

Establishing a Standardized Fitness
Test Battery for Karate Athletes

by

Kalan Anglos, CSCS

BA, Vancouver Island University, 2015

A Thesis Submitted in Partial Fulfillment
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Abstract

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The purpose of this study was twofold: to determine the physical demands of the sport of karate and to establish a standardized field-based physical fitness test battery to assess karate athletes. The Physical Demands Analysis (PDA) consisted of a heart rate analysis, a movement analysis of karate techniques by an expert panel, and a review of the current literature. Five experienced karate athletes were monitored using acticals and heart rate monitors during simulated competition to help determine the physiological demands of karate. The results of all parts of the PDA were combined to inform the development of the physical fitness test battery for karate athletes, as well as rationalize the use of the individual tests included in the battery. The PDA identified the physical requirements for karate athletes to be: kicking and punching performance, flexibility, balance, agility, short burst high intensity fitness, and stamina. Therefore, a fitness test battery was developed using field-based tests that measures lower (vertical jump) and upper body (seated medicine ball put) power, hip flexibility (lateral split test), single leg balance (modified bass test), anaerobic capacity (modified 300 metre shuttle test), agility (T-Test), as well as aerobic performance (Leger 20m shuttle run test). While this study provides some evidence on the physiological profiling and fitness testing standards for karate athletes, the proposed physical fitness test battery provides a preliminary

tool for the appropriate steps to analyze karate training and performance, establish normative data for athletes at all stages of development and experience and to determine karate fitness standards.

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DEDICATION

The following pages are dedicated to my parents

- Patricia and Pierre Anglos -

without them, none of this would have been possible.

CHAPTER 1 - INTRODUCTION

Many sport governing bodies recognize the importance of establishing standardized fitness testing protocols for athletes in their respective sports. By doing so, sport coaches, trainers, athletes, and governing bodies can recognize and highlight the areas of fitness that are required for success in their sport. Additionally, it allows them to not only review individual athlete fitness levels, but also how they relate to other athletes in similar stages of development. For example, Karate Canada, the governing body for karate across Canada, has recognized the need to establish and implement a fitness testing battery to their athletes in light of the recent announcement that karate will be the newest combat sport to enter the Olympic games in Tokyo 2020 (International Olympic Committee, 2016).

Combat sport is broadly defined as any competitive contact sport with one-on-one combat. This often resembles "fighting" sports, where two athletes engage in combat in an attempt to overcome the other by either amassing more points, or rendering the opponent disabled. On the Olympic level, sports such as judo, taekwondo, wrestling, boxing, fencing, and (most recently) karate are recognized by the International Olympic Committee (IOC) as combat sports included in the Olympic Summer Games. Other sports that are often viewed by the public as combat sports are kickboxing, jiu jitsu, muay thai and, more recently, mixed martial arts among others. However, these specific sports are not recognized by the IOC as combative sports and therefore do not take part in the Olympic Games. Therefore, for the purposes of this report, a combat sport will be defined as any combative one-on-one sport that is recognized by the IOC and included in the Olympic Games.

Karate has evolved into a popular combat sport that is practiced by athletes worldwide. The sport itself is practiced under a variety of different governing bodies, with the World Karate Federation (WKF) officially providing the rules and regulations for competition. These competitions are further organized into regional, provincial (or state-wide), national and international sectors that are sanctioned either by the WKF, or the Pan-American Karate Federation (PAKF). Each competition is composed of different divisions according to age, sex, skill level (i.e. belt level), and weight category. Additionally, karate is unique to other combat sports in that it provides two different divisions of competition known as *kata* and *kumite*. Kata consists of performing a predetermined set of movements against an imaginary opponent, whereas kumite is the fighting aspect of the sport, where two athletes compete against each other to score points using various striking and throwing techniques (Doria et al., 2009). In competition, kata performances typically last between 1 and 4 minutes, with the goal of having a better execution of techniques than your opponent, as determined by five judges. The winner advances to the next round, where they must perform another (different) kata. In competition, athletes typically have 3-4 rounds in each division to reach the gold medal match. Kata divisions are divided into age by cadet (14/15 years old), junior (16/17 years) and senior (18+ years) as well as by sex (male and female divisions). Karate point-sparring (kumite) on the other hand, consists of two athletes competing to obtain more points than their counterpart by using punches, kicks, takedowns, and defenses. In order for a point to be scored, techniques must be delivered accurately and powerfully to legal scoring areas on the body and head. Kumite matches typically last between 2-4 minutes, with the winner advancing on to the next round. In one division, athletes usually compete in 4-6 kumite bouts in order to reach the gold medal

match. Additionally, kumite divisions are separated by males and females, youth and adult and, like most combat sports, are divided according to specific weight divisions. The WKF and PKF recognizes five weight divisions for senior kumite athletes for both male and female karate athletes. Typically, a competing karate athlete is either classified as a kata or kumite athlete specifically, and only seldom do they compete in both. However, for both divisions, an athlete may compete in up to 3 divisions in one tournament, spanning over several days. The IOC has adopted both kata and kumite divisions to be part of the Tokyo 2020 Olympic Games.

Karate is a physically demanding combat sport that requires many different fitness parameters for success. It is unique from the other combat sports in that it combines certain sport-specific techniques from other martial arts in to its application. Karate performance typically uses both punching and kicking techniques, as well as takedowns. Other combat sports use only one specific type of technique and restrict the others, such as punching in boxing, without the allowance of takedowns, or throws in judo, without the addition of strikes. Overall, activities of karate performance incorporate all muscle groups in both training and competition, including (but not limited to): punching, kicking, blocking, throwing, and executing sport-specific stances. The two forms of the sport used in competition, *kata* and *kumite*, vary in their performance as well as their muscle and energy system use. Kata performance requires slow and sustained energy output with an emphasis on muscular endurance, while kumite athletes require short bouts of high intensity output and high speed muscular power. However for both divisions, a high level of physical fitness has been shown to be required for top-level karate performance (Chaabene et al., 2012). Despite this, the paucity of current literature has led to the lack of physical fitness standards for karate athletes.

It has been argued that no single performance characteristic dominates the success in any of the combat sports including karate (Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012). The limited amount of research that has been conducted on karate athletes has attempted to compare the physical and physiological characteristics of athletes at different stages of competition experience. Physiological fitness components usually include measures of body composition, cardiorespiratory capacity and power, agility, muscular strength and power as well as flexibility. Other research has attempted to assess sport-specific skills including reaction time, coordination, and efficiency of karate-specific techniques (Tabben et al., 2014; Nunan, 2006; Adamczyk & Antoniak, 2010).

It is important to understand the difference between a physiological fitness test, and a skill performance test. Physiological fitness tests measure how well an athlete's energy or muscular systems function during exercise or the performance of their sport. Contrastingly, a skill performance test assesses the effectiveness of an athlete's sport-specific skills. Measures such as reaction time, coordination, and sport-specific techniques are difficult to both reliably measure as well as improve at a physiological level. A standardized physiological fitness test measures the energy and muscular systems of athletes, and allows all athletes of a specific sport to be measured in the same parameters to better make comparisons between novice and elite level athletes. Furthermore, a standardized physiological fitness test battery should include measures of physiological performance that can be improved through training (Maud & Foster, 2006).

Despite the lack of current literature on physical fitness testing of karate athletes, there has been attempts to determine the energetics and physical demands of karate performance. Preliminary research has shown that karate athletes require high levels of cardiorespiratory fitness as measured by aerobic power (Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012). Additionally, it has been shown that elite karate athletes also rely on anaerobic metabolism to support the upper and lower body muscular power (Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004). Finally, high lean body mass appears to be an indicator of highly successful karate athletes (Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998). Despite the limited research that has been conducted on physiological profiling of karate athletes, no studies have attempted to use this information to establish a valid and reliable fitness test battery. Exercise professionals can evaluate data from a fitness test battery to determine the overall effectiveness of a training program, as well as track performance over time (Rhea & Peterson, 2012).

The development of a sport-specific, performance-related fitness test battery for karate athletes is warranted, particularly considering the high performance nature of elite competition. Most Olympic level sports have physical fitness testing standards of, and by establishing a karate-specific fitness test battery and implementing it within current elite athletes, the results can then be used to help provide objective information on the physiological strengths and weaknesses of karate athletes.

When developing a standardized fitness test battery for athletic groups, there should be considerations given to the time constraints as well as facility and equipment requirements that

are required. Furthermore, when assessing a team or large group of athletes, these resources may not be affordable or attainable. Therefore, the use of lab-based tests may not be appropriate. The use of field-based fitness tests that require minimal equipment is a useful strategy for coaches who want to assess their athletes within a restricted time period or with limited resources (McGuigan, 2016). Therefore, for the purposes of this report, an emphasis will be placed on selecting field-based fitness tests that properly evaluate the physiological performance of karate athletes.

Purpose

The purpose of this study was twofold: to determine the physical demands of the sport of karate and to establish a standardized field-based physical fitness test to assess athletes at different stages of development. Inherently, the two parts of this study are interdependent, as part one (the PDA of karate) was used to validate the specific fitness tests that were deemed important to be included in part two (test establishment). Such a test battery could provide an effective and accurate tool to evaluate karate performance.

Research Design

Phases of Development

This study was conducted in two major phases to establish and rationalize the use of a standardized karate athlete fitness test battery:

- 1) Physical demands analysis of the sport of karate

- 2) Development of the physical fitness test battery for karate athletes based on the physical demands analysis.

To establish the physical demands of karate performance, the following procedures were used:

1. A heart rate analysis to determine training zone requirements for karate performance
2. A movement analysis, including a video examination, to determine the intensity at which karate is performed and any sport-specific requirements and;
3. An extended review of all the current literature on physiological profiling and fitness testing on karate athletes.

The results of the physical demands analysis (PDA) were used to develop the physical fitness test battery for karate athletes, as well as rationalize the use of the individual tests included in the battery. An information session was conducted prior to the developing the fitness test battery that addressed all aspects of the study including the purpose, research procedures and methods, risks and benefits of participation, future directions, as well as answering questions posed by participants. Participants provided written informed consent prior to participation (Appendix B). This study was conducted with approval from the University of Victoria Human Research Ethics Board and Biosafety Committee.

Operational Definitions

Anaerobic Power:

Known as “high-speed muscular strength”, this parameter reflects the ability of a muscle to exert high force while contracting at a high speed. Tests of anaerobic power are very short in duration (<10 seconds), and performed at maximal movement speeds.

Anaerobic Capacity:

The ability to maintain a high muscular and anaerobic energy output for an extended period of time. Tests of anaerobic capacity are short in duration (<2 minutes) and measure the body's ability to perform and maintain the anaerobic energy system.

Aerobic Power:

Aerobic power (VO_{2max}) is the ability for an athlete to maintain performance primarily using the aerobic energy system. Tests of aerobic power are generally conducted by either directly measuring or indirectly estimating oxygen consumption (measured in $ml \cdot kg^{-1} \cdot min^{-1}$).

Agility:

The ability to stop, start, and change directions as rapidly as possible and in a controlled manner. Athletes who are performing agility tests typically change direction, and are timed on their ability to do so accurately.

Flexibility:

The range of motion about a joint or the mobility of a specific joint. This can be measured in a variety of different ways. Flexibility tests usually require participants to attain a full range of motion as possible, and is limited by factors such as tendon and ligament stiffness, bone structure, and injury

Balance:

The ability to maintain the center of gravity (COG) over the base of support (BOS). In balance

tests, participants are asked to hold a static position without falling outside their BOS, often performed unilaterally.

CHAPTER 2 – PHYSICAL DEMANDS ANALYSIS

Phase 1

Prior to the establishment of a sport-specific physical fitness test, a PDA or task analysis should be performed to determine what the underlying physiological requirements are in the performance of a specific sport (Rhea & Peterson, 2012). Therefore, to create a standardized karate-specific physical fitness test, a PDA was performed on the sport of karate. The results of the PDA were used to inform the development of the fitness test battery which is described in Chapter 3.

To determine the physical demands of competitive karate performance, the following procedures were used:

1. Heart Rate Analysis
- 2a. Movement Analysis
- b. Video Examination
3. Literature Review

1. Heart Rate Analysis

Participants: Five karate athletes were recruited from a local karate club for the heart rate analysis during a simulated karate performance for both kata (forms; n=2) and kumite (sparring; n=3). Three athletes were male, while two were female. The age ranged from 18 to 31 years old, while training experience ranged from three to six years of karate-specific training.

All athletes had competition experience ranging from regional to provincial level. Table 1 shows descriptive characteristics for all participants of the heart rate analysis.

Table 1. Descriptive characteristics for participants of heart rate and movement analysis during simulated performance.

Participant	Sex	Age (years)	Body Height (cm)	Body Mass (kg)	Training Experience
<i>Kumite</i>					
A - Kumite	M	31	190	87	7 years
B - Kumite	M	24	170	77	3 years
C - Kumite	F	18	163	63	4 years
<i>Kata</i>					
A - Kata	F	18	155	60	6 years
B - Kata	M	31	173	71	5 years
Means		24	170	74	5 years

Procedures: Data were collected for the heart rate analysis between September and November 2016. The athletes wore heart rate monitors (Polar Team-2 system) while performing either a single kata or kumite match in a competition setting following WKF rules and guidelines. For kata performance, the athletes were instructed to perform the kata that they considered their best for competition, while kumite athletes were matched with other athletes of similar skill and experience. Athletes were instructed to perform each bout at the same intensity as they would in competition, and a WKF recognized referee was used to facilitate the match or performance.

The heart rate data were downloaded to the Polar Team-2 system software and then analyzed according to the time spent in each of the pre-set training HR zones. These training zones were set by determining the maximum heart rate (HRmax) for each athlete using the age-predicted maximum heart rate method (220-age). The Polar Team-2 system separated each

simulated performance in to "sport zones" that relate to a percentage of HR_{peak} for the entire bout. Figure 1 provides an example of a full data set collected during the simulated kumite performance (vertically dashed lines).

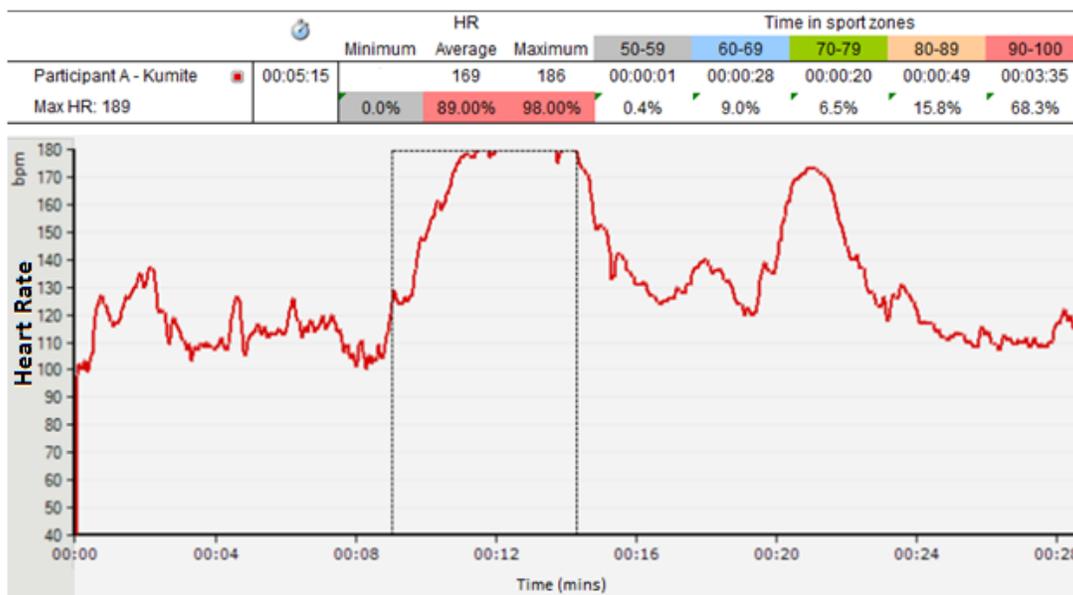


Figure 1. Sample set of heart rate and training zone data for a simulated performance kumite (sport zones are equivalent to % age predicted HRmax).

Results: The results from the heart rate analysis of simulated karate performance are summarized in Table 2. The average total duration of the simulated karate competitions differed between kata (mean = 3:23 minutes) and kumite (mean = 5:05 minutes) athletes. For the kumite athletes, the mean heart rate during simulated performance was 171 beats per minute (bpm), while kata athletes had a mean heart rate of 144 bpm during their performance. Both kata and kumite athletes spent over half of their simulated performances over the 80% HRmax training zone. For kata athletes, 51% of their time was spent above 80% HRmax, while kumite athletes spent only 20% of their performance outside of the 80% HRmax training zone.

By reviewing the data, it is apparent that kata athletes spent more time (49% of performance) in the 80-90% training zone than any other training zone, while kumite athletes spent the majority of their time (56%) in the 90-100% HRmax training zone. The data also shows that kata athletes spent 37% of their time in the 70-79% HRmax zone, while the kumite athletes spent the least amount of time in this zone (9%). Furthermore, the heart rate data showed that the average time spent in the 60-69% HRmax zone was comparatively low for both kata (10.5%) and kumite (11%) athletes. In conclusion, the results of the heart rate analysis shows that kumite performance requires a higher physiological demand at near maximal intensities (80-100% HRmax; 171 bpm HRmean; 194 bpm HRpeak) for a longer period of time, while physiological demands at moderate intensities is needed for kata performance (70-89% HRmax; 144 bpm HRmean; 161 bpm HRpeak). Additionally, the duration of a kumite bout (5:05 mins) was longer than a kata performance (3:23 mins).

Table 2. Summary of heart rate data and training zone requirements for both kata and kumite during a single simulated performance for each participant.

Training Zone (%HRmax)	60-69% HRmax (time)	%time %	70-79% HRmax (time)	%time %	80-89% HRmax (time)	time %	90-100 HRmax (time)	%time %	Total Time (mins)	HRpeak bpm	HRmean bpm
A-Kumite	:28	9%	:20	7%	:49	16%	3:35	68%	5:15	186	169
B-Kumite	:29	11%	:22	8%	1:05	23%	2:34	54%	4:44	195	175
C-Kumite	:40	13%	:37	12%	1:15	34%	2:26	46%	5:17	201	170
A - Kata	:24	13%	:58	31%	1:32	49%	:08	4%	3:12	165	144
B - Kata	:16	8%	1:31	42%	1:42	48%	:00	0%	3:35	157	143
<i>Means</i>											
Kumite	:32	11%	:26	9%	1:03	24%	2:52	56%	5:05	194	171
Kata	:20	10.5%	1:15	37%	1:37	49%	:04	2%	3:23	161	144

2a. Movement Analysis

Participants: Four of the athletes from the heart rate analysis were also recruited for the movement analysis portion of the physical demands of karate. Three athletes were males, and one participant was female. The athletes ranged from 18 to 31 years old, and were previously labeled in the heart rate analysis section (above) as "A-Kumite", "C-Kumite", "A-Kata", and "B-Kata" (Table 1). The fifth participant ("B-Kumite") opted not to be included in the movement analysis portion.

