post-bout blood lactate concentrations indicate significant anaerobic contribution to energy production the high levels of aerobic power seen in judokas point to an important role played by aerobic metabolism in energy production for judo competition. Degoutte et al. [27] found significant increases above resting values in free fatty acids, triglycerides and glycerol when measured 3 mins after a simulated 5-min combat situation, thus implicating lipid metabolism despite mean post-bout plasma concentrations of lactate of 12.3 mmol/L. However, Degoutte and colleagues [27] also noted a mean carbohydrate intake of < 332g/day, well below the recommended daily amount for a non-athletic population, therefore the *judokas* glycogen stores may not have been at maximum resulting in a greater reliance on aerobic metabolism for energy production during the bouts.

Physiological Characteristics of Elite Judokas

The demands of judo combat suggest a successful *judoka* would possess specific physiological characteristics that would match these demands and that by using these characteristics *judokas* of differing levels could be distinguished. It appears that this is the case with some but not all characteristics; this could be explained by some *judokas* utilising their technical and tactical superiority to compensate for their physical deficiencies.

Anthropometric characteristics, including fat free mass, do not appear to differentiate *judokas* competing at different levels, although body fat percentage in male *judokas* regardless of level does not appear to exceed approximately 13% [33, 35]. Kubo and colleagues [58] found an average fat-free mass of 74.9 kg in a sample of *judokas* from 7 weight categories who competed at the Olympics or Asian games, which was significantly higher compared to non-competitive university judo club members. Nonetheless, fat free mass differences did not significantly differ between the higher-level *judoka*s and competitive university club members suggesting that other factors may account for performances variations at higher levels.

In addition to the differences in fat free mass, Kubo et al. [58] found that the highest-level *judokas* possessed significantly greater height normalized values for elbow extensor (2.8 mm vs. 2.5 mm) and flexor (2.2 mm vs. 2.0 mm) musculature thickness compared to the non-competitive university club members. No significant differences were found with any other muscle thickness measurements taken (abdomen, forearm, knee extensor, knee flexor, plantar flexor, dorsi flexor, and subscapular). The greater elbow flexor and extensor muscle thickness characteristic of higher-level *judokas* may be due to the importance for the *judoka* to control the distance between them and their opponents, and the role that the elbow musculature plays in this [5, 58].

Whilst Kubo and colleagues [58] did not measure strength in addition to muscle thickness, Franchini et al. [33] did find a significant positive correlation between limb circumferences and measures of strength. However, neither measure differentiated between the A (starters), B and C (reserves) teams of the Brazilian national judo squad. Nevertheless, as all of these athletes could be classed as elite and undergo similar training it may be difficult to use such measures to differentiate between them. Despite not differentiating between levels, it should be noted that across the 7 weight categories tested, *judokas* achieved high 1 repetition maximum (1RM) bench press, row and squats scores of 1.24 kg/kg BW, 1.16 kg/kg BW, and 1.44 kg/kg of BW, respectively.

Although, VO_2max values exceeding 60 ml/kg/min have been measured in *judokas*, lower values of 48.3 ml/kg/min have also been found in elite competitors [34, 35]. In one study although, *judokas* with higher VO_2max values performed better in an intermittent, judo-specific throwing test, aerobic capacity was not found to be a distinguishing factor between competitive levels [35]. It must be taken into account that in these studies the sample consisted of *judokas* from a range of weight categories, and therefore, the mean scores reported may be distorted due to the variation in body mass within the sample. Franchini et al. [33] did account for this by demonstrating that in their sample as body mass increased aerobic power, as expected, decreased, and in studies consisting of athletes from a single weight category VO_2max values in excess of 50ml/kg/min have been obtained [27].

