

Kickboxing review: anthropometric, psychophysiological and activity profiles and injury epidemiology

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ABSTRACT: Kickboxing is one of the modern combat sports. The psychophysiological demands of a kickboxing competition require athletes to achieve high thresholds of several aspects of physical fitness. The aim of the current review is to critically analyse and appraise the kickboxer's anthropometric, physiological, physical and psychological attributes with the activity profile and injury epidemiology in order to provide practical recommendations for training as well as new areas of scientific research. The available information shows that both amateur and elite-level male kickboxers are characterized by a higher proportion of mesomorphy with a well-developed muscle mass and low body fat percentage. While there is some variation in the maximum oxygen uptake of kickboxers, moderate to high cardio-respiratory levels are reported for these athletes. Regardless of kickboxers' level, a high peak and mean anaerobic power output were reported. High-level kickboxing performance also requires well-developed muscle power in both the upper and lower limbs. Psychological factors contribute to success that requires high levels of self-confidence, motivation, dispositional hope and optimism, mental toughness/resiliency, and adaptive perfectionism. Psychological attributes also distinguished successful from less successful kickboxers. The activity-to-rest ratio was higher in elite (1:1) than both amateur and national-level (from 1:2 to 1:5) kickboxers, with no significant differences between rounds (round 1=1:4, and rounds 2 and 3=1:5) as well as between winners and losers in amateur and national-level simulated combats. These particular psychophysiological characteristics and performance aspects of kickboxers influence performance and could serve as guidance for training. Finally, kickboxing is characterized by chronic repetitive head trauma, which causes hypopituitarism due to traumatic brain injury (TBI). Future investigations into the physical, physiological and psychological characteristics related to age, gender and competitive levels of kickboxers are required to enrich the current knowledge and to help create the most suitable training programme.

CITATION: Slimani M, Chaabène H, Miarka B, Franchini E, Chamari K, Cheour F. Kickboxing review: anthropometric, psychophysiological and activity profiles and injury epidemiology. *Biol Sport*. 2017;34(2):185–196.

Received: 2015-12-14; Reviewed: 2016-04-17; Re-submitted: 2016-05-01; Accepted: 2016-10-11; Published: 2017-01-20.

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Key words:

Kickboxing

Psychophysiological

characteristics

Time motion analysis

Injuries

INTRODUCTION

Kickboxing is a combat sport which involves two competitors directing full-force strikes with the hands, elbows, knees, shins and feet at each other. Styles such as Muay Thai, American or European kickboxing, Chinese San Shou, and French Savate seem to have evolved independently and asynchronously from each other [1]. A typical kickboxing competition contains 3 to 12 rounds of 2 to 4 min each with a rest period of 1 to 2 min in between [1,2]. Typically, kickboxing medallists perform five to seven matches during international competitions, with each match having an 8-min

time limit (i.e., the match is finished only when one of the athletes scores; if no one succeeding in scoring an additional round should be added). Moreover, as kickboxing athletes have to perform a great number of actions during each match, the physical and physiological demands are high [3]. Kickboxing is a dynamic, high-intensity intermittent striking combat sport that requires complex skills and tactical excellence for success where athletes are classified by gender, body mass and age categories [1]. International level competitions have the following age categories: juniors: 16 to 18 years old;

seniors: 19 to 40 years old; veterans: 41 to 50 years old [1]. In regional, national, and international events, there are seven official senior female weight divisions (i.e., ranging from <48 to >70 kg: “light” (<48, <52, and <56 kg), “middle” (<60, and <65 kg), and “heavy” (<70, and >70 kg)) and twelve official weight divisions for both junior and senior male kickboxers (i.e., ranging from <51 to >91 kg: “light” (<51, <54, <57, and <60 kg), “middle” (<63.5, <67, <71, and <75 kg), and “heavy” (<81, <86, <91, and >91 kg)) [1].

Preceding reports in kickboxing use theories and frameworks of experimental and descriptive research performances in evaluations and tournaments analysis [1,4], which are determined by a competitor’s anthropometric, technical, tactical, psychological, physical and physiological characteristics [4-8]. For instance, from the physical conditioning perspective, the main goal of kickboxing training is to prepare the kickboxers to effectively manage both the technical-tactical and the physiological demands of combat. To be effective, kickboxing techniques should be applied with accuracy, within a good ‘window of opportunity’, with strength, velocity and power [1]. As in Muay Thai, this short burst of energy is supplied mainly by anaerobic metabolism. In contrast, the maintenance of the intermittent work performed during a match, as well as the recovery process during the short intervals, is mainly supported by aerobic metabolism [3]. Additionally, aerobic metabolism is especially important for effective recovery between matches [3]. Poor anaerobic or aerobic capacity is of concern, for the unconditioned, inexperienced competitor and therefore less technical skills and physical profile may be related to increased risk of injury [1]. Nevertheless, prolonged periods of kickboxing training each week and/or overtraining condition might increase the risk of traumatic brain injury (TBI) [1].