Procedures: Movement analysis data were collected during the same simulated performances used for the heart rate analysis. Athletes wore Actical accelerometer sensors (ADS Tech Renata model # ICP603028) placed on each wrist and ankle, as well as around the waist to determine the cumulative whole body movement that was used during the simulated performance. The movement analysis data were stored on each Actical sensor and then transferred to the Actilife software. These data were then used to estimate the intensity of whole body movement required during performance of both kata and kumite. This set up allowed for the determination of number of strikes and movements executed for each limb, as well as the intensity at which they were executed, at the same time as the HR data were being collected. Figure 2 provides an example of a full data set collected in 20 second intervals during the simulated performance of a kumite athlete, while Figure 3 shows an example of data collected for a simulated kata athlete. A summary of all the Actical results for each athlete is provided in Table 3.

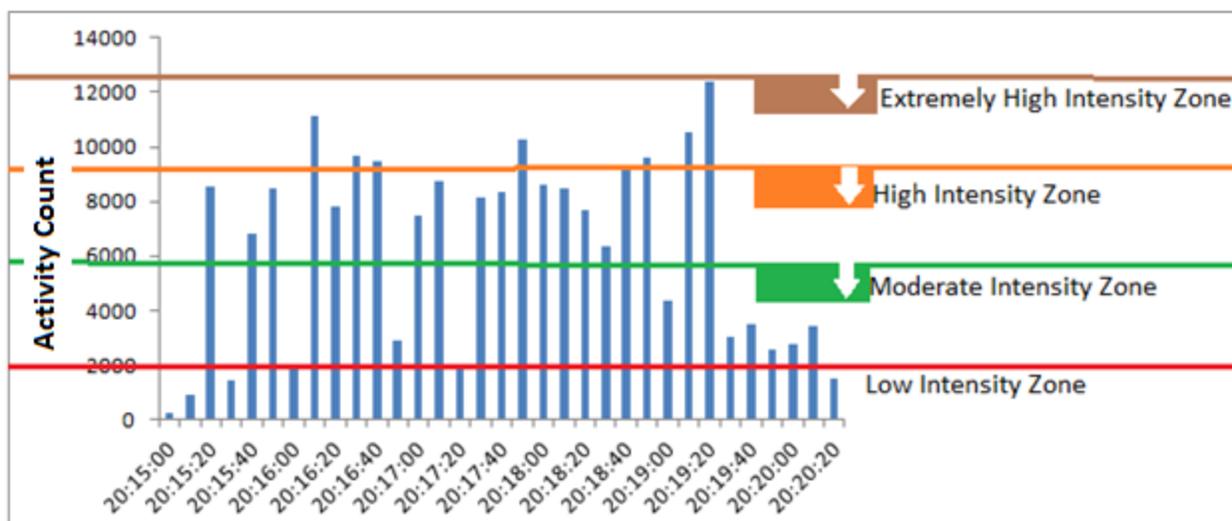


Figure 2. Sample set of cumulative full body movement analysis (Actical) data for a single athlete during one simulated performance of kumite.

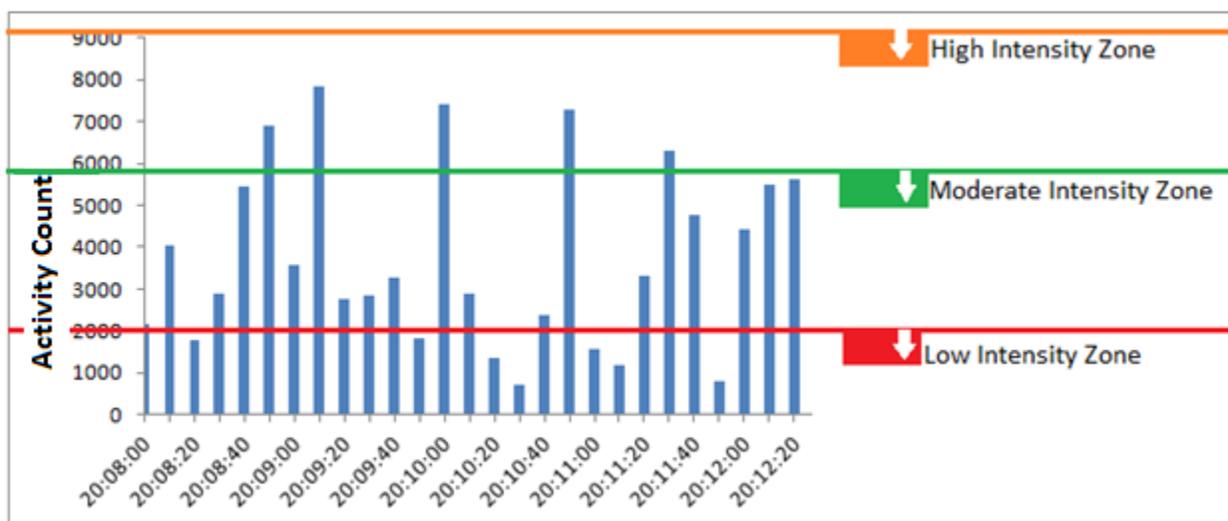


Figure 3. Sample set of cumulative full body movement analysis (Actical) data for a simulated performance of kata.

2b. Video Examination

To further validate the movement analysis for karate performance, a video examination was conducted by an expert panel consisting of a retired elite level karate athlete, a national team coach from Karate Canada, and a high performance committee member from the provincial sport organization of Karate BC. Each of the expert panel members independently

watched videos of the same three competitors: two kumite performances (one at the National and one at the World level), and one kata performance (at the World level). Each panel member was familiarized with the data collection process, and provided with a data collection sheet (Appendix C) and given specific directions to count the number of punches, kicks, and takedown attempts for each performance. Additionally, the expert panel members were asked to describe any pertinent movement requirements that they believed were necessary for the proper execution of specific karate techniques. Prior to data collection, the expert panel was informed of the objectives of the study and how their observations would be used in the PDA.

Results: The results from the movement analysis showed that karate performance requires intensities ranging from low to high for kata, and low to extremely high for kumite as determined by the Actical data (Table 3). The results showed that kata performance requires mostly moderate intensity full body requirements when each region of the Actical data (wrist, ankle, and waist) was combined. On average, the kata athletes spent 52.5% of their simulated performance in the moderate intensity zone with limited demand from the high intensity zone (19.5% time). Furthermore, kata athletes spent 28% of their performance in the low intensity zone. Conversely, the results from the Actical data showed that kumite performance involves mostly high intensity movements, with periods of extremely high intensity demands (Table 3). On average, the kumite athletes not only had a longer duration of their simulated performance, but also spent 38.5% of their time in the high intensity zone as determined by their cumulative whole body Actical data. They also spent 27% and 23% of their time in the moderate and extremely high intensity zones, respectively.

Table 3. Summary of cumulative whole body intensity requirements for both kata and kumite during simulated performance.

	Total Bout (time)	Low Intensity %time	Moderate Intensity %time	High Intensity %time	Extremely High Intensity %time
<i>Kumite</i>					
A - Kumite	5:20	12%	27%	37%	24%
C - Kumite	5:17	11%	27%	40%	22%
<i>Kata</i>					
A - Kata	4:20	27%	54%	19%	0%
B - Kata	3:35	29%	51%	20%	0%
Means					
Kumite	5:19	11.5%	27%	38.5%	23%
Kata	3:58	28%	52.5%	19.5%	0%

The results from the expert panel video examination of karate competition confirmed the use of several types of techniques in a given karate bout or performance. The expert panel determined there to be mean values of 13 punches, 6 kicks, and 3 takedown attempts in skilled (National and World level) karate competition. Because kata is performed solo, and not directly against an opponent, takedown attempts were not considered for this discipline. It was also observed that for the execution of karate techniques, and especially kicking motions, single leg balance and large range of motion for hip abduction are required. While the data show that the number of karate techniques thrown is similar for both kata and kumite, there are several performance differences that distinguish the two forms of karate. For instance, it is important to consider the duration of each bout, as the heart rate analysis showed that the average duration of kata performances (3:23 mins) is less than kumite bouts (5:05 mins). The expert panel also identified the importance of stretch-shortening cycle (SSC) movements in a kumite bout, and a more isometric muscular requirement for kata (Table 4).

Table 4. Summary of the video examination as well as karate-specific parameters that were noticed by an expert panel.

Athlete reviewed	Mean Punch Count (# per bout)	Mean Kick Count (# per bout)	Mean Takedown Attempts (# per bout)	Karate-Specific Parameters (general consensus between members of expert panel)
Kata (World)	14	4	N/A	<i>non – SSC * actions</i> (i.e. isometric holds)
Kumite 1 National)	11	5	3	<i>Balance on one leg, SSC actions, & hip abduction</i>
Kumite 2 (World)	14	7	4	<i>Balance on one leg, SSC actions, & hip abduction</i>

*SSC = stretch-shortening cycle, defined as an active stretch of a muscle followed by a rapid shortening of the same muscle.

To summarize, the movement analysis data confirms the results from the heart rate analysis, which showed that kumite performance requires a higher intensity demand than kata performance. Furthermore, because kumite athletes bounce and bound their way around the ring and then quickly initiate an attack towards the opponent, the expert panel agreed that stretch shortening cycle (SSC) actions are evident. For the kata performance, specific karate stances are held in a static position for several seconds before quickly executing the next stance or technique. Therefore, the expert panel agreed that SSC actions are only required for kumite performance, and not for kata.

3. Summary of Reviewed Literature

For the final portion of the PDA, an extensive review of the literature was performed on physiological profiling and fitness testing of all combat sports. The entire literature review can be found in Appendix A. The participants studied in the articles reviewed were all combat sports athletes, which has been operationally defined as any athlete partaking in a sport

recognized by the IOC as a combat sport (taekwondo, boxing, wrestling, judo, fencing, and karate).

Procedures: A computerized search was performed in SPORTDiscus™, PubMed, Google Scholar, and the Journal of Strength and Conditioning Research database for English-language, peer-reviewed articles. The following key words were used in addition to the specific sport being researched: "physical fitness", "fitness testing", "anthropometry", "strength", "muscular power", "aerobic", "aerobic performance", "anaerobic", and "anaerobic performance". References cited by the original studies initially reviewed were further searched for relevant research. Only scientific research published in peer-reviewed journals that studied major fitness components of combat sports and that used accepted methods that showed practical application to combat sport performance were included in this literature review.

Summary of Results: The main findings from the review of the current literature showed that karate performance relies on all the energy systems, with a variety of physiological measures deemed important for assessment. The most common test measures in the studies reviewed were: body composition and anthropometric measurements, aerobic power and capacity, as well as lower body and upper body anaerobic power and capacity (Doria, et al., 2009; Adamczyk & Antoniak, 2010; Ravier, Dugue, Grappe, & Rouillon, 2006; Chaabene, Hachana,, Franchini, Mkaouer, & Chamari, 2012; Chaabene, Hachana, Franchini, Mkaouer, Montassar, & Chamari, 2012; Nunan, 2006; Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Chaabene et al., 2014; Tabben, Coqhuart, Chaabene, Franchini, Chamari, & Tourny, 2009). For aerobic power, the graded

treadmill max test was the most common (Chaabene et al., 2014; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998). There has been several attempts to produce a karate-specific aerobic test (KSAT), using common techniques in karate performance to assess aerobic power (Tabben, Coquhart, Chaabene, Franchini, Chamari, & Tourny, 2009; Chaabene et al., 2014; Nunan, D., 2006; Chaabene, Hachana, Franchini, Mkaouer, Montassar, & Chamari, 2012). However, Chaabene and colleagues found that there was no significant correlation between the KSAT and the criterion-referenced graded treadmill VO_{2max} test ($p=0.69$; Chaabene et al., 2014). Therefore, more research is needed before the KSAT can be validated for use in the measurement of aerobic fitness of karate athletes. For anaerobic performance of the lower body, the wingate anaerobic test on a cycle ergometer was the most commonly used test in a lab setting, while the vertical jump test was used in two studies as a field-based test of lower body power (Chaabene et al.; Doria et al.). The most common body composition measurements were body mass, standing and sitting height, as well as skinfold measurements to estimate body fat percentage (Doria, et al., 2009; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012). See Table 3 for a summary of the current literature on physiological profiling and fitness testing of karate athletes.

Table 5. The current literature on physiological profiling and fitness testing of karate athletes

Author(s)	Purpose	Participants	Test Measures	Results
Doria, et al. (2009)	To determine the energetics of karate (kata and kumite techniques) in top-level athletes	<ul style="list-style-type: none"> - N= 12 - Males & females (3 per division for male/female) - senior & juniors - different weight divisions 	<ul style="list-style-type: none"> - weight/height - Anaerobic alactic power (vertical jump on force platform) - Anaerobic power And capacity (wingate) - Blood lactate - Simulated performance (portable gas analyzer) 	<p>Between genders in the same division:</p> <ul style="list-style-type: none"> - Females had significantly lower body weight and VO₂max (mL/min) for both kata and kumite (P<0.01) - Males had significantly higher mean and peak power during wingate (p<0.01)
Tabben, M., Coquhart, J., Chaabene, H., Franchini, E., Chamari, K., & Tourny, C. (2009)	To determine the validity and reliability of a new specific field test for karate athletes	<ul style="list-style-type: none"> - N=17 - men (n=14) and Women (n=3) - m = 24.1±4.6 y - w = 19±3.6 y - International level athletes - Different weight - junior & seniors 	<ul style="list-style-type: none"> - Karate specific Test (KST; gas analyzer) - VO₂max (cycle ergometer) 	<ul style="list-style-type: none"> - relative and absolute VO₂peak during KST and retest were not significantly different - Significant correlations between VO₂peak in lab test and TE from KST - no significant difference between HRpeak of two tests
Chaabene et al. (2014)	To examine the criterion related to validity of the karate specific aerobic test (KSAT) as an indicator of aerobic level of karate practitioners	<ul style="list-style-type: none"> - N=15 - males (12) & Females (3) - competed at National and international level - different weight categories - Age = 22.2±4.3 	<ul style="list-style-type: none"> - Aerobic power (time to exhaustion during KSAT) - Graded treadmill Max test - YoYo intermittent recovery test 	<ul style="list-style-type: none"> - HRpeak during KSAT represented ~99% HRmax during treadmill test - No significant correlation between KSAT's TE & relative VO₂max of treadmill test (p=0.69)
Imamura, H., Yoshimura, Y., Uchida, K., Nishimura, S., & Nakazawa, A. (1998)	To investigate VO ₂ max, body composition and strength of highly competitive karate practitioners and compare them to less experienced or novice karate practitioners	<ul style="list-style-type: none"> - N=16 - Highly competitive (n=7; 12.6±3.4 years experience) - Novice (n=9; 1.2±0.5 years experience) - Adults (19+) - Males only 	<ul style="list-style-type: none"> -Body composition (2-site skinfold measurements) - Aerobic power (graded treadmill max) - Muscular strength (1RM bench press and squat) - Blood Lactate & HR 	<p>Highly competitive group showed significantly higher mean values in:</p> <ul style="list-style-type: none"> - Age, karate experience, lean body mass, bench press and half squat strength and maximal ventilation volume relative to novice group. <p>There were no significant differences between groups in:</p>

				-Body height and weight, %Fat, fat mass, VO ₂ max (ml/kg/min), peak blood lactate and HRmax
Beneke, R., Beyer, T., Jachner, C., Erasmus, J. & Hutler, M. (2004)	To determine the energetics of karate point-fighting (kumite)	- N- 10 - males only - nationally or internationally ranked - 26.9±3.8 years	- VO ₂ (portable spirometry) - Blood Lactate	- VO ₂ = 165.3±52.4 ml/kg - changes in blood lactate = 4.2±1.9 mmol/L - Energy cost above rest = 334.3±86.3kJ per fight
Nunan, D. (2006)	To develop an aerobic fitness assessment test for competitive Karate practitioners and describe the preliminary findings	- N=5 - 31±9 years - Males - England National squad	During KSAT: - Absolute and relative peak VO ₂ - Peak ventilation - HRmax - TE	- No significant difference in absolute VO ₂ peak, relative VO ₂ peak, HRmax & TE (p > 0.05) - Significant relationship between TE and relative VO ₂ peak - Further research needed
Chaabene, H., Hachana, Y., Franchini, E., Mkaouer, B., Montassar, M., & Chamari, K. (2012)	To examine absolute and relative reliabilities and external responsiveness of the Karate-specific aerobic test (KSAT)	- N=43 - Adults (19+) - Males only - regional to National level	During KSAT: - TE - HRpeak - Blood lactate - RPE	- National-level karate athletes (1,032 ± 101 seconds) were better than regional level (841 ± 134 seconds) on TE (p<0.001) - Significant difference was detected in Peak blood lactate between national- (6.09 ± 1.78 mmol/L) & regional-level (8.48 ± 2.63) - KSAT can effectively distinguish karate athletes of different levels
Chaabene, H., Hachana, Y., Franchini, E., Mkaouer, B., & Chamari, K. (2012) Review article	To report the most important physical and physiological characteristics of karate athletes from the available scientific research	Review Article - Males & females - Juniors & seniors - Novice & elite - different weight	- Body composition (skinfolds) - Somatotype - Aerobic power - Anaerobic power and capacity (wingate) - Lower body anaerobic power (Vertical Jump) - Muscular strength (1RM bench press,	- No significant difference regarding the mean BF% between highly competitive and novice karate - In general, top-level male karate athletes have high rates of mesomorphic-ectomorphic characteristics and

			Squat)	<p>less endomorphic characteristics</p> <ul style="list-style-type: none"> - VO₂max of national and international male karate practitioners ranges from 47.8–44 to 61.4– 2.6mL/kg/min and from 32.75–4.1 to 42.9- 1.6mL/kg/min for Females - more research needed (especially on females)
Ravier, G., Dugue, B. Grappe, F., & Rouillon, J. (2006)	to compare maximal accumulated oxygen deficit (MAOD) and the time course of blood markers of the anaerobic metabolism in response to exhaustive supramaximal test in two elite (international vs. national) class karate athletes	<ul style="list-style-type: none"> - N=18 - Males only - 21.2±3.2 years - International (n=10) - National (n=8) - Adults (18+) - International VO₂max = 57.6±3.0 ml/kg/min - National VO₂max = 59.4±2.7 	<ul style="list-style-type: none"> - Maximal accumulated oxygen deficit (MOAD; treadmill ergometer) - Blood lactate, pH, and plasma ammonia 	<ul style="list-style-type: none"> - MAOD was similar in both groups (67.8 ± 8 ml·kg⁻¹ and 64.5 ± 6.4 for Int and Nat groups, respectively) - ammonia and lactate accumulation are sensitive to the level of performance in karate
Adameczyk, J., & Antoniak, B. (2010)	To determine whether and how the level of specific fitness of karate competitors changed, depending on their ranks	<ul style="list-style-type: none"> - N=16 - Males only - Different age categories (4 juniors, 7 youth, and 5 seniors) 	<ul style="list-style-type: none"> - Muscular strength (Bench press, Military press, Ez-bar preacher curls, forearm ext., squat, shank curl, chest press) - Endurance (# of roundhouse kicks in 90 minutes) - punch/kick speed 	<ul style="list-style-type: none"> - Specific fitness increases proportionally to rank - Endurance and speed most important in affecting performance

CHAPTER 3 – TEST BATTERY DEVELOPMENT

Phase 2

The selection of the following tasks for inclusion in the physical fitness test battery for karate athletes was based on the findings of the PDA described in Chapter 2. The PDA identified the most common tasks and physical requirements for karate athletes to be: kicking and punching performance as measured by lower and upper body power, hip flexibility, single leg balance, anaerobic capacity, agility, as well as aerobic performance. Additionally, body composition and anthropometric measurements were deemed important indicators for karate success. Therefore, a fitness test battery for karate athletes should include specific evaluations for these parameters.