Franchini and co-workers [35] demonstrated that performance in high-intensity intermittent exercise (4 x upper body Wingate test, with 3 min passive recovery) significantly distinguished between levels, with the two higher-level groups achieving a greater amount of work over the 4 trials than the lower level group. Although, there were no significant differences in blood lactate at any time, Wpeak in all 4 trials, or Wmean in the first trial, it was the ability to maintain high power outputs for longer in subsequent trials that differentiated the groups. This highlights that the intermittent aspect may be the most important for judo success. Moreover, Franchini et al. [34] found positive correlations between the number of attacks initiated in combat, performance in two upper body Wingate tests separated by 3 min recovery, and performance in the intermittent specific judo test. Furthermore, the Wingate protocol and the specific judo test produced similar blood lactate values to 5-min of judo combat.

In summary, judo combat is primarily a high-intensity, intermittent anaerobic activity, as evidenced by the high average heart rates (92% of maximal heart rate) and lactate concentrations (~10 mmol/L) observed during simulated and actual judo competition. The ability to produce high levels of work repeatedly characterises high-level judo performance and distinguishes *judokas* of different competitive levels. Due to the range of VO_2 max values observed and the range of options available to competitors during combat in terms of technique and tactics, elite status may be achievable without high levels of aerobic capacity. However, high levels of aerobic capacity may help to maintain power output when anaerobic energy production decreases. In addition to this, due to the performance of multiple judo bouts in one day, high-levels of aerobic fitness may allow more complete recuperation between bouts.

While, strength may not differentiate between levels in elite *judokas*, high bench press, row, and squat 1RM values were achieved by elite *judokas*. *Judokas* must deal with an external resistance (i.e., their opponent) therefore a certain level of strength and power is required, although judo advocates that it is technique and the ability to utilise the mass of an opponent that can bring success. Elbow flexor and extensor musculature thickness may differentiate between levels *judokas*, perhaps due to their role in maintaining distance and controlling the opponent.

Part II Combat Sports and Strength and Conditioning Methods

Optimal sporting performance requires the use of optimal training methods. To be considered optimal, training methods must be sports-specific, that is to say they should stress the physiological systems associated with performance in a specific sport. Specific training should consist of three components, skill specificity, muscle-group specificity, and energy system specificity. To achieve specificity similarities should exist between the training conditions and those required in the field during competition. Training methods that reflect the intensity and duration of exercise bouts in competition should be incorporated into athlete's programmes.

High Intensity Interval Training (HIT)

Amateur boxing, taekwondo and judo competition involves repetitive bouts of high-intensity exercise. Successful performance in each of these combat sports is dependent on not only maintaining these bouts over the full duration of a match, but also on the ability to recover from each exercise bout [66]. To enhance the performance of and recovery from repetitive high-intensity exercise, high-intensity interval training (HIT) is recommended. HIT may be defined as repeated bouts of short-to-moderate duration exercise (5 s - 5 min) performed at intensities above VO_2max. Recovery can be either active or passive, but of a duration where sufficient recovery is not achievable. The rationale for HIT is to provide adaptation by continually stressing sports-specific physiological components above and beyond the level required during actual competition [90].

HIT is associated with a number of desirable biochemical adaptations and improvements in high-intensity exercise performance. HIT has been shown to enhance the capacity of the ATP-PC system through an increase in intramuscular ATP, phosphocreatine, and free creatine stores, and raised concentrations and activity of specific enzymes, including creatine kinase and myokinase [108]. Furthermore, HIT has been shown to elicit adaptations associated with an improved capacity of the lactate system, including increases in intracellular and extracellular lactic acid buffering capacity, enhanced enzymatic activities related to glycolysis (e.g. phosphofructokinase and lactate dehydrogenase), and raised concentrations of glycogen [62, 26, 63, 74].

In addition to this, HIT can develop the ability of combat athletes' tolerance to the accumulation of lactic acid. This tolerance may be crucial near the end of a contest, for example, Sterkowicz and Franchini [98] observed in judo that the majority of fractional points are scored in the first 2 minutes of a bout at the elite level, this lack of points may be due to fatigue, and the *judoka* who retains the ability to attack in the final minutes may hold the advantage over their opponent as they will be able to continue to accumulate points.

Moreover, HIT may provide a more time efficient method for improving endurance performance comparable to traditional endurance training [39, 57]. HIT training comprising of 4 to 7 bouts of 30 s high-intensity cycling exercise separated by 4 minute recovery, performed six times over 2 weeks, has been shown to significantly improve exercise tolerance during tasks that rely on aerobic metabolism. These HIT sessions doubled the length of time that submaximal exercise could be maintained from 26 to 51 minutes during exercise at 80% of VO_2max [18], and also improved the ability to complete a fixed amount of work (e.g. 10% reduction in time to complete a simulated 30-km cycling time trial) [40]. Findings of this nature demonstrate the effectiveness of HIT to enhance both anaerobic and aerobic capacity, and question the use of traditional non-specific training methods such as long distance running to increase combat athletes aerobic capacity.

As mentioned previously, successful combat sport athletes tend to possess lower body fat levels. In addition to this, most combat sport athletes compete at a weight classification lower than their natural body weight. To avoid the use of performance inhibiting and dehydrating weight loss methods, such as calorie restriction, saunas, and the wearing of wet-suits during exercise, in the final 3-days prior to competition, trainers must identify a time scale for safe weight reduction [94]. HIT has been shown to result in a greater reduction in sum of skinfold measures compared to continuous endurance training [96, 105]. Using interval training intensities of 120% VO_2max, Overend et al. [72] demonstrated that while HIT over 6 weeks resulted in similar increases in VO_2max as endurance training at 80% VO_2max, HIT resulted in a significant decrease in sum of skinfold values from a pre-test level of 39.6 mm to a post-test level of 36.5 mm. Therefore, HIT training provides an effective method of reducing athletes' body fat levels, and in turn controlling body weight.

Sample Sessions for Combat Athletes

The adaptations that HIT elicits are specific to the bout intensity and the work-to-rest ratio employed [43]. Brief, high-intensity ($\leq$ 10 s) bouts with longer recovery periods are proposed to induce an adaptive response in phosphocreatine metabolism, while longer higher intensity intervals (30 - 60 s) are used to produce a greater adaptive response in lactate metabolism [19, 24, 43]. Insufficient recovery periods between repeated HIT have been shown to inhibit phosphocreatine hydrolysis and anaerobic glycolysis, and result in an increased contribution from aerobic metabolism [73]. Thus, to impose adaptations upon specific energy systems the work-to-rest ratio employed must be carefully considered, whilst keeping in mind the specific demands of the sport.

A HIT session specific for boxing and taekwondo would involve repeated intervals of high-intensity sprinting or cycling matching the duration of a round (2 or 3 min), with a 1 min rest period. The aim of these sessions should be to produce concentrations of lactic acid similar to those observed post-competition (> 9.0 mmol/L) [41, 44]. While for judo, work-to-rest ratios of 1.5 and 3: 1 would accurately reflect those observed in actual competition, for example, *judokas* can perform high-intensity exercise lasting between 10 to 30 s, separated by 10 s rest periods, performed over a duration of 5-min [35]. To focus more on developing specifically the capacity of the ATP-PC system high-intensity interval durations of 5 to 10 s with work-to-rest period ratios of 1: 12 to 1: 20 are required, while for adaptations to the lactate system capacity high-intensity interval durations of 15 to 60 s with work-to-rest ratios of 1:3 to 1:5 are recommended [24].

As well as being energy system specific, optimal sports training should also be skill-specific and muscle group-specific. The importance of technique in combat sports means that time spent engaged in non-specific training modalities may be counter-productive as technique may suffer. With this in mind, skill-based HIT sessions utilising pad work, bag work, and sparring (or *randori* for judo) should be incorporated for more sport specific conditioning manipulated to reflect the work-to-rest ratios observed actual competition and effectively develop combat specific anaerobic capacity [5, 80]. For example, interval pad work, such as eight 1-minute rounds with 1-minute recovery, has been shown to be an effective method of stressing the anaerobic glycolytic energy system with lactate values frequently above 10 mmol/L [93]. Pad work is a method of training particularly effective for combat athletes because the coach dictates the training intensity.