Successful combative strikes such as kicking and punching are performed extensively by karate athletes as described by the expert panel (Table 4) and Actual results (Table 3). The ability to perform these strikes using high intensity movement speeds is important for karate performance at all stages of development, as seen in the results from the movement analysis (Table 3). Additionally, the expert panel agreed that flexibility is required to perform each task, especially in the case of kicking techniques (Table 4). Therefore, a full range of motion flexibility at the hip, especially through hip abduction, is a common action performed in karate. Because kicking is performed while maintaining stability on a single leg, unilateral balance is also required (Table 4).

The PDA also revealed that there is a difference in the intensity requirements for karate athletes who compete in kata (forms) and those who compete in kumite (sparring; see Tables 2 & 3). In the performance of each, both the aerobic and anaerobic systems are relied upon,

however to a different extent. The duration of both kata and kumite performance lasted greater than three minutes, which therefore indicates that the aerobic energy system is contributing to the performance due to activity lasting longer than 2 minutes. For kata performance, the aerobic energy system is more steadily required at a lower intensity when compared to kumite (Table 2). However, intensity of performances, as measured by both the heart rate and movement (Actical) analysis, show that time spent in the high intensity zone is required in the performance for both kata and kumite, and the extremely high intensity zone for kumite specifically (Tables 2 and 3). Therefore, it can be argued that both kata and kumite performance rely on the anaerobic energy systems as well. Furthermore, in kumite competition, the use of the anaerobic systems is used more often than in kata because kumite athletes tend to throw several karate techniques in succession and at a higher intensity (Table 3). Additionally, as determined by the expert panel in the movement analysis, kata athletes only minimally use stretch-shortening cycle (SSC) actions, while kumite athletes use the SSC more regularly throughout a match (Table 4). Finally, it can be argued that because karate athletes quickly maneuver around the ring, that agility is an important requirement for karate performance. This is especially true when it comes to the sparring discipline, which requires athletes to change directions in a rapid and controlled manner. By reviewing the research already conducted on karate athletes, it is apparent that agility testing is a common assessment of karate athletes and should therefore be considered important for success (Table 5).

It cannot be overlooked that fitness in all of these areas is required to not only optimally perform in repeated performances during competition, but also to handle the training load in preparation for competition. Having high maximal aerobic power allows athletes to properly

recover between bouts and even between successive techniques, while high anaerobic power and capacity, both from the lactic and alactic energy systems, prepares the athlete to successfully execute techniques at high intensities.

Establishment of Test Battery

When designing the physical fitness test battery for karate athletes, consideration was given to selecting tests that were reflective of the physical demands of karate performance, as determined through the PDA. The tests also needed to be designed to meet the demands of both type of karate athletes - kata and kumite - especially because both disciplines train together on Provincial and National teams. Consequently, tests representing flexibility, balance, agility, anaerobic capacity and power, and aerobic power were chosen to be included in the fitness test battery for measuring the physical fitness abilities of trained karate athletes. Field-based fitness tests were selected based on their ability to assess a large group of individuals with minimal equipment requirements. Furthermore, at karate training camps, where groups of athletes often exceeding 100 athletes meet to prepare for premiere competitions, such a fitness test battery could be useful to evaluate the athletes current fitness levels. The results of these tests could help determine if the athlete has prepared appropriately for competition.

Based on the results from the PDA, the following tests were chosen to assess the physiological demands of karate performance:

Flexibility - Split Test

Flexibility is determined by the range of motion within a specific joint. This can be measured in a variety of different ways, and is important for karate athletes to ensure they have adequate flexibility to execute certain karate techniques. As the video review examination by the expert

panel showed, good range of motion for hip abduction is a common requirement in karate performance (see Table 4). Implementing a test that resembles this motion would be of importance to include in a fitness test battery for these athletes. However, to date, there is no research identifying a valid test to measure hip abduction in an athletic population.

Implementing a lower limb lateral or hip abduction split test was selected as it would allow athletes to be measured on their ability to abduct both of their legs, while maintaining an upright posture - similar to that seen in karate kicking techniques. Therefore, the lower limb lateral split test was chosen as a measure of hip abduction in karate athletes and was included in the fitness test battery.

Balance - Modified Bass Test

Balance is the ability to maintain the centre of gravity over the base of support. Because karate athletes in both kata and kumite disciplines utilize the stability of one leg while executing a technique with the other in the air (see Table 4), and the movement of the center of gravity outside the base of support in dynamic motions is similar to that seen in the performance of both kata and kumite, balance was deemed important to be included in the test battery. The Modified Bass Test is a balance assessment tool that measures the stability of an individual using dynamic unilateral movements (Flanagan, 2012). During this test, the subject is required to jump from point to point, in numbered sequence, using only one leg (Riemann, Caggiano, & Lephart, 1999). It was selected for inclusion in the physical fitness test battery for karate athletes for its similarities to karate movements as well as its use of minimal equipment, simple test protocols, and ability to assess a large group of athletes in a relatively short amount of time.

Anaerobic Capacity - Modified 300m Shuttle

Anaerobic capacity refers to the maximal rate of energy production and the ability to maintain a high energy output over an extended period of time (McGuigan, 2016). These tests typically last from 1 – 2 minutes, and measure the ability to maintain the usage of the anaerobic energy systems. Energy is produced in anaerobic lactic system through the process of glycolysis, and can be indirectly measured through blood lactate accumulation during exercise. When blood lactate begins to accumulate faster than it can be cleared (lactate threshold), it can be an indication of work being done in the anaerobic system. It has been shown that the lactate threshold corresponds to approximately 85% of HRmax (Dwyer & Bybee, 1983). Data from the heart rate analysis of simulated karate performance in phase 1 shows that athletes spent more than half their simulated performance at over 80% HRmax, with 49% of the overall kata performances spent in the 80-89% training zone, and another 2% in the 90-100% zone, while kumite athletes spent 24% of the overall performance in the 80-89% training zone, and 56% of their time in the 90-100% training zone (Table 2). Therefore, it can be argued that the capacity of the anaerobic energy system is an important measure of karate performance. The standard 300 metre Shuttle Test has been shown to be a valid and reliable assessment of anaerobic capacity in trained individuals (Moore & Murphy, 2003). However, the standard procedure uses 25 metre long shuttles. A modified version, established by the authors of this report, takes into account the smaller competition area for karate athletes, which is a 10x10 metre area. Because of this, the Modified 300m Shuttle test shortens the distance of the shuttles from 25 metres in the standard version to 10 metres in the modified one. A study was completed to ensure that the Modified 300 Metre Shuttle test is still a valid assessment of anaerobic capacity when

compared to the standard 300 metre shuttle test. Although unpublished at the time of this report, the study was performed by having college-aged participants perform three anaerobic capacity tests (the standard 300 metre shuttle, the modified 300m shuttle, and the Cunningham and Faulkner anaerobic capacity test; Cunningham & Faulkner, 1969). The score on each test was recorded, and a Pearson Correlation Analysis showed that there was a strong relationship between the Modified 300m Shuttle test and both the Cunningham & Faulkner ($r=.935$ $p<0.001$) and standard 300m shuttle ($r=.987$; $p<0.001$) tests. Therefore, it was determined that the Modified 300 Metre Shuttle test is an appropriate measure of anaerobic capacity and was therefore chosen to assess anaerobic capacity for karate athletes.

Agility - T-Test

Agility is the ability to stop, start, and change direction while maintaining control of the body. For karate athletes, agility is important to maneuver around the ring in a kumite match, as well as to perform sudden changes of direction in kata performance. The T-Test is a common measure of agility used in many collegiate sport programs (Triplett, 2012). Pauole, and colleagues showed that the T-Test is a reliable and valid measure of agility (Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000). The test utilizes both lateral shuffling, as well as forward and backward movement. These movements are similar in the biomechanical movements in karate performance, as well as in other combat sports similar to karate where agility assessments are prevalent, and therefore was chosen to assess agility of karate athletes.

Anaerobic Power - Vertical Jump (Lower Body) and Medicine Ball Put (Upper Body)

Anaerobic Power is often referred to as “high-speed muscular strength”, and measures the ability of a muscle to exert high force while contracting at a high speed (McGuigan, 2016). In the movement analysis data of simulated karate performance, it was found that karate athletes perform cumulative full body movement at high intensities (Figures 2 & 3). For kumite athletes specifically, movements at extremely high intensities were observed and included both high speed movements of both upper (striking) and lower (kicking) limbs. Therefore, to measure anaerobic power, both an upper body and lower body assessment should be performed. The vertical jump test is a field-based measure of lower body anaerobic power used in a variety of sports (Peterson, 2012). The seated medicine ball put is a protocol that has been shown to be a valid and reliable assessment of upper body power (Clemons, Campbell, & Jeansonne, 2010). Therefore, the vertical jump test (lower body) and medicine ball put (upper body) were chosen for their ability to measure anaerobic power, with minimal equipment and time requirements.

Maximal Aerobic Power - Leger 20m Run Test

Aerobic power is the ability for an athlete to maintain performance primarily using the aerobic energy system (McGuigan, 2016). Individuals who have high maximal aerobic power have high oxygen consumption levels ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), which is necessary for sports that utilize the aerobic energy system. The aerobic energy system is dominant in activities that last over 2 minutes (McGuigan). Furthermore, it has been determined that high aerobic fitness improves recovery from repeated high intensity exercise (Tomlin & Wegner, 2001). By reviewing the heart rate analysis data from Chapter 2 (Table 2), it is apparent that each simulated performance lasted

over 2 minutes, and therefore the aerobic energy system is present. Additionally, because there are periods of rest in between each bout in competition, maximal aerobic power is also important for effective recovery. As previously described, aerobic fitness is important for athletes to ensure they can handle the training loads of karate. Therefore, the inclusion of a valid and reliable field-based fitness test on aerobic power is justified. The Leger 20 metre shuttle run test has been used in a variety of sports to assess maximal aerobic power, and is the preferred method due to its simplicity and ability to predict VO_2 max scores (Cetin, Karatosun, Baydar, & Cosarcac, 2005). Furthermore, it is a protocol that has already been used in studies of karate athletes (Chaabene et al., 2014; Nunan, 2006). Therefore, the Leger 20 metre shuttle test was chosen as a field-based assessment of maximal aerobic power for karate athletes.

Anthropometric Measures

Anthropometric measurements are used to provide information on the body proportions and characteristics of an individual, and are important for developing a complete athlete profile (Ratamess, 2012). For inclusion in the physical fitness test battery for karate athletes, consideration was given to anthropometric measures that were commonly used in the current literature reviewed (Table 5). Additionally, simple procedures that were non-invasive and that could be quickly and easily performed on a large group of athletes were preferred. Therefore, the following anthropometric measurements were chosen: Body mass, standing height, sitting height, leg length, and arm span. For all the measurements included in the fitness test battery, the International Society for the Advancement of Kinanthropometry (ISAK) guidelines and measurement protocols were followed.

Table 6. Summary of test included in the physical fitness test battery for karate athletes.

Test	Measure	Rationale	Supporting Evidence
Split Test	Hip Flexibility	Large ROM hip abduction required for optimal kicking techniques and stance performance	Expert panel review of movement analysis (Table 3)
Modified Bass Test	Balance	Unilateral limb balance required for optimal kicking techniques	Movement analysis (Table 3)
Modified 300m Shuttle	Anaerobic Capacity	Repeated high intensity physical demands	Heart rate analysis (Table 2)
T-Test	Agility	Manoeuvring around ring	Literature review (Table 5)
Vertical Jump	Lower Body Muscular Power	High intensity lower body movement requirements	Actual data from movement analysis (Table 3) Literature review (Table 5)
Seated Medicine Ball Put	Upper Body Muscular Power	High intensity upper body movement requirements	Actual data from movement analysis (Table 3)
Leger 20m Shuttle Run	Maximal Aerobic Power	Aerobic energy system demand and recovery of repeated high intensity movements	Heart rate analysis (Table 2) Literature review (Table 5)

Test Considerations

When establishing the test protocols for the physical fitness test battery for karate athletes, considerations were given to the order of assessment of each test. Following the guidelines previously put forth by the National Strength and Conditioning Association (NSCA), the proper sequence of tests should be determined prior to the implementation of the test battery. Tests that require high-skill movements should be performed prior to ones that produce substantial fatigue which may confound the performance of subsequent tests. Additionally, adequate recovery times should be given in between tests to ensure test reliability (McGuigan, 2016).

Trials: Two trials should be given for the flexibility (split test), balance (modified bass test), agility (T-Test), and anaerobic power (vertical jump and medicine ball put) assessments, while one trial should be given for the anaerobic capacity (modified 300 metre shuttle) and aerobic power (Leger 20 metre shuttle run) tests. At least three minutes should be given between the first and second trials where applicable, as well as between each test (McGuigan, 2016).

Measurements: For tests that measure distance (centimetres), scores are reported to the nearest whole centimetre (example: 164cm). For tests that measure time, scores are reported to the nearest 0.1 seconds (example: 24.3 seconds).

Cool down: After athletes have completed the entire fitness test battery, they should be instructed to perform a cool down as follows: light jogging for 5 minutes, myofascial release (i.e. foam rolling) and static stretching of the legs (quadriceps, hamstring, and gluteus muscle regions) for 5 minutes each.

Specific Test Protocols

When administering the physical fitness test battery for karate athletes, the order of assessment should be conducted as it is presented.

Warm Up

Prior to performing the test battery, an adequate warm up should be administered to all athletes led by a team coach. The warm up should include the following:

General Warm Up (performed in succession for 30 seconds each): jogging, jogging with forward knee raises, lateral side shuffles, forward lunges, forward straight leg raises, lateral leg raises, arm swings (forwards and backwards).

Specific Warm Up (each performed in succession for 10 repetitions): squat jumps, 10 metre sprints, push-ups.

The entire warm up should take between 10-15 minutes to complete, and athletes should be given an additional 5 minutes afterwards to warm up any additional body region they feel necessary.

Flexibility - Split Test

Equipment: Measuring tape anchored to floor & anthropometric tape.

Procedure: Prior to the test, have the athlete assume a standing position with the feet together and arms positioned outwards. Measure the athlete's leg length from their hip protrusion (anterior superior iliac spine) to the floor, using the procedures outlined under anthropometric measurements.

A measuring tape is also placed (and anchored) along the floor in a straight line.

1. On a marked area, the athlete stands and places their heels in front of the measuring line,

with the inside of their left heel placed at the start of the measuring tape on the floor.

2. The athlete performs a split stretch as far as they can by abducting their right leg as far as possible along the floor, while the torso remains upright (Figure 4).

3. The distance between the inside of their heels is determined.

Scoring: The stretch distance (hip abduction) is then subtracted by their leg length and this is the score on the test (*example: 160cm stretch - 110cm leg length = 50cm difference*). Positive or negative scored may be obtained.

Attempts: Two (2) attempts are given and the best of the two should be recorded.



Figure 4. Demonstration of Split Test.

Balance - Modified Bass Test

Equipment: Non-transparent adhesive tape 2.5cm thick.

Procedures: 2.5cm (1 inch) tape squares are laid out in a course as shown in Figure 5

For ease of administration, and because karate mats are 1 square meter, the distance between each marker should remain the same for all athletes at 1.0m in lateral distance between markers, and 0.5m in anterior distance (Figure 5).

The athlete stands over the square that is labeled "start".

1. The athlete jumps from square to square, in numbered sequence, using only one leg (landing on the right leg for all odd numbers - 1, 3, 5, 7, & 9 - and landing on the left leg for all

even numbers - 2, 4, 6, 8, & 10).

2. On landing at each square, the athlete remains facing forward, does not move the support leg, and holds for five (5) seconds before jumping to the next square. The tester should count aloud the 5 seconds the athlete is required to stay at each marker, as measured by a stopwatch to ensure accuracy and consistency.

Note: Because of the moderate intra-rater reliability of the Modified Bass Test, the tester should be a trained individual with knowledge of the testing procedures.

Scoring: There are two different types of "errors" that occur during the test:

1. Landing errors: occurs if the athlete's foot does not cover the tape square, if the foot does not remain facing forward, or if the athlete stumbles on landing
2. Balance errors: if the athlete takes the hands off the hips, or if the non-support leg (i.e. the foot in the air) touches down (1 error per occurrence of each).

2 types of errors are collected & points are given to the athlete for each as follows:

- ten (10) points are given for each period in which there was a landing error.
- three (3) points are given for each period in which there was a balance error.

The sum of the two (landing and balance errors) is the score on the test.

Attempts: Two trials are completed and the best (lowest) score of two attempts is recorded.

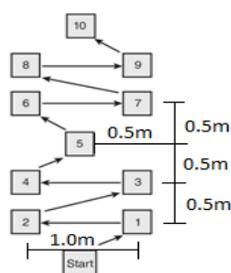


Figure 5. Layout for the Modified Bass Test.

Anaerobic Capacity - Modified 300m Shuttle

Equipment: Marker Cones; Stopwatch.

Procedures: Marker cones are placed 10 metres apart to indicate the shuttle distance (Figure 6). Start with a foot behind the start line.

1. When instructed, the athlete runs to the opposite 10m line, touching it with their foot.
2. The athlete then turns and runs back to the start line (10 metre's apart). This represents one 'lap'.

This is repeated 15 times without stopping (20 metres X 15 laps = 300 metres total).

Scoring: The time it takes to complete the 300metre shuttle is the score on the test.

Attempts: Two trials are performed and the best of the two is recorded.

Reasons to redo: Athlete fails to touch the line with their foot.

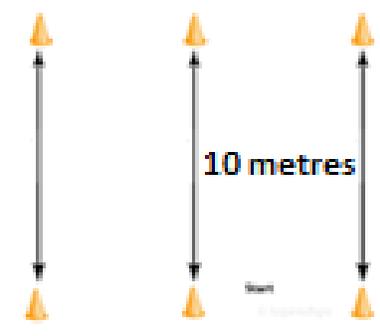


Figure 6. Layout for the Modified 300m Shuttle Test.

Agility - T-Test

Equipment: Marker Cones; Stopwatch.

Procedures: Set out four cones as illustrated in the diagram (Figure 7). The athlete starts behind cone A.

1. On the command of the timer, the athlete sprints to cone B and touches the base of the cone

with their right hand.

2. They then shuffle sideways (laterally, to their left) to cone C, while remaining facing forwards, and touches its base, this time with their left hand.

3. Then shuffling sideways to the right to cone D and touching the base with the right hand.

4. They then shuffle back (still facing forward) to cone B touching it with the left hand, and run backwards to cone A.

Scoring: Time is stopped and recorded as they pass cone A.

Attempts: Two (2) trials are performed and the best of the two should be recorded.

Reasons to redo test: feet cross at any point, athlete does not touch each cone, or the athlete discontinues to face forwards throughout the test.

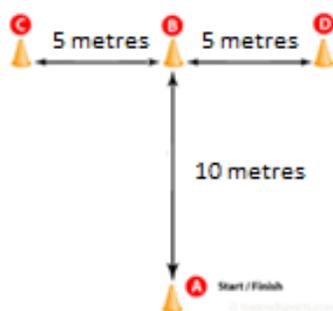


Figure 7. Layout for the T-Test.

Anaerobic Power - Lower Body (Vertical Jump Test)

Equipment: Vertec high jump apparatus.