Similarly, it has also been demonstrated that specific taekwondo racket (specific taekwondo pads) work exercises can reproduce in part the metabolic impact of competition [17]. The maximal heart rate response and blood lactate values measured during competition were significantly correlated to values measured during performance of 10 s and 3-min of repeated maximal front kicking (onto a racket held by a trainer at abdominal level).While, the 10 s bout of kicking exercise yielded maximal heart rates of 91% of maximal heart rate measured during competition, the heart rate observed in 1-min and 3-min specific exercise bouts was 92% and 100%, respectively [17].

Short duration, high-intensity sparring intervals are vital to simulate the intensity and conditions of actual competition. For this purpose, sparring bouts of 30 to 60 s for 6 to 8 sets with 1 to 3-min recovery between bouts would be effective for boxing or taekwondo. While in judo, the rest periods observed in during competition are not sufficient to allow the judoka to recover, as such rest intervals for HIT should not exceed 60 s [5, 15]. Thus for judo, *randori* intervals of 45 to 60 s with 30 s rest, repeated 5 to 6 times, would be ample to develop the judo-specific anaerobic ability of *judokas*. In addition to developing anaerobic and aerobic capacity, sparring can be used to increase the choice reaction time of athletes, i.e. sensory skills specific to an athlete's sport, described as the shortest interval needed to respond to a stimulus that is presented as an alternative to a number of other stimuli [70, 87].

However, there are some important limitations of this type of reaction time training that should be considered. For example, because training partners become familiar with one another, they can easily predict and anticipate each other's movement, and while this can be effective in training situations, in competition where the opponents are most often unknown, the reaction time will be longer [85]. Therefore, there is a need for combat sports athletes to spar with a large variety of opponents, which may involve travelling to other clubs to prevent this 'anticipation contaminated' choice reaction time training.

Skill-Based Aerobic Conditioning

Shadow boxing is a traditional boxing exercise that has been shown to elicit intensities high enough to produce cardiovascular and aerobic adaptations. Kravitz and colleagues [50] have shown that punching tempos of 108 beats/min and 120 beats/min, established with the use of a metronome, can elicit heart rates consistent with those required to elicit cardiovascular adaptations (heart rates between 85.6% and 93.1% of maximum heart rate, and 67.7 – 72.5% VO_2max). Thus, cardiovascular adaptations can be achieved by employing high tempo ($\geq$108 beats/min) shadow boxing.

In combat sports such as taekwondo, *katas* or forms-based training can be used to elicit aerobic training effects [77,118]. One study demonstrated average heart rates of 176 bpm (89% of maximum heart rate) and blood lactate concentrations as high a 5.15 mmol/L as a result of performing *wushu* (Chinese martial art) based *katas* [81]. Similarly, [25] suggested that judo *kata* (often performed with opponent) is an excellent aerobic exercise for *judokas*.

Strength and Power Training for Combat Sports

Grip strength has been indicated as predictor of boxing success [42], while, the ability to throw repeated punches of sufficient force is a key component of amateur boxing [94]. Similarly, taekwondo athletes are required to perform kicks and punches with enough force to displace their opponents. *Judokas* need to be to able to develop high forces in order to throw opponents despite their defensive resistance, and to perform a wider range of throws, so that they can incorporate more power-based throws into their technical repertoire. In addition to developing throwing specific strength, *judokas* require the development of elbow flexion/extension strength [58] and grip strength [20] in order to obtain an advantageous position, and neck strength to minimise the risk of cervical spine injury. While, isometric strength is not as important during standing fighting, it has an important role during ground fighting [33, 98].

Resistance training, through manipulation of variables such as training modality, frequency, volume, intensity, velocity and rest intervals, can elicit favourable neuromuscular adaptations [100]. Of particular benefit to the combat sport athlete is the potential to increase strength and power. However, due to combat sport athletes competing in weight categories, prudent use of resistance training is required as increases in mass can result from the use of certain protocols.

Strength gains are typically achieved with loads in excess of 80% of 1RM in order to achieve an intensity that will recruit the higher threshold fibres [47, 117]. Rest intervals must be long enough (> 2mins) to ensure that this intensity can be maintained over several sets [111]. Adaptations to training of this nature are primarily neural as the fibres do not undergo enough mechanical work to provoke sufficient protein degradation to induce muscular hypertrophy due to the lower volumes of training [117]. This may be of benefit to the combat sport athlete as greater forces can be exerted as a result of strength training without the gaining of mass, which allows the athlete to remain in their particular weight category.