Procedures: From a standing position, the subject's above-head arm reach height is measured and recorded by adjusting the height of the Vertec so that the lowest vane is touching the tip of the longest finger when the athlete is standing directly below the vanes with heels on the floor.

Note: Each vane represents 2.54cm (1 inch), and each red vane represents an increment of

15.24cm (6 inches).

1. From a full standing position with legs extended, the athlete performs a countermovement jump by quickly descending into a squat, with arm backswing, followed by a maximal jump straight up.
2. Using the dominant hand, the athlete hits and "swipes" the highest vane possible with their fingers (Figure 8).

Scoring: Vertical jump height is recorded as the difference between the highest jump and the athletes reach height.

Attempts: Two attempts are performed and the best of the two trials is recorded.

Reasons to redo: Athlete steps forward before the countermovement jump, athlete misses vanes.



Figure 8. Demonstration of Vertical Jump Test.

Anaerobic Power - Upper Body (Seated Medicine Ball Put)

Equipment: adjustable workout bench; medicine balls (4, 6, & 9kg); measuring tape to floor.

Procedures: The bench should be set to 45° and the athlete should be seated comfortably with

their feet flat on the floor (Figure 9).

1. Start with the appropriate ball grasped with both hands at the chest.
2. Without any additional body movements, the athlete propels ("puts") the medicine ball as far as possible ahead of them at an optimum trajectory of 45°.

Scoring: The distance from the front of the bench to where the ball lands is the score of the test (in centimetres).

Attempts: Two trials are completed and the best of the two is recorded.

Reasons to redo test: favouring one arm or rotating about the spine. Feet leave the ground.

Medicine Ball Weight Guidelines: Junior females (4kg), junior males (6kg), senior females (6kg), & senior males (9kg).



Figure 9. Demonstration of medicine ball put

Aerobic Power - Leger 20m Shuttle Run Test

Equipment: marker cones; Leger 20m run test audio track; speaker system.

Procedures: Marker cones are placed 20m apart to indicate shuttle distance. Start with a foot behind the start line (Figure 10).

1. When instructed from the audio track, the athlete runs to the opposite 20m line and touches it with their foot.

2. The athlete continues the 20m shuttle back-and-forth to the tempo of the "beeps" on the audio track. The "beeps" start out slow, and become faster (i.e. closer together) as the test progresses through each stage. The athlete must maintain the 20m shuttle within consecutive "beeps" until they are unable to keep up with the prescribed pace increments.

Scoring: The athlete's score is the level and number of shuttles (20m) reached before they are unable to keep up with the required pace, or elected to stop voluntarily. Record the last level successfully completed.

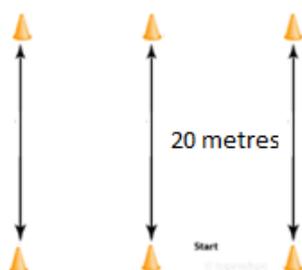


Figure 10. Layout for the Leger 20m Shuttle Run Test.

Anthropometric Measurements

1. Body Mass

Equipment: calibrated weighing scale

Procedure: With the weight distributed evenly on both feet, have the athlete stand on the centre of the scale in minimal clothing (i.e. light t-shirt, shorts) and shoes off. Record mass (in kilograms) to the nearest .1 kilogram (*example: 65.3kg*). Repeat until an accurate measurement is obtained (two consecutive readings that are the same).

2. Standing Height

Equipment: Stadiometer or alternative method using a calibrated measuring tape attached vertically to the wall and precisely positioned with zero (0) at the junction of floor and wall.

Procedure: Have the athlete stand straight up with their head held high, chin lifted and eyes forward. Instruct the athlete to stand as up-right as possible. Record height (in cm) to the nearest whole centimetre (*example: 163cm*). Repeat until an accurate measurement is obtained (two consecutive readings that are the same).

3. Sitting Height

Equipment: Stadiometer or standard anthropometric measuring tape for alternative method. Box or bench adjusted to a height where, when seated, the athlete's feet do not touch the ground, and their legs are hanging with a 90 degree angle at the knee and hip.

Procedure: Have the athlete sit on the appropriate box or level platform with their back against the stadiometer or wall, and hands rested on thighs (Figure 11). Instruct the athlete to sit up-right as possible while sitting on the box while maintaining a straight spine. Using either the stadiometer or alternative method, record athlete's height (in cm) to the nearest whole centimetre. Repeat until an accurate measurement is obtained (two consecutive readings are the same).

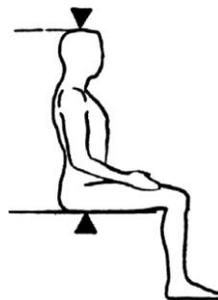


Figure 11. Illustration of Sitting Height measurement.

4. Leg Length

Equipment: Anthropometric Tape

Procedure: Measure the athlete's leg length from their hip protrusion (anterior superior iliac

spine) to the floor. This landmark can be found by feeling for the top of the bony protrusion at the hip (Figure 12). Record the athlete's leg length to the nearest whole centimetre.

Measurement taken on athlete right-hand side of the body. Repeat to ensure accuracy.

Note: Leg length should also be recorded on for split test as it is also used for this purpose.

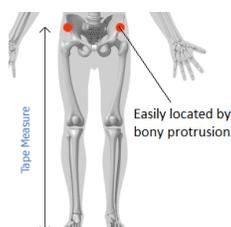


Figure 12. Leg length measurement landmarks.

5. Arm Span

Equipment: Standard Anthropometric Tape

Procedure: Have the athlete stand up with back flat against a wall, facing forward, with their chin tucked to one side so that their body is pressed right up against the wall, feet together, and heels against the wall (Figure 13). Arms raised parallel to the floor, backs of the hands against the wall, hands stretched as far apart as possible. In a straight line, measure the distance from the tip of the longest finger on one hand, to the longest finger on the other hand. Record the athlete's arm span to the nearest whole centimetre. Repeat until an accurate measurement is obtained (two consecutive readings are the same).



Figure 13. Illustration of Arm Span measurement.

CHAPTER 4 – LIMITATIONS & FUTURE DIRECTIONS

The physical fitness test battery for karate athletes was established with preference on field-based fitness tests that are easy to administer to a large group of athletes and have minimal equipment requirements. A field-based test battery is appropriate for karate athletes due to the large number of athletes that are present during training camps, and the minimal amount of time they require in relation to lab-based tests. Furthermore, a field-based fitness test battery with easy to follow protocols allows coaches to administer the test with basic training, instead of relying on an exercise professional to perform each test protocol. Because of this, many of the tests are not considered gold-standard assessments and therefore are not always the most valid or reliable tests for each physiological measure. Future directions of research should focus on developing a battery of lab-based performance tests that can be administered to elite level karate athletes. This stage could include gold-standard fitness tests such as the graded maximal treadmill test, wingate anaerobic capacity/power tests, and vertical jumps using force platforms. Furthermore, as previously discussed, lean body mass has been shown to be an indicator of highly competitive karate athletes (Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998). A test of lean body mass was not included in the current field-based fitness test battery, however a measurement of lean body mass should be included in future research on elite athletes using skinfold measurements. By establishing a lab-based fitness test battery of more advanced assessments, it would allow a link to be made between athletes being tested in the field, and those tested in lab.

One of the limitations to physical fitness testing of karate athletes is that there are no current performance standards in the literature. Because of this, it is difficult to compare

athletes performance on specific fitness tests to those of other athletes in similar stages of development. An important next step would be to implement the proposed test battery within elite/competitive as well as recreational karate athletes to ensure the effectiveness of the test battery and also a first step in developing test standards. Through continued research it would be beneficial to establish normative data using the physical fitness test battery for karate athletes as the standardized test protocols for karate, and determine cut scores of where certain athletes should be performing when compared to other athletes of similar skill and experience.

During the PDA, one of the limitations was the small number of karate participants that were used for the heart rate and movement analysis (Chapter 2). Future research should continue to analyze the physical demands of karate performance in competition using a larger number of athletes to better validate selected fitness tests. The proposed physical fitness test battery for karate athletes offers the authors current interpretation of the field-based fitness tests that best meet the physical demands of karate athletes, however more research needs to be conducted on a greater sample of participants.

Another limitation to the current physical fitness test battery for karate athletes is the lack of reliability testing. Future research should focus on performing reliability tests that determine if the current fitness test battery is reliable (i.e. repeatable) across athletes of different stages of development. Finally, to better validate specific fitness tests included in the test battery, a questionnaire should be administered to the athletes to subjectively determine if the performance of the fitness tests was similar to that of competition.

The current research provides only limited evidence on the physiological profiling and fitness testing standards for karate athletes. However, the proposed physical fitness test battery for karate athletes provides a preliminary tool for the appropriate steps to analyze karate training and performance, set athletic standards, and establish normative data for athletes at all stages of development and experience.

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APPENDIX A - LITERATURE REVIEW

Introduction

Many sport governing bodies recognize the importance of establishing standardized fitness testing protocols for athletes in their respective sports. By doing so, coaches and sport governing bodies can recognize and highlight the areas of fitness that are required for success in their sport. Additionally, it allows them to not only review individual athlete fitness levels, but also how they relate to other athletes in similar stages of development. For example, Karate Canada, the governing body for karate across the country of Canada, has recognized the need to establish and implement a fitness testing battery to their athletes in light of the recent announcement that karate will be the newest combat sport to enter the Olympic games in Tokyo 2020. However, before a fitness test battery can be determined, it is important to understand and analyze the research that has already been done on combat sports in order to effectively establish a valid and reliable fitness testing battery. Therefore, the purpose of this review is to summarize the research examining physical fitness testing of combat sport athletes.

The Combat Sports

Combat sports is broadly defined as any competitive contact sport with one-on-one combat. This often resembles "fighting" sports, where two athletes engage in combat in an attempt to overcome the other by either amassing more points, or rendering the opponent disabled. On the Olympic level, sports such as judo, taekwondo, wrestling, boxing, fencing, and

(most recently) karate are recognized by the International Olympic Committee (IOC) as combat sports that take part in the Olympic Summer Games. In fact, in August 2016, karate was announced as the newest combat sports to take part in the Olympic Games (International Olympic Committee, 2016). Other sports that are often viewed by the public as combat sports are kickboxing, jiu jitsu, muay thai and, more recently, mixed martial arts among others. However, these specific sports are not recognized by the IOC as combative sports and therefore do not take part in the Olympic Games. Therefore, for the purposes of this review, combat sports will be defined as any combative one-on-one sport that is recognized by the IOC and takes part in the Olympic Games.

Sport Karate

Karate has evolved into a popular Olympic combat sport that is practiced by hundreds-of-thousands of athletes worldwide. The sport itself is practiced under a variety of different governing bodies, with the World Karate Federation (WKF) officially providing the rules and regulations for competition. These competitions are further organized into regional, provincial (or state-wide), national or international sectors that are sanctioned either by the WKF, or the Pan-American Karate Federation (PKF). Each competition is composed of different divisions according to the athletes' age, sex, skill level (i.e. belt level), and weight category. Additionally, karate is unique to other combat sports in that it provides athlete's two different avenues to compete under known as "kata" (forms), or kumite (point-based sparring). In kata (forms), athletes perform a set of pre-determined techniques and are scored on their technical and athletic ability. Kata performance's typically last between 1 and 4 minutes, with the goal of

having a better performance than your opponent, as determined by five judges. The winner advances to the next round, where they must perform another (different) kata.. Karate point-sparring (kumite) on the other hand, consists of two athletes competing to obtain more points than their counterpart by using punches, kicks, takedowns, and defenses. In order for a point to be scored, techniques must be delivered accurately and powerfully to legal scoring areas on the body and head. Kumite matches typically last between 2-4 minutes, with the winner advancing on to the next round. Additionally, kumite divisions are separated by males and females, youth and adult and, like most combat sports, are divided according to specific weight divisions. The WKF and PKF recognizes five junior male and female, as well as five senior male and female weight divisions. However, it is important to note that at the time of publication, it is unclear which specific weight divisions karate will adopt for use in to the 2020 Tokyo Olympic Games. However, the IOC has adopted both kata and kumite divisions to be participated in.

Additionally, karate is unique from the other combat sports in a sense that it not only has two separate avenues for competition - kata and kumite - but also in the sense that it incorporates a variety of techniques from each combat sports discipline. Certain martial arts focus on a variety of dominant strikes or techniques in a given performance, such as punching (in boxing), kicking (in taekwondo), takedowns (judo), and ground control (wrestling). Outside of the latter, karate athletes use a combination of all other techniques in a kumite match, as well as in a kata performance (albeit not against an opponent). It is important to note that taekwondo athletes commonly practice their own version of kata, called "poomsae", at the club level - however there is no competitive stream for this discipline in the Olympic Games.

Understanding the specifics of karate competition is important because it allows comparisons to be made to the other combat sports - something which will help guide future research on karate specifically. For the purposes of this review, comparisons will be made in the fitness testing parameters of the respective combat sports. However, before this can be done, it is important to understand the research that has already been conducted. The current literature specifically on fitness testing for combat sports athletes is sparse, however there is some evidence for fitness measures related to performance in the respective combat sports.

Review of the Literature

Because of the variety of combat sports - and their physiological demands - current literature for fitness testing parameters will be reviewed in a sport-specific manner, and then compared to how similar or different they are from karate specifically. The participants that were studied in the articles reviewed were all combat sports athletes, which has been operationally defined as any athlete partaking in a sport recognized by the IOC as a combat sport (taekwondo, boxing, wrestling, judo, fencing, and karate).

Methods

A computerized search was performed in SPORTDiscus™, PubMed, Google Scholar, and the Journal of Strength and Conditioning Research database for English-language, peer-reviewed articles. The following key words were used in addition to the specific sport being researched: "physical fitness", "fitness testing", "anthropometry", "strength", "muscular power", "aerobic", "aerobic performance", "anaerobic", and "anaerobic performance". References from the original studies that were found were further searched for relevant

research. Only scientific research that studied major fitness components of combat sports and that used accepted methods that showed practical application to combat sport performance were included in the current review.

Judo

Table 1 provides a summary for all articles included in the literature review for judo athletes.

Participants

All participants in the studies reviewed for judo performance were specifically judo athletes. Of which, three authors studied male judo athletes specifically (Santos et al., 2010; Santos et al., 2011; Farzaneh, Mirzaei, Ortakand, Rabienejad, & Nikolaidis, 2013), while all other studies included both males and females (Casals et al., 2015; Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic, 2015; Sterkowicz, 2005; Franchini, Del Vecchio, Matsushigue, & Artioli, 2011; Little, 1991; Szmuchrowski et al., 2013). In judo, like most other combat sports, divisions are separated in to junior (<21 years old) and senior (>21 years old) categories. Of the articles reviewed, two focused on senior athletes specifically (Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic; Farzaneh, Mirzaei, Ortakand, Rabienejad, & Nikolaidis), while all other articles assessed both junior and senior athletes (Santos et al.; Santos et al.; Casals et al.; Sterkowicz; Franchini, Del Vecchio, Matsushigue, & Artioli; Little; Szmuchrowski et al.). Similarly, in judo, divisions are also divided by weight categories, as is the case in most combat sports. Of the articles reviewed on judo fitness testing, only one study looked at athletes from a specific division - the half-heavyweight category consisting of athletes weighing between 90-100 kilograms (Stojanovic & Ostojic). All other articles included a variety of athletes from different weight categories.

Finally, different levels of judo performance and development was also monitored. Athletes can be considered regional (zone-dependent), state or province, national, or international competitors. In several cases, they can be further identified through their performance as elite (international medalists), sub-elite (national medalists), or non-elite (non-medalists). In the articles analyzed for this review, five articles consisted of state or national level athletes specifically, without considering performance (Santos et al.; Casals et al.; Farzaneh, Mirzaei, Ortakand, Rabienejad, & Nikolaidis; Little; Szmuchrowski et al.). However, four articles studied performance by looking at judo athletes who are non-elite, sub-elite, or elite level athletes (Santos et al.; Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic; Sterkowicz; Franchini, Del Vecchio, Matsushigue, & Artioli). It is also important to note that a review article by Franchini et al. (2011) looked at a wide variety of judo athletes in all divisions, weight classes, development level, and performance.

Test Measures

The current literature has shown that fitness testing measures for judo athletes consists primarily of body composition, anthropometric measures, and parameters of both anaerobic and aerobic power. Specifically, skinfold thickness has been used in a number of studies to assess body composition and relative body fat. (Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic, 2015; Casals et al., 2015; Franchini, Takito, Kiss, & Sterkowicz, 2005; Little, 1991). Of which, the preferred method of skinfold and body fat measurements was either a 3, 4, 5, or 7-site method. A number of these studies have used these measurements to compare elite level athletes to their non-elite counterparts. Of these, several studies looked at a complete

physiological profile of elite versus non-elite judo athletes (Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic; Franchini, Takito, Kiss, & Sterkowicz; Little, 1991). Among these studies it was shown that in addition to anthropometric measurements, aerobic power and capacity (Graded Treadmill VO_{2max} test), as well as upper body anaerobic power and capacity (medicine ball throw and upper body wingate) were common test measurements. Additionally, Franchini 2011 and Drid and Little also used isometric hand grip strength as a measurement for grip strength. Drid and colleagues also further studied physiological measures such as muscular endurance (pull-up test), peak torque (of the thigh and shoulders) as well as strength (using 1 repetition max tests for the deadlift, bench press, and squat exercises; Drid, Casals, Mekic, Radjo, Stojanovic, & Ostojic). Little was the only study to measure trunk flexibility. While the aim of these specific studies was to help determine physiological profiles for elite and non-elite judo athletes, several studies looked a judo-specific test that was previously designed.

Special Judo Fitness Test

Santos et al. (2010) aimed to design a Special Judo Fitness Test (SJFT) that could be used as a field test to assess both aerobic and anaerobic power and capacity using a judo-specific technique. The design of the test uses a judo throwing technique, and allows participants three series of trials in performing the technique in a given amount of time on a partner of the same weight category (Santos et al., 2010). Following this initial research, several studies were conducted in an attempt to validate the use of the SJFT as a field-based assessment for judo athletes (Santos et al., 2011; Farzaneh, Mirzaei, Ortakand, Rabienejad, & Nikolaidis, 2013; Sterkowicz, & Franchini, 2001; Szmuchrowski et al., 2013). Santos et al. (2011) first looked to

retest the validity of the SJFT in a different group judo athletes. Casals et al. (2015), looked to determine the physiological measures that best predicted performance on the SJFT, while Farzneh assessed the relationship between both aerobic and anaerobic power and the SJFT. Sterkowicz & Franchini (2001), compared elite and non-elite judo athletes in the performance of the SJFT, while Szmuchrowski (2013) compared the standard lower body wingate anaerobic test (WAnT) to the SJFT to determine if the WAnT has enough specificity for evaluation of anaerobic capacity of judo athletes.