Whilst increasing the amount of force a combat sport athlete can exert is important, training the athlete to be able to exert force rapidly is equally, if not more important. Working with loads greater than 80% 1RM when utilising traditional power-lifting exercises (e.g. squat, deadlift) will not improve rate of force development (RFD) as the velocity of the movement will not necessarily be sufficient to develop power [67]. Therefore, when the aim is to increase RFD using lighter loads (30-80% 1RM) for traditional power-lifting type exercises, and the use of explosive lifting techniques such as the Olympic lifts (clean and jerk, snatch) and their variations (e.g., power clean, high pull) is recommended as higher movement velocities can be achieved [8]. Similar to strength training protocols the volume for explosive lifting is low and the rest periods between sets must be of sufficient duration to ensure recovery and therefore maintenance of intensity [111]. This is of particular importance with lifts of this nature as neurally they are very demanding [117].

Improvements in throwing technique and increases in the force developed whilst throwing have been achieved utilising a validated judo specific strength-training machine. In addition, were also noted [11, 13]. In the absence of a judo-specific machine, maximal strength weight training techniques, plyometrics, and complex training methods utilising an opponent have all been shown to improve throwing speed [110] and the number of throws achieved in a judo specific throwing test [109]. Villani and Vincenzo [110] utilised a contrast throwing technique known as *butsukari* where a third *judoka* provides additional resistance to a set of throws followed by *nagekomi* (throw without the additional resistance). This method of 3 sets of 2 x 3 *butsukari* followed by a single *nagekomi* with complete recovery between sets significantly improved throwing speed compared to a group utilising *nagekomi* and lifting exercises.

Grip strength can be developed by employing supplemental resistance exercises (e.g. towel pull-ups) in addition to multi-joint, judo-specific strength training [5, 56, 101]. Elbow flexion/extension strength endurance can be developed using loads of up to 80% of 1RM with multiple sets separated by short rest intervals [117]. The need for specific neck musculature training in addition to other strength training methods has been recommended for *judokas* [23]. Amtmann and Cotton [5] proposed 3 sets of 10 to 20 repetitions in a circuit format would be effective for developing neck musculature. All cervical spine movements (flexion, extension, lateral flexion) must undergo the same volume of training unless there is a weak movement that requires a greater volume to bring it to the same level as the other movements [114].

Combat Sports Circuit Training

The requirement of combat sport athletes to maintain force output for the duration of a bout necessitates the development of muscular endurance [71]. A method commonly used by combat sport athletes to enhance muscular endurance is circuit training. An effectively designed circuit may increase capillarization, thereby improving the potential to clear metabolic by-products which in turn can enhance the ability of the muscle to deal with metabolic acidosis during intense exercise [102]. In addition to this, circuits can be designed to safely create a metabolic state similar to that elicited during actual sports competition. This provides trainers with an effective alternative specific conditioning method that reduces the need for continuous sparring, which exposes combat sport athletes to an increased risk of injury [4].

Circuit training sessions can include resistance training exercises only, or a combination of resistance training and conditioning exercises (e.g. sprinting, skipping, shadow striking, etc.).

Both dynamic bodyweight exercises, such as pull-ups/chin-ups, dips, and press-ups, and isometric bodyweight exercises, including squat holds and planks, in addition to partner assisted exercises such as lifting or carrying a partner of similar body mass, can be used in circuit training to effectively develop relative strength [71]. Upper body exercises targeting the trapezius (e.g. inverted body row) can be included in boxing circuits, as research has shown that in all boxing movements the trapezius was the most active muscle in the upper body [117]. Circuits can also include explosive resisted sprints to develop leg power and resisted punching and kicking actions to develop punching and kicking power and speed [95].