Main Findings

For all studies included in the review of the literature of judo athletes, the main fitness test measures that were used consist of body composition and anthropometric measurements, upper body (more so than lower body) anaerobic power, aerobic power and capacity, grip strength, as well as the Special Judo Fitness Test. Of which, the latter has been researched as a valuable field test instrument for anaerobic capacity, which utilizes judo-specific skills. As a result of these findings, a judo-specific fitness test battery should include these primary fitness parameters

Table A1. Summary of current literature on fitness testing and physiological profiling of judo athletes

Author(s)	Purpose	Participants	Test Measures	Results
Santos et al. (2010)	Develop a field test as close as possible to real judo combat	<ul style="list-style-type: none"> - N=8 - Male - 18+ years - State and national level judokas - Different weight categories 	<ul style="list-style-type: none"> - HRmax - Anaerobic threshold - Lactate measures - V02max (graded treadmill) - SJFT 	<ul style="list-style-type: none"> - 198.2 ± 3.9bpm HRmax - 58.3 ± 4.4 ml.kg.min V02max - 85 ± 1.8% of %HRmax for anaerobic threshold

Santos et al. (2011)	Retest the validity of a specifically designed judo field test (Santos Test) in a different group of judokas.	<ul style="list-style-type: none"> - N=8 - Male - 19.7±1.9 yrs - regional judo champions and medalists in national championships 	<ul style="list-style-type: none"> - Graded treadmill test to determine V02max, anaerobic threshold - Santos field test, using judo-specific movements to monitor same variables 	No significant differences between data on both tests in any parameter except maximum lactate concentration. The Santos Test can be considered a valid tool for judo-specific training
Casals et al. (2015)	Determine anthropometric measures that best predict SJFT performance	<ul style="list-style-type: none"> - N=51 - 29 females (12 Junior) - 22 males (13 Junior) - All weight categories - National team members 	<ul style="list-style-type: none"> - SJFT Performance - Anthropometric measures (skinfold thickness of biceps, triceps, subscapular, supraspinal, abdominal, thigh, & calf) 	<ul style="list-style-type: none"> - Males significantly higher muscle mass & lower fat mass than females ($p<0.001$) - Biceps skinfold significantly predicted the SJFT in elite athletes ($p<0.001$)
Drid, P., Casals, C., Mekic, A., Radjo, I., Stojanovic, M., & Ostojic, S. (2015)	Determine anthropometric profiles of international vs. national judo medalists in half-heavyweight category	<ul style="list-style-type: none"> - N=10 - n=5 elite (international medalists) - n=5 subelite (national medalists) - senior athletes (>21 yrs) 	<ul style="list-style-type: none"> - Anthropometric assessment (body mass, height, skinfold, and limb circumference, body fat %) - peak torque (thigh and shoulder) - handgrip strength - high/long jumps - med. ball throw - pull-ups - strength (deadlift, bench press, & squat exercises) - aerobic power (V02max) - Max power - tokui waza (judo specific) test 	<ul style="list-style-type: none"> - Significant differences ($p<0.05$) for forearm and upper-arm circumference, peak torques, pull-ups, bench press, deadlift, squat, V02max, max power, and tokui-waza tests. - Elite judokas in the half-heavyweight division have higher arm muscle mass than subelite. but a similar body fat %
Farzaneh Hesari, A., Mirzaei, B., Ortakand, M., Rabienejad, A., & Nikolaidis, P.T. (2013)	Assess the relationship between aerobic and anaerobic power & SJFT	<ul style="list-style-type: none"> - N=19 - Males - Elite judokas - Senior (>21 yrs) 	<ul style="list-style-type: none"> - SJFT Performance - Graded Treadmill Test (V02max) - Upper body Wingate (peak and mean power) 	<ul style="list-style-type: none"> - SJFT inverse direct Relationship with V02max ($r=-.87$, $p<.01$), peak power ($r=-.74$, $p<.01$), & mean power ($r=-.62$, $p<.05$) - SJFT describes aerobic power and short-term power output (to a lesser

				degree)
Franchini, E., Takito, M.Y., Kiss, M., & Sterkowicz, S. (2005)	To determine difference between elite & non-elite junior & senior judo athletes	<ul style="list-style-type: none"> - N=136 - n=43 (elite) - n=93 (non-elite) - males & females - junior & seniors <p>elite: National or international medalists</p> <ul style="list-style-type: none"> - non-elite: Non-medalists 	<ul style="list-style-type: none"> - Skinfold thickness - Circumference - breadths - upper body wingate test (upper body) - SJFT - Aerobic power & capacity - Lactate after combat - isometric hand grip strength 	<ul style="list-style-type: none"> -Elite group performed better in ($p<0.05$): - circumference - breadths - Wingate Test (mean/peak power) - SJFT
Franchini E., Del Vecchio, F., Matsushigue, K., & Artioli, G. (2011) (review article)	Review the physiological profiles of elite judo athletes from different sex, age, and weight categories	Mixed Review of literature	<ul style="list-style-type: none"> - Body Fat % - Upper body anaerobic power and capacity - Lower body dynamic strength - Aerobic power and capacity (V_{O2max}) 	<ul style="list-style-type: none"> - Elite have higher upper body anaerobic power and capacity than non-elite - no difference between aerobic power and capacity between groups
Little, N. (1991)	To compare the physical performance abilities of high level, developing juvenile men and junior and senior men and women judokas	<ul style="list-style-type: none"> - N=60 - n= 17 females - n=43 males - Members of Alberta Judo Team - juvenile, junior, and senior levels 	<ul style="list-style-type: none"> - Anthropometric Measures (height, weight, skinfold thickness) - static strength - trunk flexibility - Aerobic Power Graded Treadmill Test (v_{o2max}) - Upper body anaerobic power and capacity (upper body wingate) 	Successful judo participation by high level, developing athletes is dependent upon appropriate levels of endurance capacity, upper body anaerobic power and capacity, static strength, and flexibility.
Sterkowicz, S., & Franchini, E. (2001)	Compare elite and novice judoists in the performance of a SJFT.	<ul style="list-style-type: none"> - N=80 - n=50 (under 21 years old) - n=30 (over 21 years old) - Medalists or non-medalists in National or international championships - Different weight 	<ul style="list-style-type: none"> - Number of throws in the SJFT - Heart Rate 	<ul style="list-style-type: none"> - Elite judoists performed a greater number of throws of the SJFT compared with novice, demonstrating higher anaerobic capacity in specific setting. - Elite group lower HR after SJFT

		Categories		
Szmuchrowski et al. (2013).	To correlate results between WAnT and SJFT for the lower and upper limbs	- N=19 - Judo athletes 19±2 yrs, 88±26.5kg body mass	- Standardized WAnT test - SJFT (number of judo throws)	No significant correlation between SJFT and WAnT therefore; WAnT likely does not have enough specificity for evaluation of anaerobic capacity of judokas.

Taekwondo

Table 2 provides a summary for all articles included in the literature review for taekwondo athletes.

Participants

Because taekwondo competition at the Olympic level includes only point-sparring, all participants in the studies analyzed in this review were considered "fighters" (i.e. don't participate in strictly traditional taekwondo practice) and comprised of athletes in a variety of weight categories (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005; Bridge, Jones, Hitchen, & Sanchez, 2007; Noorul, Pieter, & Erie, 2008; Chatterjee, Banerjee, Majumdar, Chatterjee, 2006; Cetin, Karatosun, Baydar, & Cosarcan, 2005; Butios, & Tasika, 2007; Campos, Bertuzzi, Dourado, & Santos, 2012; Matsushigue, Hartmann, & Franchini, 2009). Of which, 4 studies included only male participants (Cetin, Karatosun, Baydar, & Cosarcan, 2005; Butios, & Tasika, 2007; Campos, Bertuzzi, Dourado, & Santos, 2012; Matsushigue, Hartmann, & Franchini, 2009), 4 studies used both males and females (Bridge, Chaabene, Pieter, & Franchini, 2014; Bridge, Jones, Hitchen, & Sanchez, 2007; Noorul, Pieter, &

Erie, 2008; Chatterjee, Banerjee, Majumdar, Chatterjee, 2006), and 1 study looked at strictly females (Markovic, Misigoj-Durakovic, & Trninic, 2005). Additionally, one paper that was included in this review was a review article of a variety of different aspects to taekwondo performance (Bridge, Chaabene, Pieter, & Franchini, 2014). Because taekwondo, like all other combat sports, also separates athletes in to junior (<18 years) and senior (18+) categories, the participants age rank is also important to examine. In 3 of the studies, strictly senior athletes were observed (Markovic, Misigoj-Durakovic, & Trninic, 2005; Bridge, Chaabene, Pieter, & Franchini, 2014; Butios, & Tasika, 2007), while 2 studies used only junior participants (Chatterjee, Banerjee, Majumdar, Chatterjee, 2006; Campos, Bertuzzi, Dourado, & Santos, 2012). Furthermore, 4 of the articles reviewed had participants from both junior and senior divisions (Bridge, Chaabene, Pieter, & Franchini, 2014; Campos, Bertuzzi, Dourado, & Santos, 2012; Noorul, Pieter, & Erie, 2008; Matsushigue, Hartmann, & Franchini, 2009). Finally, several articles separated athletes in to elite (medalists at international tournaments) or non-elite (non-medalists) groups. Of these, 2 of the studies included only elite athletes (Butios, & Tasika, 2007; Cetin, Karatosun, Baydar, & Cosarcan, 2005). All other athletes in the articles reviewed ranged from recreational (minimum 2 years training experience) to National level (invited to National training camp)

Test Measures

The taekwondo-specific articles included in this review used physical fitness testing of the following measures: body composition, anthropometric measurements, aerobic capacity and power (direct and an indirect method to predict), lower body anaerobic power, lower and

upper body muscular strength, muscular endurance, flexibility, agility, % heart rate max, and blood lactate measurements (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005; Bridge, Jones, Hitchen, & Sanchez, 2007; Noorul, Pieter, & Erie, 2008; Chatterjee, Banerjee, Majumdar, Chatterjee, 2006; Cetin, Karatosun, Baydar, & Cosarcan, 2005; Butios, & Tasika, 2007; Campos, Bertuzzi, Dourado, & Santos, 2012; Matsushigue, Hartmann, & Franchini, 2009). For body composition, some form of skinfold measurements (3, 4, or 7-site methods) was predominant in the research, and was used in 3 different studies (Bridge, Chaabene, Pieter, & Franchini; Markovic, Misigoj-Durakovic, & Trninic; Noorul, Pieter, & Erie). For anthropometric measurements, the most common measures were weight and height (standing and sitting). Aerobic power and capacity, as well as maximal oxygen consumption, was determined using both a direct (gas analysis during a maximal graded treadmill test) and indirect (20m shuttle test) test measurements (Bridge, Chaabene, Pieter, & Franchini; Markovic, Misigoj-Durakovic, & Trninic; Noorul, Pieter, & Eric; Chatterjee, Banerjee, Majumdar, Chatterjee; Cetin, Karatosun, Baydar, & Cosarcan; Butios, & Tasika; Campos, Bertuzzi, Dourado, & Santos). When the direct measure was used, the Bruce Protocol was the chosen method (Bridge, Chaabene, Pieter, & Franchini; Markovic, Misigoj-Durakovic, & Trninic; Noorul, Pieter, & Eric). When an indirect measure was performed, the Leger 20m run test was used to predict VO_{2max} (Cetin, Karatosun, Baydar, & Cosarcan, 2005). When tests for anaerobic power of the lower body was performed, both the wingate anaerobic test on a cycle ergometer and vertical jump tests were used (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005; Noorul, Pieter, & Erie, 2008). In one study, the vertical jump test was used to describe "explosive strength" (Markovic, Misigoj-Durakovic, & Trninic;

Noorul, Pieter, & Trninic, 2005). Muscular strength tests that were found in the literature were 1-repetition max protocols of the squat and bench press exercise for the lower and upper body respectively (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005). Additionally, muscular endurance tests measured the number of sit-ups, push-ups, or crunches performed in either 30 or 60 seconds (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005; Noorul, Pieter, & Erie, 2008). For flexibility, the sit-and-reach test was strictly used in the reviewed literature (Bridge, Chaabene, Pieter, & Franchini, 2014; Markovic, Misigoj-Durakovic, & Trninic, 2005; Noorul, Pieter, & Erie, 2008). One study included an agility test, which was measured by the "side-step test" (Markovic, Misigoj-Durakovic, & Trninic, 2005). Finally, blood lactate measurements were used in several of the studies to indirectly measure aerobic or anaerobic metabolism along with the heart rate response (Matsushigue, Hartmann, & Franchini, 2009).

Main Findings

After analyzing the current literature on taekwondo physical fitness testing and physiological profiling, the fitness test measures which dominate the research consist of body composition (skinfold measurements), aerobic power and capacity (graded treadmill VO_{2max} test and 20m shuttle test), lower body anaerobic power (wingate anaerobic test and vertical jump), flexibility (sit-and-reach), as well as muscular strength and endurance of the upper, lower, and trunk muscles (bench press and squat exercises for strength, sit-up, push-up, and crunch exercises for endurance). It can therefore be argued that in a fitness testing profile of taekwondo athletes, these parameters should be measured using the suggested protocols.

Table A2. Summary of current literature on fitness testing and physiological profiling of taekwondo athletes

Author(s)	Purpose	Participants	Test Measures	Results
Bridge, J., Chaabene, H., Pieter, W., & Franchini, E. (2014)	To determine the physical and physiological characteristics of taekwondo athletes	Review Article - All weight classes - Junior and Senior athletes - Elite and Non-Elite - Males & Females	- Skinfold Measures - Graded Treadmill V02max test - Lower body anaerobic power (Wingate & vertical jump) - Dynamic Strength (Bench press & Squat) - Muscular Endurance (Situps in 30s, pushups in 60s) - Flexibility(sit-and-reach)	- Taekwondo athletes exhibit high peak anaerobic power of the lower body - Taekwondo athletes have moderate levels of maximum dynamic strength and muscular endurance of the lower and upper limbs.
Markovic, G., Misigoj-Durakovic, M., & Trninic, S. (2005)	Assess fitness profile of elite Croatian female taekwondo athletes and determine which aid in fighting success	- N=13 - Females - Senior athletes - National taekwondo champions - Group A: n=6 athletes won medal at international tournament - Group B: n=7 non-medalists - different weight categories	- Skinfolds (subscapular, suprailiac, triceps, & biceps) - V02max (graded treadmill) - maximum strength (1RM bench press and back squat) - muscular endurance (60s pushups & 60s crunches) - explosive strength (vertical jump) - anaerobic power (15s vertical jump) - agility (side step test) - flexibility (sit-and-reach)	- Group A had running speeds and significantly higher anaerobic threshold ($p<0.05$) - Group A significantly greater explosive power ($p<0.05$), anaerobic alactic power ($p<0.01$) and agility ($p<0.05$). Therefore; - Performance of female taekwondo athletes depends on anaerobic power, explosive power in SSC movements, agility and power
Bridge, C., Jones, M., Hitchen, P., & Sanchez, X. (2007)	Evaluate heart rate responses to specific taekwondo training	- N=8 - Experienced practitioners - Males - Senior athletes - 5.4±3.2 years experience	- HR measurements at 5-second intervals during 6 training sessions.	- Taekwondo training elicits HR profiles at 64.7-81.4% HRmax.

Noorul , H., Pieter, W., & Erie, Z. (2008)	Describe physical fitness of adolescent recreational taekwondo athletes	<ul style="list-style-type: none"> - N= 17 - n=8 females (18.1±1.37 years) - n=9 males (18.63±1.92 years) 	<ul style="list-style-type: none"> - Flexibility (sit-and-reach) - Lower body anaerobic power (vertical jump) - muscular strength & endurance (pushups and situps total number) - aerobic fitness (20m multi-stage test) - HRmax - Skinfolds 	<ul style="list-style-type: none"> - males performed significantly better on explosive leg power (p=0.001) than girls - No significant difference between groups in pushups or situps - Males performed better in aerobic fitness but effect was small (p=0.003)
Chatterjee, P., Banerjee, A., Majumdar, P., Chatterjee, P. (2006)	Validate the applicability of the 20-m multi stage shuttle run test in junior taekwondo players of India	<ul style="list-style-type: none"> - N=33 - Juniors (15-17 years old) - training for 2-3 Years 	<ul style="list-style-type: none"> - Direct VO₂max (graded treadmill gas analysis) - Indirect predicted VO₂max (20m multi-stage test) 	<ul style="list-style-type: none"> -Difference between mean VO₂ max values of direct measurement (44.82 ± 7.78 ml/kg/min) and the 20m MST (VO₂ max = 44.49 ± 7.59 ml/kg/min) was statistically significant (p<0.05)
Cetin, C., Karatosun, H., Baydar, M., & Cosarcan, K. (2005)	Examine the validity of using 20 meter multistage shuttle run test to estimate VO ₂ max in Taekwondo athletes	<ul style="list-style-type: none"> - N=22 - 11 males - 11 females - Juniors (15-17 years old) - Elite taekwondo athletes (Turkish National Team) 	<ul style="list-style-type: none"> - Direct VO₂max using portable gas analysis system - Estimated VO₂max using Leger 20m shuttle test 	<ul style="list-style-type: none"> - Gas analysis mean score= 51.79 ml/kg/min - Shuttle run mean score = 43.59 ml/kg/min - Correlation between tests was significant (r=0.810) therefore; - VO₂max can be predicted from shuttle test scores
Butios, S., & Tasika, N. (2007)	Investigate the physiological responses of taekwondo athletes during competition	<ul style="list-style-type: none"> - N=24 - Males - Senior athletes (20-24 years old) - elite athletes - different weight categories 	<ul style="list-style-type: none"> - Heart rate and blood lactate responses during multiple simulated competition bouts to determine aerobic-anaerobic metabolism and physical demands - VO₂max during 20m shuttle test 	<ul style="list-style-type: none"> - Mean VO₂max was 53.92 ml/kg/min (no significant difference between weight divisions) - Mean HR = 158bpm - Mean BL = 3.35 mmol/L
Campos, f., Bertuzzi, R., Dourado, A., & Santos, V. (2012)	Investigate energy system contributions	<ul style="list-style-type: none"> - N=10 - Male athletes - 21±6 years old 	<ul style="list-style-type: none"> - VO₂ - Blood lactate Concentration 	<ul style="list-style-type: none"> - Contributions of: - Aerobic = 66±6% - Anaerobic Alactic

	and energy costs in simulated taekwondo performance	- 67.2±8.9 kg - Compete at National or International Level		= 30±6% - Anaerobic Lactic = 4±2% Therefore; - anaerobic alactic and aerobic energy systems are dominant
Matsushigue, K., Hartmann, K., & Franchini, E. (2009)	Determine time structure and physiological responses during taekwondo competition	- N= 14 - Males - Juniors and Senior athletes - Trained taekwondo athletes	- Blood lactate concentration - Heart rate - interval between high intensity and rest periods	Post-match : -BL = 7.8±3.8 mmol/L -HR = 183±9 bpm -glycolytic metabolism was not predominant energy source and did not differ from winners/losers

Wrestling

Unlike the two combat sports already mentioned, wrestling offers athletes two separate styles of competition, having both Greco-Roman and Freestyle wrestling divisions. While both categories look similar in appearance, the main difference is that Greco-Roman forbids wrestlers from grappling below the waist, or from attacking with the legs. As the oldest and one of the original Olympic sports, wrestling has been more researched than any other combat sport to date. For the purposes of this report, a total of 15 studies were reviewed to examine the current literature on physical fitness testing of wrestling athletes (Pallares, Lopez-Gullon, Muriel, Diaz, & Izquierdo, 2011; Pallares, Lopez-Gullon, Maria, Torres-Bonete, & Izquierdo, 2012; Callan et al., 2000; Utter, O'Bryant, Haff, & Trone, 2002; Mirzaei, Curby, Barbas, & Lotfi, 2015; Demirkan, Kutlu, Koz, Ozal, & Favre, 2014; Baic, Sertic, Starosta, 2007; Mirzaei, Curby, Rahmani-Nia, & Moghadasi, 2009; Rahmani-Nia, 2010; Mirzaei, Curby, Barbas, & Lotfi, 2013; Demirkan, Unver, Kutlu, & Koz, 2012; Taskiran, 2014; Ohya, Takashima et al., 2015; Karimi,

2016; Nikooie, Cheraghi, & Mohamadipour, 2015). Table 3 provides a summary for all articles included in the literature review for wrestling athletes.