Circuit training sessions can be developed in accordance with the specific demands of the sport by matching the work-to-rest ratios of the bouts. For example, a 2-min circuit comprising of eight alternating lower and upper body exercises performed for 15 s, with no rest given between exercises, followed by a 1-min rest, repeated three times for taekwondo. For boxing, perform 8 lower and upper body exercises for 20 s with 5 s recovery between exercises, then rest for 1-min and repeat three times. A judo specific circuit could consist of a 5 min circuit consisting of 10 exercises performed for 20 s each, with 10 s given for changeovers, followed by a 10 min rest, repeated two to three times (see table below for sample exercises).

Table 1. Sample Circuit Training Sessions for Combat Sports

Sample Boxing Circuit Training Session	Sample Taekwondo Circuit Training Session	Sample Judo Circuit Training Session
1. Press-ups with feet on stability ball	1. One-legged squats	1. Pull-ups (with hold*)
2. Lunges with torso rotation holding medicine ball	2. Three-point press-up	2. Static squat
3. Sit-ups with Medicine ball throw	3. Repeated resisted kicks (10% resistance)	3. Woodchop
4. Repeated resisted sprints (10% resistance, 10 m distance)	4. Repeated unresisted kicks	4. Neck Bridge
5. Repeated unresisted sprints	5. Woodchop	5. Tractor tyre flip
6. Towel Pull-ups	6. Squat jumps on to raised platform	6. Mountain climbers
7. Dips	7. Prone dumbbell row in plank position	7. Inverted Body Press
8. Inverted Body Row	8. Side Plank	8. Rope climb
		9. Sandbag clean and shoulder
		10. 2-point plank

*isometric hold ½ way on eccentric phase for 2 s in each rep

Plyometric Training

Both taekwondo athletes and boxers require explosive leg and trunk power in order to displace opponents and score points. While any increase in the amount of force that a *judoka* can develop in the short period of time available for a throw to be executed, provides them with a greater chance to overcome the defensive force exerted by their opponent. Due to the short duration of kick and punches, maximal power cannot be generated; therefore, it is the rate of muscular force development that increases in power are largely dependent on [91]. Plyometric training is a method of choice when aiming to enhance both lower and upper body muscular power [64]. Plyometrics seeks to improve the rate of force development and power output arising from the stretch-shortening cycle (SSC) [16]. The SSC combines mechanical and neurophysiological components, and involves a rapid eccentric muscle action to stimulate the stretch reflex and storage of elastic energy, which increases the force produced during subsequent concentric [79]. Lower body plyometric exercises are primarily based on jumping activities, such as depth jumps, standing jumps, hopping, etc., while upper body plyometric exercises typically include a variety of medicine ball throws and clap push-ups.

There are numerous studies illustrating the effectiveness of plyometric training in improving muscular power. In a meta-analytical review of studies on plyometric studies that investigated the effect of plyometrics on vertical jump height (a measure of leg power), Markovic [64] discovered that most of the previous research has shown that plyometric training is able to improve the vertical jump height in healthy individuals. Toumi et al. [104] reported improvements in jumping height in well trained handball players after combined weight training and plyometric training. Such improvements were not found in the weight-training only group. In another study, 6 weeks of training consisting of a combination of weight lifting and plyometric exercises significantly improved kicking performance, and vertical jump and sprint ability [75]. In regards to the effectiveness of upper body plyometrics, Schulte-Edelmann et al. [88] reported that after 6-weeks of plyometric training, the plyometric training group showed significant improvement in the power generated in the elbow extensor muscles compared to the control group which showed no significant changes in power output.

However, although there appears to be a large evidence base justifying the use of plyometric training for athletes, it is not recommended for inexperienced or poorly conditioned individuals, and should not be performed over prolonged periods due to the risk of injury and the rapid onset of fatigue [79]. Furthermore, due to the number of high eccentric contractions performed during plyometric training delayed onset muscle soreness (DOMS) is invariably experienced, which can impact on subsequent sessions [16]. Highlighting the effect of plyometric training on subsequent sessions, Twist et al. [106] recently demonstrated a latent impairment of balance performance following a bout of plyometric exercise, which the authors suggested has implications for both skill-based activities performed post plyometric training and for increased injury risk following high-intensity plyometric training.

Aquatic Plyometric Exercise

Aquatic plyometric training may be of particular interest to athletes and trainers as it may potentially reduce the risk of injury and the amount of post bout muscle soreness associated with plyometric training, whilst producing power gains equivalent to those seen after land-based plyometric training. Robinson et al. [82] reported that after 8 weeks of either land-based or aquatic plyometric training, participants in both groups experienced similar improvements in muscle power, torque, and velocity. However, the aquatic training group reported significantly less muscle soreness. Similarly, Stem and Jacobsen [97] demonstrated significant improvements in vertical jump performance as a result of land-based plyometric training and aquatic-based plyometric training performed in knee-deep water compared to the control group, while again no significant difference was found between the land-based and aquatic-based group. These findings suggest that aquatic training may produce similar performance improvement compared to land-based plyometric exercise, while potentially reducing injury due to a possible reduction of impact afforded by the buoyancy and resistance of the water upon landing.

However, it appears that the depth of the water has a significant effect on the performance gains possible with aquatic based plyometric exercise. Miller and colleagues [69] reported no differences in vertical jump displacement, peak force, or power values between the control group, a chest deep aquatic-based plyometric group, and a waist deep water aquatic-based plyometric training group. The advice based on current research would suggest that aquatic-based plyometric training could provide a reduced risk of injury while providing equivalent performance gains to land-based plyometric training, as long as the level of the water is knee height or below. However, further research regarding plyometric exercise effectiveness and water depth is needed, in addition to longitudinal research to confirm the potential reduced injury risk associated with aquatic plyometric training.

The following plyometric programme design recommendations have been adapted from Ebben [31]:

Plyometric Training Recommendations

- Athletes should perform only 2-3 plyometric sessions per week.
- Plyometric training should be performed in a non-fatigued state, therefore, it should not be performed after resistance training or sports conditioning sessions.
- Plyometric sets should not exceed 10 reps, and should be performed across a variety of rep ranges, such as sets of 1, 3, 5, or 10 reps, so as to develop explosiveness as well as power endurance.
- Generally, rest intervals between sets should be 5 to 10 times the duration of the set of plyometric exercises performed. For example, if a set of vertical jumps lasts 6 s, the rest interval should be 30 to 60 s duration.
- For beginners a volume of 80 to 100 foot contacts are recommended, while 100 to 120 and 120 to 140 foot contacts are recommended for intermediates and advanced level athletes, respectively.
- When possible perform in knee-deep water [82, 97]

In addition to foot contacts, the intensity of the plyometric exercise should be considered when deciding training volume. Plyometric intensity is based on the muscle activation, connective tissue and joint stress associated with various exercises. Assuming all exercises are performed maximally, a single leg exercise is more intense than its two-legged equivalent. Typically, the higher the jump the greater the ground reaction force (GRF), therefore, the greater stress caused. Jumps with added resistance (e.g. using dumbbells) are classed as moderate intensity due to the limiting effect that added resistance has on the jump height, and in turn GRF. Conversely, jumps performed while reaching the arms overhead result in higher jump heights, and therefore, greater intensity [31].

Table 2. Sample Plyometric Training Session

1. Squat Jumps	2 x 8
2. Split-squat jumps	2 x 8
3. Clap press-ups	2 x 6
4. Plyometric sit-up with Medicine ball	2 x 6
5. Box jump	2 x 5
6. 12 inch depth jump	5 x 3
Volume	81 foot contacts

Complex Training

Power can be developed with the use of heavy loads (80-90% of 1RM), plyometric exercises using body weight, and the use of explosive movements where the athlete moves 30-50% of 1RM as fast as possible [29]. Recently the use of complex training techniques has been advocated as an effective method of improving power by practioners and researchers, including most notably Verkoshanski. Complex Training involves the completion of a strength training exercise using a heavy load (1-5RM) followed after a relatively short period by the execution of a biomechanically similar plyometric exercise [32]. For example, 5 repetitions of a bench press with a 5RM load followed by 8 clap press-ups.