Participants

Because a particular wrestling team (Provincial, National etc.) may have athletes from both Greco-Roman and Freestyle divisions, fitness tests are often performed on a group which combines both types of wrestlers. Furthermore, in several of the studies, researchers attempt to draw comparisons between the fitness measures and physiological profiles between the two wrestling categories (Demirkan, Kutlu, Koz, Ozal, & Favre, 2014; Baic, Sertic, Starosta, 2007; Mirzaei, Curby, Barbas, & Lotfi, 2013; Pallares, Lopez-Gullon, Maria, Torres-Bonete, & Izquierdo, 2012). In some studies, only one type of wrestler- either Greco-Roman or Freestyle - was used in the research (Mirzaei, Curby, Barbas, & Lotfi, 2015; Demirkan, Kutlu, Koz, Ozal, & Favre, 2014). In nine of the studies, both male and females participants were studied (Mirzaei, Curby, Barbas, & Lotfi, 2015; Demirkan, Kutlu, Koz, Ozal, & Favre, 2014; Baic, Sertic, Starosta, 2007; Mirzaei, Curby, Rahmani-Nia, & Moghadasi, 2009; Rahmani-Nia, 2010; Mirzaei, Curby, Barbas, & Lotfi, 2013; Demirkan, Unver, Kutlu, & Koz, 2012; Taskiran, 2014; Nikooie, Cheraghi, & Mohamadipour, 2015). Furthermore, in five articles included in the review, only male participants were studied (Pallares, Lopez-Gullon, Muriel, Diaz, & Izquierdo, 2011; Callan et al., 2000; O'Bryant, Haff, & Trone, 2002; Ohya, Takashima et al., 2015; Karimi, 2016). There was only one study which looked specifically at female wrestlers (Pallares, Lopez-Gullon, Maria, Torres-Bonete, & Izquierdo, 2012). When weight categories are considered, there were two studies that look at specific weight classes (Utter, O'Bryant, Haff, & Trone, 2002; (Demirkan,

Kutlu, Koz, Ozal, & Favre, 2014). All other articles included in this review studied athletes across a range of different wrestling weight classes. In wrestling, athletes are classified as juniors if they are aged between 18-20 years (or 17 years with a medical certificate and parental authorization). If an athlete is over 20 years old, they are considered a senior athlete, and if they are younger than 17 years old, they are considered a cadet athlete. There was only one study included in this review that studied cadet athletes specifically (Mirzaei, Curby, Barbas, & Lotfi, 2015). Additionally, there was another one study which used only junior participants (Demirkan, Kutlu, Koz, Ozal, & Favre, 2014). All other studies used either both junior and senior, or strictly senior athletes (See Table 3)

Test Measures

In the current literature on physical fitness testing of wrestling athletes, the most common test measures are: anthropometric measures, body composition (% body fat), upper and lower body anaerobic power, aerobic power and capacity, agility, speed, flexibility, muscular strength and endurance. Studies that used body composition did so to indirectly measure body fat percentage, and used either the 3, 5, or 7-site skinfold method. For all the studies that assessed upper body anaerobic power, strictly the wingate anaerobic test (WaNT) using an arm-crank ergometer was used (Pallares, Lopez-Gullon, Muriel, Diaz, & Izquierdo, 2011; Pallares, Lopez-Gullon, Maria, Torres-Bonete, & Izquierdo, 2012; Demirkan, Kutlu, Koz, Ozal, & Favre, 2014; Demirkan, Unver, Kutlu, & Koz, 2012; Taskiran, 2014). For lower body, a mixture of the standing long jump, vertical jump, and the WaNT protocols was used. Aerobic power was predominantly measured using a graded treadmill test. However, in one of the studies, the Leger 20m shuttle

run test was used to indirectly measure and predict VO₂max (Demirkan, Unver, Kutlu, & Koz, 2012). Additionally, one other study used the Cooper 12-minute run test (Taskiran, 2014). In five of the studies, agility tests consisted of the 4x9m shuttle run test, while two other studies used the "zigzag" and "envelope" agility tests. Eight of the studies presented in this review used tests of speed, all of which used sprinting for their assessment, with the distance covered ranging from 20-40 metres (Pallares, Lopez-Gullon, Muriel, Diaz, & Izquierdo, 2011; Pallares, Lopez-Gullon, Maria, Torres-Bonete, & Izquierdo, 2012; Callan et al., 2000; Utter, O'Bryant, Haff, & Trone, 2002; Mirzaei, Curby, Barbas, & Lotfi, 2015; Mirzaei, Curby, Barbas, & Lotfi, 2013; Demirkan, Unver, Kutlu, & Koz, 2012; Taskiran, 2014). Flexibility a common measure in most of the studies, all of which used the sit-and-reach protocol (Callan et al., 2000; Demirkan, Kutlu, Koz, Ozal, & Favre, 2014; Baic, Sertic, Starosta, 2007; Rahmani-Nia, 2010; , Curby, Barbas, & Lotfi, 2013; Nikooie, Cheraghi, & Mohamadipour, 2015). Similar to fitness testing in other combat sports, strength was assessed using the 1-repetition max protocol for the bench press and squat exercise. Finally, muscular endurance was commonly assessed using the amount of repetitions for the push-up, pull-up, and sit-up exercises in a given amount of time - usually 30 or 60 seconds (Callan et al., 2000; Mirzaei, Curby, Barbas, & Lotfi, 2015; Baic, Sertic, Starosta, 2007; Mirzaei, Curby, Rahmani-Nia, & Moghadasi, 2009; Rahmani-Nia, 2010; Mirzaei, Curby, Barbas, & Lotfi, 2013). In one of the studies, it was determined that the Special Judo Fitness Test previously established by Santos et al. (2010) for Judo athletes is a valid test to assess anaerobic fitness in wrestling athletes as well (Karimi, 2016). They found that there was a significant relationship between the SJFT and the standardized WAnT test when administered to wrestling athletes ($r=0.92$, $p<0.001$). While the SJFT has previously been determined to be a

valid and reliable field-based test of anaerobic fitness in judo athletes, more research is needed before it can be used across all combat sports.

Main Findings

For wrestling specifically, the research appears to show that the most common physical fitness tests for wrestling athletes are: anthropometric measures, body composition, upper and lower body anaerobic power, aerobic power and capacity, agility, speed, flexibility, muscular strength and endurance. Therefore, any fitness test battery that is established for wrestling athletes should, at the minimum, include these parameters while using the standardized protocols mentioned above. Research on wrestling athletes is the most abundant when compared to research done in other combat sports. Therefore, by analyzing the fitness testing research on these athletes, it can provide a better understanding of the physiological demands and measures used in similar combat sports.

Table A3. Summary of the current literature on fitness testing and physiological profiling of wrestling athletes

Author(s)	Purpose	Participants	Test Measures	Results
Pallares, J., Lopez-Gullon, J., Muriel, X., Diaz, A., & Izquierdo, M. (2011)	To determine physiological differences between elite and amateur wrestlers according to weight classes	- N=92 Lightweight n=18 elite n=15 amateur Middleweight n=18 elite n=19 amateur Heavyweight n=10 elite n=12 amateur - Males only - Greco-Roman (n=53) and Freestyle (n=39) - Elite = at least 3 international	- fat-free mass - maximum strength (1RM bench and squat) - anthropometric Measures - Upper body anaerobic power (wingate) - Lower body anaerobic power (vertical jump) - Hand grip - back strength	Compared to amateurs, elite group had: - more training experience (25-37%) - more fat-free mass - greater maximal strength (8-25%) - greater muscle power - greater mean and peak power during upper body wingate (13-22%) - greater jumping height (8-17%)

		competitions representing country		- greater grip & back Strength No differences were observed in: - height & BMI - % body fat - running speed
Pallares, J., Lopez-Gullon, J., Maria, J., Torres-Bonete, M. & Izquierdo M. (2012)	Determine differences in anthropometric, body composition, physiological and neuromuscular markers between elite and amateur female wrestlers	- N=35 Lightweight n=6 elite n=12 amateur middleweight n=7 elite n=10 amateur - Females only - Both Greco-Roman & Freestyle - Elite = at least 3 international competitions	- fat-free mass - maximum strength (1RM bench and squat) - anthropometric power - Upper body anaerobic power (wingate) - Lower body anaerobic power (vertical jump) - Hand grip - back strength	Compared to amateurs, elite group had: - more training experience (27-29%) - more fat-free mass - greater maximal strength (13-33%) - greater mean and peak power during upper body wingate (17-23%) - greater jumping height (2-9%) - greater grip & back strength
Callan, S., Brunner, D., Devolve, K., Mulligan, S., Hesson, J., Wilber, R., & Kearney, J. (2000)	To evaluate U.S. Freestyle Wrestling Team and give a physiological profile while in preparation for the World Championships	- N=8 - Males - Different weight - Freestyle only - Members of US National Team	- upper-body muscular power and endurance (5.6-m rope climb, RC, & 5-stage Modified Wingate) - body composition (BF%, skinfold measures) - Lower-body muscular power (vertical jump) - upper-body power and anaerobic capacity (5-stage modified Wingate protocol) - peak aerobic power (peak Vo2) - Flexibility (sit and reach)	- Body fat% = 7.6±3.4 - Vertical Jump = 60 ± 10 cm - flexibility = 3.8 ± 5.8 cm - 54.6 ± 2.0 ml/kg/min
Utter. A.C., H.S. O'Bryant, G.G. Haff, and G.A. Trone (2002) CASE STUDY	Describe physiological changes of a nationally ranked elite free-style wrestler during	- N=1 - Male - 33 years old - 69kg weight category - Nationally ranked (3rd)	- Body Composition (hydrostatic weighing) - Isometric Strength Assessment (force platform)	During the 7 month training period: - body weight decreased by 1kg - Muscular strength and aerobic power were maintained

	7 month observation period	free-style wrestler - Studied during 7 month training period	- Anaerobic Capacity (cycle ergometer) - VO2max (graded max test) - Resting Metabolic Rate (indirect Calorimetry) - Blood lactate	- Anaerobic work capacity higher and blood lactate lower - vertical jump remained same - maintain isometric Strength - graded treadmill test improved 1 minute
Mirzaei, B., Curby, D., Barbas, I., & Lotfi, N. (2015)	Describe physical fitness profile of elite cadet wrestlers	- N=44 - Male & Female - age: 15.66±0.56 years - weight: 65.75±16.65 kg - Invited to National training camp	- Body weight - VO2max (Graded treadmill) - muscular endurance (pull-ups, push-ups, knee-bent sit-ups) - Upper body strength (1RM bench press) - Lower Body Anaerobic power (standing long jump) - Speed (40-yard dash) - Agility (4x9m shuttle run)	- VO2max:46.84±3.76 ml/kg/min - Standing long jump: 227.45±20.86 cm - 1RM bench press: (relative): 0.88±0.16kg - Push-ups (rep/min): 53.48±10.04 - Pull-ups (rep): 16.32±8.14 - Sit-ups (rep/min): 53.41±9.82 - Speed: 6.03±0.46 seconds - Agility: 9.62±0.65 seconds
Demirkan, E., Kutlu, M. Koz, M., Ozal, M., & Favre, M. (2014)	Examine physical fitness differences between Freestyle and Greco-Roman junior wrestlers	- N=126 - n=70 (Freestyle) - n=56 (Greco-Roman) - Juniors 16.4 ± 0.7 years - Males & females - Invited to Turkey National training camp	- Body mass and height - body composition (3-site skinfolds) - Upper and lower anaerobic power and capacity (WAnT) - Speed(30m sprint) - Maximal hand-grip and leg/back strength) - flexibility (sit-and-reach) - Predicted VO2max (Leger 20m shuttle run)	- No significant differences in: anthropometric and physical features between groups - Greco-Roman wrestlers had a significantly higher level of relative leg and arm power than Freestyle wrestlers (p < 0.05). - Greco-Roman wrestlers were significantly faster, had better agility, and had a greater level of leg strength than Freestyle wrestlers - Freestyle wrestlers were more flexible than Greco-Roman wrestlers (p < 0.05). - Peak arm power,

				agility, speed, and flexibility were selective factors for the differences between groups
Baic, M., Sertic, H., Starosta, W. (2007)	Identify physical fitness differences between Greco-Roman and freestyle wrestlers	<ul style="list-style-type: none"> - N=107 - n=46 (Greco) - n=61 (freestyle) - 17-20 years old - 6.84±1.72 years of participation - Males & females - Junior national team members 	<ul style="list-style-type: none"> - Agility (zig zag) - Strength (1RM max of bench press, snatch, back squat) - muscular endurance (pull-ups, dips, situps) - lower body power (vertical jump) - flexibility (trunk bend) - Speed (20m run) 	<ul style="list-style-type: none"> - Greco-Roman wrestlers had greater agility and flexibility of the spine - Freestyle wrestlers had greater strength endurance of trunk and arms, absolute max strength of arm and trunk extensors, lower body power and speed
Mirzaei, B., Curby, D., Rahmani-Nia, F., & Moghadasi, M. (2009)	Describe physiological profile of elite Iranian junior freestyle wrestlers	<ul style="list-style-type: none"> - N=70 - 19.86±0.9 years - Males & females - Invited to national training camp (elite) - Freestyle only 	<ul style="list-style-type: none"> - Body weight - Flexibility (sit and reach test) - VO2max (graded treadmill, Bruce protocol) - Lower body Anaerobic power (WaNT) - Muscular Endurance (pull-ups, push-ups, sit ups) - Strength (bench press squat, grip strength) - Speed(40m sprint) - Agility (4X9m shuttle) - Body comp (7-site skinfolds) 	<ul style="list-style-type: none"> - Body weight (kg): 77.5 ± 19.8 - Flexibility (cm): 38.2 ± 3.9 - Vo2max(ml/kg/min): 50.5 ± 4.7 -Anaerobic power(W): 455.5±87.6 -1RM bench press(kg/body weight):1.4 ± 0.15 - 1RM squat: 1.7 ± 0.2 - Push-ups (n): 66.9±7.6 - Pull-ups (n): 31.6±9.7 - Grip strength 1.02 ± 0.11 - sit-ups(n): 66.5 ± 8 - speed (s): 5.07 ± 0.17 - Agility(s): 8.7 ± 0.25 -BF (%): 10.6±3.8
Rahmani-Nia, F. (2010)	Describe the physiological profile of elite Iranian junior Greco-Roman wrestlers	<ul style="list-style-type: none"> - N=71 - 19.7±0.8 years - Males & females - Participated in Iranian National Training camp - Greco-Roman only 	<ul style="list-style-type: none"> - Body weight - Flexibility (sit and reach test) - VO2max (graded treadmill, Bruce protocol) - Muscular Endurance (pull-ups, push-ups, sit ups) - Strength (bench 	<ul style="list-style-type: none"> -Body weight (kg): 77.4 ± 19.5 -Flexibility (cm): 40.95 ± 5.25 -Vo2max (ml/kg/min): 50 ± 4.75 -Bench press (w/kg): 1.47 ± 0.18 -Squat (w/kg): 1.76 ± 0.22 -Push ups (n) :

			<ul style="list-style-type: none"> press squat, grip strength) - Speed(40m sprint) - Agility (4X9m shuttle) - Body comp (7-site skinfolds) 	<ul style="list-style-type: none"> 66.7 ± 8.4 -Pull ups (n): 31.4 ± 11 -Grip strength (W/N): 0.89± 0.14 -Sit-ups (n): 67± 6.6 -Speed (s): 5.1± 0.23 -Agility(s): 8.9± 0.7 -BF (%): 10.8±4.1
Mirzaei, B., Curby, D., Barbas, I., & Lotfi, N. (2013)	To investigate the differences in physical fitness and anthropometric measures between Greco-Roman and freestyle wrestlers	<ul style="list-style-type: none"> - N=33 - n=13 (freestyle) - n=20 (Greco) - 24.54±3.43 years (freestyle) - 23.05±1.95 years (Greco) - Males & females - Invited to Iranian National training camp 	<ul style="list-style-type: none"> - Anthropometrics (height, sitting height, arm-span) - Flexibility (sit-and-reach) - Muscular endurance (pull-ups, sit-ups) - Agility (4x9 shuttle run) - Speed (40 yard sprint) - Visual reaction 	<ul style="list-style-type: none"> Greco-Roman wrestlers were better in: - speed, reaction time, flexibility, and pull-ups. Freestyle wrestlers were better in: - agility - sit-ups Differences were NOT statistically significant
Demirkan, E., Unver, R., Kutlu, M., & Koz, M. (2012)	To determine physical and physiological differences between selected and nonelected wrestlers to the national team	<ul style="list-style-type: none"> - N=48 - 18-20 years - Males & females - Greco-roman only 	<ul style="list-style-type: none"> - height, weight, body comp from bioelectrical impedance - Upper and Lower anaerobic power (WAnT) - Handgrip strength - back-leg dynamometer - Agility (Illinois agility test) 	<ul style="list-style-type: none"> Selected athletes were significantly different to nonelected in: - training experience - average leg power - average arm power - back strength - agility
Taskiran, C. (2014)	To determine the physical and physiological characteristics of international caliber Turkish freestyle wrestlers and then compare these results with the physiological variables of the U.S. National Freestyle Wrestling Team	<ul style="list-style-type: none"> - N=18 - n=10 (Turkish) - n=8 (USA) - Males & females - All weight categories - Freestyle only 	<ul style="list-style-type: none"> - height/weight - BF % - vital capacity - Vo2max (Cooper 12 min run test) - Speed (40 yard sprint) - 400m run - 2400m run - hand grip strength 	<ul style="list-style-type: none"> USA group was statistically different than Turkish group in: - Vo2max - 400m run - 2400m run - No statistical difference between other variables
Ohya, T., Takashima, W., Hagiwara, M., Oriishi, M.,	To determine the physical	<ul style="list-style-type: none"> - N=22 - Males 	<ul style="list-style-type: none"> - 90 second maximal 	<ul style="list-style-type: none"> - Relative Peak power during 90-MAT did

<p>Hoshikawa, M., Nishiguchi, S., & Suzuki, Y. (2015)</p>	<p>fitness of Japanese elite male wrestlers and compare results by groupings of weight classes</p>	<ul style="list-style-type: none"> - participating in national training camps - n=7 (lightweight 59-65kg) - n=8 (middle 71-88kg) - n=7 (heavy 99-122kg) 	<p>anaerobic power test (90-MAT) on cycle ergometer</p> <ul style="list-style-type: none"> - Maximal Graded Exercise Test (MGT) on cycle ergometer 	<p>not differ among groups</p> <ul style="list-style-type: none"> - mean relative power in heavy group was lower than that in other groups (p=0.006) - Relative Vo₂peak during MGT was lower in heavy group than other groups
<p>Karimi, M. (2016)</p>	<p>Determine the validity of the special judo fitness test among Iranian male wrestlers</p>	<ul style="list-style-type: none"> - N=30 - Males - Age = 24.9 ± 3.4 years - Weight = 77.7 ± 19.7 kg - Body Fat = 13.2% ± 2.3% - minimum 6 years training experience 	<ul style="list-style-type: none"> - Special Judo Fitness Test - Anaerobic Power and Capacity (wingate on cycle ergometer) - HR and Blood Lactate 	<ul style="list-style-type: none"> - Significant relations between SJFT and WAnT (r = 0.93, p < .001) therefore; - SJFT is a valid field test to assess anaerobic fitness of male wrestlers
<p>Nikooie, R., Cheraghi, M., & Mohamadipour, F. (2015)</p>	<p>To describe the fitness profile and physiological determinants of wrestling success in Greco-Roman wrestlers</p>	<ul style="list-style-type: none"> - N=26 - n=14 (juniors) - n=12 (seniors) - males & females - Groups split into Successful (National medalists) and unsuccessful (non-medalists) 	<ul style="list-style-type: none"> - Flexibility (sit-and-reach) - Muscular endurance (push-ups, pull-ups) - Upper and Lower anaerobic power (peak and mean during wingate) - vo₂max (graded treadmill) - speed (40-yard sprint) - agility (4x9 test) - strength (grip) 	<p>In seniors, significant differences in favour of success were:</p> <ul style="list-style-type: none"> - relative grip strength (p < 0.01) - pull-ups (p < 0.01) - Peak and mean anaerobic power of upper limbs (p < 0.05) <p>In junior wrestlers, successful wrestlers had significantly more:</p> <ul style="list-style-type: none"> - relative grip strength (p < 0.01) - pull-ups (p < 0.01) - peak and mean anaerobic power of upper limbs (p < 0.05) - peak anaerobic power of lower limbs (p < 0.05)

Boxing

Boxing has been an Olympic sport since 1904, and is one of the oldest and most globally recognized combat sports. Boxing athletes can go to the professional level, and fight for organizations who offer purses (i.e. cash prizes) for defeating your opponent. However, at the Olympic level, amateur boxers represent their respective countries and compete to obtain medals and make the podium. Like the other combat sports, boxing also utilizes weight classes to separate their athletes. Additionally, at the amateur (i.e. Olympic) level, boxing athletes must be between the ages of 17-39 to compete. Although one of the older combat sports in the Olympic Games, the current literature on fitness testing and physiological profiling of boxing athletes is sparse. Table 4 provides a summary for all articles included in the literature review for boxing athletes.