Advocates of complex training purport that the explosive capability of muscle is enhanced after it has just been subjected to maximal or near maximal contractions, which in turn creates optimal training conditions for subsequent plyometric exercise [29]. This effect of prior maximal or near maximal contractions appears to last up to 8-10 min, and is referred to a 'post-activation potentiation' (PAP) [30, 86, 92]. This PAP effect has been acknowledged as providing an opportunity for enhancing force and power production and exceeding performance achieve without prior loading [28]. Ebben and Watts [32] suggest that the most powerful affect of complex training may be neuromuscular, and in particular an increased motorneuron excitability and reflex potentiation, in addition to a possible increase in the motor units recruited, leading to an enhanced training state.

Complex training should only be used after functional strength is developed, basic jump training is performed, and/or after several weeks of sprint and resistance training [22, 45]. Sessions should be designed around the following recommendations of Ebben and Watts [32]:

- The volume of complex training should be low enough to guard against undue fatigue so the athlete can focus on quality.
- Sets of 2-5 of each pair with 2-8 reps of the resistance exercise and 5-15 reps of the plyometric should be performed, with 0-5 min rest between exercises and 2-10 min rest between pairs.
- 1-3 complex training sessions recommended per week with 48-96 hours recovery between sessions.

Table 3. Sample Complex Training Session

Exercises	Sets	Reps	Load	Tempo	Rest
1A. Clean and Press	3	5	5RM	Explosive	30 s sets
1B. Vertical Jump		10	-	Explosive	4 min pairs
2A. Dumbbell Chest Press	3	5	5RM	Slow	30 s sets
2B. Medicine Ball (MB) Drop		10	≥10 kg	Explosive	4 min pairs
3A. Back Squat	3	5	5RM	Slow	30 s sets
3B. Depth Jump		10	-	Explosive	4 min pairs

Blais and Trilles [11] found considerable benefits for *judokas* by performing complex training methods in a 10-week training programme consisting of 2 sessions per week, with 5 sets of 10 repetitions on a judo-specific machine alternated every set with 10 repetitions of a partner throwing exercise. The utilisation of such a machine allows the maintenance, or even improvement, of technique whilst increasing the force developed at appropriate velocities whilst throwing, and minimising the amount of throws an opponent has to be subjected to if a similar protocol was to be followed using an opponent as resistance.

In addition to this, performing near maximal squats (95% 1RM) or depth jumps (plyometrics) prior to throwing also improves throwing speed as more throws can be carried out in a given period of time after using either of these techniques [109]. Both the depth jumps and maximal squats utilise lower body musculature and it is the lower limbs that provide the majority of the force when throwing [12], therefore this musculature must be targeted when developing strength and power if throwing performance is to be improved.

Table 4. Judo Specific Complex Training Pairs

Authors	Modality	Sets	Reps
Blais & Trilles [11]	Judo specific strength machine	5	10 x strength machine/10 x partner throws
Villani & Vincenzo [110]	Opponent(s) as resistance	3	(3 x *butsukari*/1 x *nagekomi*) Repeat twice = 1 set

Conclusion

It is clear each of the combat sports addressed in this chapter place unique metabolic demands on the competitors, and in turn require training strategies that are specific to these demands. Effective strength and conditioning programme design for each of the combat sports is multi-faceted and must look to implement training methods that sufficiently stress the anaerobic and aerobic energy systems, while developing strength and power components in a manner specific to how they are utilised in competition. Due to the technical nature of each of the combat sports, it is recommended that combat athletes integrate specific skill-based conditioning methods, such as pad and sparring-based HIT sessions, into their training. It is advised that in combat sports where maintenance of a particular weight category is important, power and strength training that targets improvements in relative strength should be preferred to traditional high-volume bodybuilding resistance training methods. The methods recommended in this chapter include Olympic weightlifting exercises, circuit training using predominantly bodyweight exercises, plyometric training, and complex training. In closing, it is important that strength and conditioning coaches employ evidence-based practice when designing training programmes for combat athletes and utilise training methods that are as sport-specific as possible.

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