Participants

All of the studies that were analyzed in this review of the literature used amateur boxing athletes as participants (Guidetti, Musulin, & Baldari, 2002; Chaabene et al., 2014; Barbosa de Lira et al., 2013; Cinar, Bicer, Pala, Savucu, 2009; Smith, 2006; Bruzas, Stasiulis, Cepulenas, Mockus, Statkeviciene, & Subacious, 2014; Giovani, & Nikolaidis, 2012; Davis, Leithauser, & Beneke, 2014; Khanna, & Manna, 2006). One study was a review article comprising many different aspects of boxing competition (Chaabene et al., 2014). Most of the studies used participants from different boxing weight classes. However, one study included athletes strictly from the middleweight (75-81kg) category (Guidetti, Musulin, & Baldari, 2002). While men have competed in Olympic boxing since its induction, it wasn't until 2012 that women were allowed to compete in boxing at the Olympic level. Because of this, much of the current literature on

boxing athletes has been conducted on males. In the review of fitness testing on boxing athletes, the majority of studies used strictly male athletes participants (Guidetti, Musulin, & Baldari, 2002; Cinar, Bicer, Pala, Savucu, 2009; Smith, 2006; Bruzas, Stasiulis, Cepulenas, Mockus, Statkeviciene, & Subacious, 2014; Giovani, & Nikolaidis, 2012; Davis, Leithauser, & Beneke, 2014; Khanna, & Manna, 2006). However, there were two studies which used both males and females (Chaabene et al., 2014; Barbosa de Lira et al., 2013). No studies to date have looked at fitness testing or physiological profiling for strictly female boxing athletes. While all of the studies included senior athletes (between 17-39 years old), two of the studies also included junior athletes (<17 years old) in their group of participants (Smith, 2006; Barbose de Lira et al., 2013). In these cases, junior and senior athletes were analyzed in separate groups. The majority of the studies used athletes that either participated on their respective National team, or were considered highly trained. However, several of the studies included recreational or novice level boxing athletes (Giovani, & Nikolaidis, 2012; Davis, Leithauser, & Beneke, 2014; Khanna, & Manna, 2006). None of the articles reviewed aimed to show the difference between elite and novice athletes.

Test Measures

In the current literature, the main fitness and physiological performance measures of boxing athletes are aerobic power, as well as body composition and anthropometric measurements. In nearly all of the studies included in this review, some form of an aerobic power and/or capacity test was performed (Guidetti, Musulin, & Baldari, 2002; Chaabene et al., 2014; Barbosa de Lira et al., 2013; Cinar, Bicer, Pala, & Savucu, 2009; Smith, 2006; Bruzas, Stasiulis, Cepulenas,

Mockus, Statkeviciene, & Subacious, 2014) The most common test protocol was the graded treadmill max test using a gas analyzer to determine maximal oxygen consumption (VO₂max), as well as ventilatory and lactate thresholds. Other testing procedures for aerobic capacity and power included the Douglas Bag method (Smith, 2006), and the use of the 12-minute run test to predict these values (Cinar, Bicer, Pala, & Savucu, 2009). Body composition and anthropometric measurements included height, weight, as well as the 7 or 10 site skinfold methods to determine percentage of body fat (Guidetti, Musulin, & Baldari, 2002; Chaabene et al., 2014; Barbosa de Lira et al., 2013; Cinar, Bicer, Pala, Savucu, 2009; Smith, 2006; Giovani, & Nikolaidis, 2012; Khanna, & Manna, 2006). Additionally, 3 studies included measures of muscular strength of the upper body (bench press), lower body (squat), and/or grip (Guidetti, Musulin, & Baldari, 2002; Chaabene et al., 2014; Barbosa de Lira et al., 2013). Two studies included tests for lower body anaerobic power by using the cycle ergometer or vertical jump tests (Chaabene et al., 2014; Cinar, Bicer, Pala, Savucu, 2009). There was only 1 study found that used a measure of flexibility (sit-and-reach test) on boxing athletes.

Main Findings

Despite being one of the original Olympic sports, research on fitness testing of boxing athletes is limited. However, the current literature included in this review provides an overview of the common physical fitness testing measures that have been used on boxing athletes. It is generally accepted that boxing is considered predominantly an aerobic sport, due to the length and number of rounds for each fight. This is supported by the literature which shows the most common physical fitness testing measure being aerobic power and capacity. Because the gold

standard assessment for these parameters is the graded treadmill max test, it can be argued that this protocol is imperative to include in any testing of boxing athletes. Additionally, due to the weight categories that are used in boxing competition, some form of body composition and/or anthropometric measurements are common. Due to the anaerobic nature of performing boxing techniques, a test that measures lower and upper body anaerobic power may also be included, such as the wingate anaerobic test on a cycle ergometer or arm-crank ergometer. More research needs to be conducted in order to validate the use of other physiological parameters in fitness testing of boxing athletes.

Table A4. Summary of current literature on fitness testing and physiological profiling of boxers

Author(s)	Purpose	Participants	Test Measures	Results
Guidetti, L., Musulin, A., & Baldari, C. (2002)	To examine the relationship between ranking in boxing competition performance and some physiological factors	N= 8 - Males only - Middleweight category (75-81kg) - Participated in International tournaments	- Anthropometric and body composition (weight, height, skinfold, circumferences) - Grip Strength - Vo2max, ventilatory and lactate threshold (graded treadmill) - Boxing competition performance (based on AIBA rankings)	Highly related ($p<0.01$) to boxing performance: - anaerobic threshold = 46.0 ± 4.2 ml/kg/min ($r=0.91$) - Grip Strength = 58.2 ± 6.9 kg ($r=0.87$) Moderately related ($p<0.05$) to boxing performance: - Vo2max = 57.5 ± 4.7 ml/kg/min ($r=0.81$) - wrist girth = 17.6 ± 0.6 cm ($r=0.78$)
Chaabene et al. (2014)	To critically analyze the amateur boxer's physical and physiological characteristics	(review article)	- Anthropometrics - Body composition - Aerobic Power and capacity - Anaerobic power and capacity - Strength (squat and bench press) - Isometric Strength (grip)	Measures related to boxing success: - Low body fat levels - High level of cardiorespiratory fitness - High peak and mean anaerobic power output - Muscle strength in upper and lower limbs

				<ul style="list-style-type: none"> - Muscle power in upper and lower limbs - isometric grip strength
Barbosa de Lira et al. (2013)	To describe heart rate (HR) responses during a simulated Olympic boxing match and examine physiological parameters of boxing athletes	<ul style="list-style-type: none"> - N=10 - n=6 (men, 2 junior and 4 senior) - n=4 (women, 2 junior and 2 senior) - Different weight - Highly trained (5x per week, 2.5 hour sessions, >2 years training) 	<ul style="list-style-type: none"> - Vo2max & ventilatory thresholds (graded maximal test) - Heart rate - Skinfold measurements (7-site) - Simulated boxing match 	<ul style="list-style-type: none"> - VO2max = 52.2±7.2 ml/kg/min - HRmax = 193±7bpm - Ventilatory threshold = 47.5±6.0 ml/kg/min Highly correlated (p<0.01) with boxing competition ranking: - VO2 at the individual anaerobic threshold (46.0± 4.2 ml/kg/min, r = 0.91 - Hand-grip Strength (58.2±6.9 kg, r = 0.87)
Cinar, V., Bicer, Y., Pala, R., Savucu, Y. (2009)	To compare Turkish and Ukrainian national team boxers in their physical availability	<ul style="list-style-type: none"> - N=26 - 13 from each Country - Different weight - 20.77±1.34 years old - Compete on Turkish national Team - Males only 	<ul style="list-style-type: none"> - Height/Weight - Skinfolds - Resting HR - aerobic capacity (Cooper 12min run) - Lower body anaerobic power (vertical jump) - aerobic power (VO2max) -Flexibility (sit-and-reach) 	<p>No difference between 2 countries in:</p> <ul style="list-style-type: none"> - height, age, weight - resting HR - Aerobic capacity - vertical jump - Aerobic power - Anaerobic Power <p>Meaningful differences in:</p> <ul style="list-style-type: none"> - flexibility (in favour of Turkish) - % fat (in favour of Ukraine)
Smith, M. (2006)	To determine the physiological profile of Senior and Junior England international amateur boxers	<ul style="list-style-type: none"> - N=49 - n=23 (seniors) - n=26 (juniors) - Amateur boxers - Different weight - Males only 	<ul style="list-style-type: none"> - HR analysis - Blood Lactate - Body Composition (4-site skinfold) - Aerobic capacity (Douglas bag method for seniors, Aero test for juniors) - Punch profile - Blood profile 	<p>Seniors:</p> <ul style="list-style-type: none"> - Relative VO2max = 63.8±4.8 ml/kg/min - 9.1±2.3% body fat <p>Juniors:</p> <ul style="list-style-type: none"> - Relative VO2max = 49.8±3.29 ml/kg/min - 10.1±2.6% body fat
Bruzas, V., Stasiulis, A., Cepulenas, A., Mockus, P., Statkeviciene, B., & Subacious, V. (2014)	To assess the aerobic capacity of boxers and its relation with sport mastery	<ul style="list-style-type: none"> - N=12 - 21.8±3.4 years - Males only - Lithuanian National Team 	<ul style="list-style-type: none"> - Sport mastery (achieved results during last year of boxing competition) 	<p>VO2max in correlation with boxers mastery:</p> <ul style="list-style-type: none"> - 58.03±3.0 ml/kg/min (p<0.05)

		- Different weight categories	- Aerobic capacity (Graded treadmill test) - Gas analysis	
Giovani, D., & Nikolaidis, P. (2012)	to examine the ratios of physiological characteristics between upper and lower limbs of male boxers.	- N=12 - Males only - Recreational - 29.5±3.2 years old - Different weight classes	- Body Composition (height, weight, 10-site skinfolds) - Force-velocity test (upper and lower body ergometers)	- 77.9±8.1kg mass - 22.4±3.9 %BF - Pmax, rPmax, FO, vO and vO/FO differed significantly between upper and lower limbs (p<0.01)
Davis, P., Leithauser, R., & Beneke, R. (2014)	To determine the energy expenditure of boxing athletes during a semi-contact simulated performance	- N=10 - Senior athletes (23.7 ± 4.1 years) - Males only - Novice - Different weight	- VO2peak (graded treadmill test) - semi-contact boxing bouts (1 per subject)	During treadmill test: - Mean VO2peak = 59.8 ± 4.3 ml/kg/min - Mean HRpeak = 191.6 ± 11.1 bpm - Overall lactate significantly decreased over all 3 rounds of simulated performance (p<0.05) - Metabolic profile of amateur boxing is predominantly aerobic
Khanna, G., & Manna, I. (2006)	To study the morphological, physiological and biochemical characteristics of Indian National boxers as well as to assess the cardiovascular adaptation to graded exercise and actual boxing round	2 studies: - N=60 (junior boxers, <19 years, n=30; senior boxers 20-25 years, n=30) - N=21 (n=7 lightweight, n=7 medium weight, n=7 medium heavyweight) - Males only - All participants from Indian National camp	- Body Composition (weight/height) and skinfolds - aerobic capacity (graded treadmill) - Biochemical Parameters (hemoglobin, triglyceride, cholesterol) - HR and Blood lactate responses - Muscle strength (back and grip)	- Significantly higher (p < 0.05) stature, body mass, body fat and strength of back and grip in senior boxers compared to juniors - Significantly lower (p < 0.05) aerobic capacity and anaerobic power were noted in junior boxers compared to seniors. - Significantly higher (p < 0.05) maximal heart rates and recovery heart rates in seniors compared juniors

Fencing

Fencing is unique from the other combat sports in that its movement patterns remain relatively similar throughout a bout. Athletes attempt to lunge at their opponent, and strike them with a fencing sword. Contests consist of three 3-minute bouts, with a 1-minute rest in between. It is a combat sport rooted in tradition that dates back to 1896 in the Olympic Games. However, despite this, there is limited evidence to show the physiological demands or physical fitness testing measures of fencing athletes. As Turner et al. (2014) explains, there needs to be more scientific research in the sport of fencing to help determine competition demands and athlete physical characteristics. There are no weight classes for fencing athletes, however there are three forms of Olympic fencing: Foil, Épée, and Sabre - all of which have the same scoring system and movement patterns, but use different types of swords. Using the search requirements for this review (see methods) produced four studies. Table 5 provides a summary for all articles included in the literature review for fencing athletes.

Participants

The participants reviewed in the studies on fencing athletes ranged from skilled (train >10 hours/week) to elite (members of respective National teams) athletes (Milia et al., 2014; Nyström et al., 1990; Tsolakis, Kostaki, & Vagenas, 2010; Bottoms, Sinclair, Gabrysz, Szmatlan-Gabrysz, & Price, 2011). Three of the studies used both male and female participants (Milia et al., 2014; Nyström, et al., 1990; Tsolakis, Kostaki, & Vagenas, 2010), while one study looked specifically at female athletes (Bottoms, Sinclair, Gabrysz, Szmatlan-Gabrysz, & Price, 2011). The sample size remained small for all studies, with no study exceeding more than 33 athletes.

Test Measures

The research on physiological profiling and sport demands of fencing shows that maximal aerobic power and capacity, anthropometric measures, lower body anaerobic power, and grip strength are used to describe fencing athletes (Milia et al., 2014; Nyström et al., 1990; Tsolakis, Kostaki, & Vagenas, 2010; Bottoms, Sinclair, Gabrysz, Szmatlan-Gabrysz, & Price, 2011). For aerobic power and capacity, gas analysis during a graded treadmill maximal test was used (Nyström et al., 1990; Bottoms, Sinclair, Gabrysz, Szmatlan-Gabrysz, & Price, 2011).

Anthropometric measurements consisting of height, weight, muscle breadth and girth, skinfold, and limb length was used in one study (Tsolakis, Kostaki, & Vagenas, 2010). This same study was the only one which used flexibility (sit-and-reach), lower body anaerobic power (vertical jump), and a fencing-specific shuttle tests. Additionally, a study by Nystrom et al. used tests of isometric strength (grip, finger, and leg). Only Milia et al. have looked at the physiological responses during a simulated fencing performance. They tested 15 fencers who regularly participated in competitions and found that during a simulated 3x3-minute bout, the aerobic energy system was only moderately recruited (measured using a portable metabolic system). Similarly, oxygen consumption and heart rate remained below the anaerobic threshold, which shows that the anaerobic system was minimally used. This is further supported by Bottoms et al. who showed that blood lactate readings remain relatively low during a similar bout.

Main Findings

Due to the lack of evidence, it can be argued that fencing performance requires mostly anaerobic contributions from the alactic system, with moderate contributions from the lactic

system, and minimal aerobic energy requirements. However, more research is needed on these athletes to further support or oppose the current scientific literature.

Table A5. Summary of current literature on fitness testing of fencing athletes

Author(s)	Purpose	Participants	Test Measures	Results
Milia et al. (2014)	To understand the physiological capacities underlying fencing performance during a simulation	N= 15 - Males (13) & Females (2) - Skilled athletes trained 10-12h per week - 21.4 ± 6.9 years	- Aerobic energy expenditure (portable gas analyzer) - Blood Lactate	- Mean EE = 10.24 ± 0.65 kcal/min - O ₂ & HR remained below anaerobic threshold In Fencing: - Physical demand is Moderate - Aerobic/Anaerobic both moderately used
Nyström, J. Lindwall, O., Ceci, R., Harmenberg, J., Svedenhag, J & Ekblom, B. (1990)	To analyze the physiological & morphological characteristics of world class épée fencers	- N=6 - Males & females - Age = 24.±4.1 - Members of Swedish National Team	- Aerobic power & Capacity (graded treadmill test) - Grip strength - Finger strength (steel rod test) - Isometric leg Strength - Blood Lactate	- Aerobic Power = 67.3±3.7 ml/kg/min - RQ = 1.18±0.04 - Significantly stronger isometric handgrip strength in the weapon hand compared to the other hand (p < 0.01)
Tsolakis, C., Kostaki, E., & Vagenas, G. (2010)	To investigate selected structural correlates of fencing performance	- N=33 - Males (15) & Females (18) - 19.9±3.5 years - Elite (Members of Greek National Team	- Anthropometric Measurements (height/weight/breadths/girths/6-site skinfold/limb length - Lower body power (vertical jump force platform) - Flexibility (sit-and-reach) - Fencing-specific Shuttle test	- BF% = 15.1±4.11 - Arm span (cm) = 172.5±11 - CMJ(cm) = 32.6±8.9 - flexibility(cm) = 12.6±7.44 - Shuttle test = 13±1.08 seconds
Bottoms, L., Sinclair, J., Gabrysz, R., Szmatlan-Gabrysz, U., & Price, M. (2011)	Examine the physiological and energy expenditure responses required during fencing	- N=4 - Age = 24.8±3.3 - Females only - Polish National Team	- VO ₂ peak (graded Treadmill test) - Simulated fencing (3x3min fencing)	- Mean VO ₂ peak during simulated: 47±5 ml/kg/min - Mean HRpeak: 196±8 bpm - Blood lactate = 2.2-3.1 mmol/L (low)

Karate

Karate is the newest combat sport to be introduced in to the Olympic Games, having been accepted in August 2016. Karate is unique from other combat sports in that it offers two different and unique avenues for competition. An athlete may be classified and therefore compete as a *kata* athlete (i.e. where karate techniques are pieced together in a pre-determined pattern to create a form), or *kumite* (i.e. point-sparring against another opponent). In some cases, an athlete may compete as both a kata and kumite athlete in the same competition. For both divisions, athletes are separated in to male and female categories, as well as in age and belt rank. Additionally, for kumite, athletes are further divided in to weight categories, similar to the other combat sports. There are five weight categories among senior kumite karate athletes for both male (<60 kg, <67 kg, <75 kg, <84 kg and >84 kg) and females (<50 kg, <55 kg, <61 kg, <68 kg and >68 kg). Only senior athletes (18 years or older) will be eligible to compete at the Olympic Games. For the purposes of this review, 10 articles were reviewed that met the inclusion criteria (see Table 6).

Participants

All of the studies that were analyzed in this review of the literature used karate athletes as participants (Doria, et al., 2009; Tabben et al., 2009; Chaabene et al., 2014; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004; Nunan, 2006; Chaabene et al., 2012; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012; Ravier, Dugue, Grappe, & Rouillon, 2006; Adamczyk, & Antoniak, 2010). Of

which, 4 articles included both male and female participants (Doria, et al., 2009; Tabben et al., 2009; Chaabene et al., 2014; Chaabene et al., 2012). Therefore, 6 of the articles used only male karate athletes (Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004; Nunan, 2006; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012; Ravier, Dugue, Grappe, & Rouillon, 2006; Adamczyk, & Antoniak, 2010). There were no articles included in this review that included only female athletes. When looking at articles who included junior or senior athletes, 5 of the articles used both (Doria, et al., 2009; Tabben et al., 2009; Chaabene et al., 2014; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012; Adamczyk, & Antoniak, 2010), while 5 other articles used senior athletes only (Chaabene et al., 2014; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004; Nunan, 2006; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012). Additionally, no articles were found that looked at athletes in specific weight categories for kumite. When it comes to athletes who compete in either kata or kumite, none of the articles made an attempt to differentiate between physiological parameters or fitness measures between groups. However, Beneke and colleagues aimed to determine the energetics of a kumite match and only kumite athletes were used (Beneke, Beyer, Jachner, Erasmus, & Hutler, 2004). No studies were conducted on kata athletes specifically. Finally, the majority of studies included in this review used athletes who competed at either National or International tournaments, and were members of their respective National teams.

Test Measures

When it comes to the physiological profiling of karate athletes, the common test measures that appear in the literature are similar to the other combat sports. Body composition and anthropometric measurements, aerobic power and capacity, as well as anaerobic power and capacity were the more predominant parameters measured. For aerobic power and capacity, the graded treadmill max test was the common procedure (Chaabene et al., 2014; Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012). However, there has been several attempts to produce a karate-specific aerobic test, using common techniques in karate performance (Nunan, 2006; Chaabene et al., 2012; Tabben et al., 2009; Chaabene et al., 2014). One study used the Yo-Yo intermittent test of aerobic capacity as a field-test for aerobic capacity (Chaabene et al., 2014). For anaerobic performance of the lower body, the wingate anaerobic test on a cycle ergometer was used in a lab setting, while the vertical jump test was used in two studies as a field-based test of lower body power (Chaabene et al. 2012; Doria et al., 2009). Finally, strength was assessed in several of the studies by using the 1-repetition max procedure of the bench press, squat, and military press exercises (Imamura, Yoshimura, Uchida, Nishimura, & Nakazawa, 1998; Chaabene, Hachana, Franchini, Mkaouer, & Chamari, 2012; Adamczyk, & Antoniak, 2010).

Main Findings

The main findings are that karate athletes rely on all the energy systems, with an emphasis on the anaerobic alactic system, as well as the aerobic energy system. Because of this, physiological profiling and fitness testing of karate athletes should include tests that measure these parameters. While there has been an attempt to validate the use of a karate-specific

aerobic test, more research is still needed. For example, Chaabene et al. aimed to validate the karate-specific aerobic test, but found there was no significant correlation between it and the criterion-referenced graded treadmill test ($p=0.69$). Furthermore, Nunan found that there were only significant relationships in a select number of measures of oxygen consumption in a small sample size ($N=5$). Therefore, the use of a karate-specific aerobic test should be further researched before it is used before a previously validated aerobic test such as the graded treadmill or Yo-Yo intermittent test. When it comes to anaerobic performance, the vertical jump test appears to be the most prevalent in determining lower body power, while the wingate anaerobic test should be used in a lab setting.

Table A6. The current literature on physiological profiling and fitness testing of karate athletes

Author(s)	Purpose	Participants	Test Measures	Results
Doria, et al. (2009)	To determine the energetics of karate (kata and kumite techniques) in top-level athletes	<ul style="list-style-type: none"> - N= 12 - Males & females (3 per division for male/female) - senior & juniors - different weight divisions 	<ul style="list-style-type: none"> - weight/height - Anaerobic alactic power (vertical jump on force platform) - Anaerobic power And capacity (wingate) - Blood lactate - Simulated performance (portable gas analyzer) - 	Between genders in the same division: <ul style="list-style-type: none"> - Females had significantly lower body weight and VO₂max (mL/min) for both kata and kumite ($P<0.01$) - Males had significantly higher mean and peak power during wingate ($p<0.01$)

<p>Tabben, M., Coqhuart, J., Chaabene, H., Franchini, E., Chamari, K., & Tourny, C.</p>	<p>To determine the validity and reliability of a new specific field test for karate athletes</p>	<ul style="list-style-type: none"> - N=17 - men (n=14) and Women (n=3) - m = 24.1±4.6 y - w = 19±3.6 y - International level athletes - Different weight - junior & seniors 	<ul style="list-style-type: none"> - Karate specific Test (KST; gas analyzer) - VO2max (cycle ergometer) 	<ul style="list-style-type: none"> - relative and absolute VO2peak during KST and retest were not significantly different - Significant correlations between VO2peak in lab test and TE from KST - no significant difference between HRpeak of two tests
<p>Chaabene et al. (2014)</p>	<p>To examine the criterion related to validity of the karate specific aerobic test (KSAT) as an indicator of aerobic level of karate practitioners</p>	<ul style="list-style-type: none"> - N=15 - males (12) & Females (3) - competed at National and international level - different weight categories - Age = 22.2±4.3 	<ul style="list-style-type: none"> - Aerobic capacity (time to exhaustion during KSAT) - Graded treadmill Max test - YoYo intermittent recovery test 	<ul style="list-style-type: none"> - HRpeak during KSAT represented ~99% HRmax during treadmill test - No significant correlation between KSAT's TE & relative VO2max of treadmill test (p=0.69)
<p>Imamura, H., Yoshimura, Y., Uchida, K., Nishimura, S., & Nakazawa, A. (1998)</p>	<p>To investigate VO2max, body composition and strength of highly competitive karate practitioners and compare them to less experienced or novice karate practitioners</p>	<ul style="list-style-type: none"> - N=16 - Highly competitive (n=7; 12.6±3.4 years experience) - Novice (n=9; 1.2±0.5 years experience) - Adults (19+) - Males only 	<ul style="list-style-type: none"> -Body composition (2-site skinfold measurements) - Aerobic power (graded treadmill max) - Muscular strength (1RM bench press and squat) - Blood Lactate & HR 	<p>Highly competitive group showed significantly higher mean values in:</p> <ul style="list-style-type: none"> - Age, karate experience, lean body mass, bench press and half squat strength and maximal ventilation volume relative to novice group. <p>There were no significant differences between groups in:</p> <ul style="list-style-type: none"> -Body height and weight, %Fat, fat mass, VO2max (ml/kg/min), peak blood lactate and HRmax

Beneke, R., Beyer, T., Jachner, C., Erasmus, J. & Hutler, M. (2004)	To determine the energetics of karate point-fighting (kumite)	<ul style="list-style-type: none"> - N- 10 - males only - nationally or internationally ranked - 26.9±3.8 years 	<ul style="list-style-type: none"> - VO2 (portable spirometry) - Blood Lactate 	<ul style="list-style-type: none"> - VO2 = 165.3±52.4 ml/kg - changes in blood lactate = 4.2±1.9 mmol/L - Energy cost above rest = 334.3±86.3kJ per fight
Nunan, D. (2006)	To develop an aerobic fitness assessment test for competitive Karate practitioners and describe the preliminary findings	<ul style="list-style-type: none"> - N=5 - 31±9 years - Males - England National squad 	During KSAT: <ul style="list-style-type: none"> - Absolute and relative peak VO2 - Peak ventilation - HRmax - TE 	<ul style="list-style-type: none"> - No significant between test difference in absolute VO2peak, relative VO2peak, HRmax & TE (p > 0.05) - Significant relationship between TE and relative VO2peak - Further research needed
Chaabene, H., Hachana, Y., Franchini, E., Mkaouer, B., Montassar, M., & Chamari, K. (2012)	To examine absolute and relative reliabilities and external responsiveness of the Karate-specific aerobic test (KSAT)	<ul style="list-style-type: none"> - N=43 - Adults (19+) - Males only - regional to National level 	During KSAT: <ul style="list-style-type: none"> - TE - HRpeak - Blood lactate - RPE 	<ul style="list-style-type: none"> - National-level karate athletes (1,032 ± 101 seconds) were better than regional level (841 ± 134 seconds) on TE (p<0.001) - Significant difference was detected in Peak blood lactate between national- (6.09 ± 1.78 mmol/L) & regional-level (8.48 ± 2.63) - KSAT can effectively distinguish karate athletes of different levels

<p>Chaabene, H., Hachana, Y., Franchini, E., Mkaouer, B., & Chamari, K. (2012) Review article</p>	<p>To report the most important physical and physiological characteristics of karate athletes from the available scientific research</p>	<p>Review Article - Males & females - Juniors & seniors - Novice & elite - different weight</p>	<ul style="list-style-type: none"> - Body composition (skinfolds) - Somatotype - Aerobic Power - Anaerobic power and capacity (wingate) - Lower body anaerobic power (Vertical Jump) - Muscular strength (1RM bench press, Squat) 	<ul style="list-style-type: none"> - No significant difference regarding the mean BF% between highly competitive and novice karate - In general, top-level male karate athletes have high rates of mesomorphic-ectomorphic characteristics and less endomorphic characteristics - VO₂max of national and international male karate practitioners ranges from 47.8–44 to 61.4– 2.6 mL/kg/min and from 32.75–4.1 to 42.9- 1.6 mL/kg/min for Females - more research needed (especially on females)
<p>Ravier, G., Dugue, B. Grappe, F., & Rouillon, J. (2006)</p>	<p>to compare maximal accumulated oxygen deficit (MAOD) and the time course of blood markers of the anaerobic metabolism in response to exhaustive supramaximal test in two elite (international vs. national) class karate athletes</p>	<ul style="list-style-type: none"> - N=18 - Males only - 21.2±3.2 years - International (n=10) - National (n=8) - Adults (18+) - International VO₂max = 57.6±3.0 ml/kg/min - National VO₂max = 59.4±2.7 	<ul style="list-style-type: none"> - Maximal accumulated oxygen deficit (MOAD; treadmill ergometer) - Blood lactate, pH, and plasma ammonia 	<ul style="list-style-type: none"> - MAOD was similar in both groups (67.8 ± 8 ml·kg⁻¹ and 64.5 ± 6.4 for Int and Nat groups, respectively) - ammonia and lactate accumulation are sensitive to the level of performance in karate

Adamczyk, J., & Antoniak, B. (2010)	To determine whether and how the level of specific fitness of karate competitors changed, depending on their ranks	<ul style="list-style-type: none"> - N=16 - Males only - Different age categories (4 juniors, 7 youth, and 5 seniors) 	<ul style="list-style-type: none"> - Muscular strength (Bench press, Military press, Ez-bar preacher curls, forearm ext., squat, shank curl, chest press) - Endurance (# of roundhouse kicks in 90 minutes) - punch/kick speed 	<ul style="list-style-type: none"> - Specific fitness increases proportionally to rank - Endurance and speed most important in affecting performance
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Karate Long Term Athlete Development (LTAD) Model

In 2009, Karate Canada established a Long Term Athlete Development (LTAD) model for karate athletes at different stages of development. The purpose of establishing a karate-specific LTAD was to provide a training framework for athletes of all ages and levels and to encourage long-term enjoyment and participation in karate. The Karate Canada model follows certain guidelines that have been outlined by many other sports who use the LTAD model for their respective sports, but highlights certain areas that are specific to karate athlete development. Just like other LTAD models in other sports, the Karate Canada version highlights general recommendations for training loads for athletes as they progress through different stages of development. The specific stages that are included in the Karate LTAD model are:

1. Active Start
2. FUNdamentals
3. Learn to Train
4. Train to Train
5. Train to Compete

6. Train to Perform

7. Train to Win

8. Active for Life

The particular training ratios for each stage are divided into activity fun based training (games, fundamental movements etc.), general training (i.e. conditioning, weight training, flexibility training etc.), karate training (sport-specific movements and drills), competition specific training (i.e. simulated performances), and competition (tournaments, games etc.). The recommended ratios for each stage are as follows:

Table A7. Training to competition ratios for each stage of development in the karate LTAD model

Stages	Recommended Ratio
Active Start	All activity fun based
FUNDamentals	All activity fun based
Learn to Train	95% karate training, 4% competition specific training and 1% competition
Train to Train	70% karate training, 28% competition specific training and 2% competition
Train to Compete	40% general training, 55% competition specific training and 5% competition
Train to Perform	30% general training, 65% competition specific training and 5% competition
Train to Win	25% general training, 70% competition specific training and 5% competition
Active for Life	Based on individual's desire

As seen from Table 7, the Karate Canada LTAD model helps outline progressing stages of development for karate athletes and the training loads of each phase. While this is important in helping coaches and athletes understand certain training regimes, it does not give an indication of how well an athlete compares to other individuals in the same stage of development. This is important information for those athletes who wish to compete at the Provincial, National, or World level, as well as those in the Train to Compete, Train to Perform, and Train to Win phases of the LTAD. However, gaps in the research have been noticed in areas such as fitness testing

for athletes in these stages of development, especially when it comes to competition specific training.

Conclusions

To date, there is no physical fitness test battery for karate athletes. However, before a test battery can be established, a review of the current literature needs to be performed. By reviewing the current research on fitness testing in all combat sports, it helps provide a framework for the establishment of a sport-specific fitness test battery. For karate, a sport which has already highlighted the need for fitness testing standards, such a fitness test battery could be useful to not only review individual athlete fitness levels, but also how they relate to other athletes in similar stages of development.

APPENDIX B - INFORMED CONSENT

UNIVERSITY OF VICTORIA INFORMED CONSENT STATEMENT

Fitness Test Battery for Karate Athletes

Kalan Anglos, Graduate Student, School of Exercise Science, Physical and Health Education

Dr. Lynneeth Stuart-Hill, PhD, School of Exercise Science, Physical and Health Education

Dr. Kathy Gaul, PhD, School of Exercise Science, Physical and Health Education

You have been invited to participate in an athletic research study. The aim of this study is to determine a valid and reliable fitness testing battery for Karate athletes.

INFORMATION

It is expected that there will be approximately 30-40 participants taking part in this study. You will be asked to participate in a variety of fitness testing protocols that measure the physiological parameters of Karate performance. Data collection will be gathered in one session, and will take approximately 45 minutes – 1 hour to complete.

Additionally, the researcher will require you to fill out a Physical Activity Readiness Questionnaire (Par-Q) and will facilitate a health screening protocol prior to test administration. The information from these protocols will be used to gain important health information on you such as: gender, date of birth, medications they are taking or if they diagnosed with asthma, head injuries, emotional/psychological, major surgery, high blood pressure, and/or epilepsy as well as how many years you've participated in Karate and any major tournaments you have participated in.

RISKS

There are minimal risks to you participating in this study and the fitness testing will not be more strenuous than your daily training activities.

BENEFITS

This research study will provide researchers with information on valid and reliable fitness testing protocols for Karate athletes. Currently, there is no established test for Karate athletes.

COMPENSATION

You will not be compensated for your participation in this study.

CONFIDENTIALITY

Your name will be removed from any/all data sources and replaced with a code number in order to ensure confidentiality. All information will be kept in a locked cabinet in a research lab at the University of Victoria. Kalan Anglos and his supervisors, Dr. Lynneeth Stuart-Hill, and Dr. Kathy Gaul will be the only people who will have access to the raw data. The results of this study will be used in written publications. These publications may contain data collected on your athlete, however no disclosure of personal identity will be made in any publication or presentation.

CONTACT

If you have any questions at any time about the study and its procedures, or you experience adverse effects as a result of participating in this study, you may contact Kalan Anglos at 250-465-1809 or by email at Kalan_Anglos@outlook.com at any time throughout this process. This project has been reviewed and approved by the Human Research Ethics Board at the University of Victoria. If you feel you have not been treated according to

the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the Human Research Ethics board at the University of Victoria at 250-472-4545

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

FEEDBACK & PUBLICATION

The results of this study will be disseminated via conferences and written in other publications. You may obtain a copy of the results by contacting the researcher at the email address stated above. It is estimated that the final copy of the results will be made available after May 2017.

APPENDIX C - VIDEO EXAMINATION DATA COLLECTION SHEET

Panel Member: _____

Date: _____

Instructions: For each bout, the panel member is required to count the number of kicks, punches, and takedown attempts (kumite only) that were thrown for the entire match. Additionally, the panel member should describe any specific movement requirements that they notice or believe to be vital for correct execution. These characteristics can include techniques, or physiological requirements that are deemed necessary for optimal performance.

Kumite Match

Bout	Punches Thrown	Kicks Thrown	Takedown Attempts	Additional Movement Requirements

Kata Performance

Bout	Punches Thrown	Kicks Thrown	Additional Movement Requirements

APPENDIX D - DATA COLLECTION SCORE SHEET FOR TEST BATTERY

Athlete's name _____ **Body mass** _____ kg
Date _____ **Time** _____ **Standing Height** _____ cm
Location _____ **Sitting Height** _____ cm
Birthdate _____ **Age** _____ Years **Leg Length** _____ cm
Division(s): Kata / Kumite **Arm Span** _____ cm

Test	First Trial	Second Trial*
Flexibility (split/leg length diff.)	cm [†]	cm
Modified Bass Test	score	score
300 metre Shuttle	seconds [‡]	seconds
T- Test	seconds	seconds
Vertical Jump	cm	cm
Seated Medicine Ball Put	cm	cm
Leger 20 metre run "beep" test	stage (completed)	predicted VO2max

* On test days, at least 3 minutes should be given between first and second trials (where applicable)

† For tests measuring distance (centimetres), round scores to the nearest whole cm (*example: 164cm*)

‡ For tests that measure time, round scores to the nearest 0.1 seconds (*example: 24.3 seconds*).

Implementing the Test:

If entire test battery is being done on the same day, the order of assessment should follow the way it is presented on the score sheet (above). If only individual tests are being done, or tests are being done on separate days, then order of assessment should be done in this order: (day 1) **flexibility test, seated medicine ball put, 300m shuttle**, and (day 2) **T-Test, Vertical Jump, Leger 20m run, Modified Bass Test**. In these cases, subsequent testing days should be separated by at least 48 hours and no longer than 1 week.

If anthropometric measurements are being taken during the implementation of the test battery, they should be performed first, before continuing on to the rest of the fitness battery.