It can be established that kickboxing is a complex sport with demands comprising a number of specific characteristics to achieve a high-level competitive performance. It is well known that understanding the characteristics of elite-level athletes can provide insightful information regarding what is truly needed for competitive success [8]. Particularly, physiological characteristics of athletes are generally measured through testing their components of fitness and skill. The fitness components include cardiorespiratory endurance, muscular strength, muscular endurance, flexibility and body composition. Skill related components include speed, agility, power, balance, coordination and reaction time. Most combat sports require a mix of technique, strength, aerobic fitness, power, and speed. Usually, no single performance characteristic dominates in combat sports [9]. Psychological skills are the most important factors that are related to performance for most sports such as motivation, self-confidence, and mental toughness. Therefore, it is important for coaches, trainers, and sports scientists to collect objective information about their kickboxers’ main physical, physiological and psychological characteristics to improve training organization, establishing short- and long-term training goals, to provide objective and accurate feedback and to motivate athletes during training. In this review, the aerobic

and anaerobic power and capacity as well as strength (strength-endurance, muscle power and maximal strength) characteristics of amateur and elite kickboxers are presented.

Kickboxers have been studied for competitive performance improvements over the past three decades, contributing to increased knowledge of sports research methods [10], through the characterization of physical fitness, technical-tactical and time-motion analysis, creation of specific physical assessments and with description of psychological factors which could affect the fight outcome [4-8,11]. This information has driven interest and investment in developments of new intervention strategies, including multifaceted approaches to creating training environments conducive to better championship results. Despite the several studies on kickboxing [4-8,11-15], no review has been able to organize Kickboxer Performance Design Guidelines (KPDGs) using an interdisciplinary complex arrangement. Creation of KPDGs could describe the main domain issues. The purpose of developing guidelines is to discuss some subjects in the design and profile comparisons of kickboxing performance, rather than to supply an authoritative ‘cookbook’ of methods. To the authors’ knowledge, there are no in-depth review papers on the applied physiology of amateur and elite kickboxers. Therefore, KPDGs could reveal kickboxers’ characteristics which could improve athletes’ and coaches’ knowledge to develop individualized strength and conditioning programmes. The purpose of this review is to provide and critically appraise the scientific data available related to kickboxers’ anthropometric, physical, physiological, and psychological attributes together with the activity profile and injury epidemiology.

MATERIALS AND METHODS

Literature search strategies

For the development of the KPDGs, a computerized search was performed in the PubMed, Web of Science, Google Scholar and Scopus databases (up to April 2016) for English-language, peer-reviewed investigations using the term kickboxing alone and together with “physical fitness”, “body composition”, “somatotype”, “strength”, “muscular power”, “aerobic level”, “anaerobic level”, “psychological characteristics”, “motivation”, “self-confidence”, “mental toughness”, “activity profile”, and “injuries”. Manual searches were also made using reference lists from the recovered articles.

RESULTS

Descriptive characteristics of included studies

A total of 30 investigations were found. Sixteen papers examined anthropometric, physiological and physical profiles of kickboxers [3, 8,10,12-14,16-25] and 4 focused on the activity profile of amateur and elite kickboxing competitions [2,4,11,22]. Thus, 6 articles determined kickboxers’ psychological characteristics [5-7,15,10,26] and 6 focused on injury epidemiology in kickboxing [27-32]. Furthermore, each research work was analysed to evaluate the kickboxers’ anthropometric and psychophysiological attributes, activity pro-

file and injury epidemiology, particularly in terms of a wide range of characteristics, including participants' gender and level. Below we discuss the evaluation analysis and the challenge of how to optimize the competition level performance, with the main research results shown in tables.

DISCUSSION

Anthropometric characteristics

Somatotype and body composition

In kickboxing, as occurs in any other combat sport, where competitors are divided by weight classes, optimal body composition is a major concern. Considering the broad range of weight classes, it is impossible to establish a single body type or an anthropometry profile for all kickboxers. Prior to each match, kickboxers need to conform to a body mass limit by maximizing the fat-free mass and minimizing the amount of body fat. In agreement with this approach, high-level elite and amateur kickboxers of both sexes showed a propensity for low values of body fat. The mean range of body fat percentage varies from 6.1 to 11.4% for male national and elite kickboxers and from 9 to 16% for male amateur kickboxers (Table 1).

Body fat percentage in male amateur kickboxers is similar to that previously recorded in boxing (range from 9 to 16% for male amateur boxers from different levels of practice and/or weight categories) [33] and mixed martial artists (MMA) (range from 7 to 17% in male amateur MMA fighters) [34]. However, body fat percentage in elite kickboxers is lower than that in elite karate athletes (range from 7.5%

to 16.8% for male high-level karatekas) [35]. This observation suggests that, as in other striking combat sports, a low body fat percentage seems to be a prerequisite for a kickboxer's high-level performance.

Three studies dealing with elite and recreational kickboxers' somatotype were found [8,16,19]. Zabikovec and Tiidus [8] found the following values for somatotype in elite kickboxers: endomorphic component, 2.7 ± 1.2 ; mesomorphic component, 4.3 ± 0.2 ; and ectomorphic component, 2.7 ± 0.7 . Catikkas et al. [16] reported that kickboxers presented: endomorphic component, 2.9 ± 1.3 ; mesomorphic component, 4.25 ± 1.30 ; and ectomorphic component, 3.10 ± 1.30 . Furthermore, Nikolaïdis et al. [19] reported that recreational kickboxers presented: endomorphic component, 3.5; mesomorphic component, 4.9; and ectomorphic component, 2.3. Thus, kickboxers have a profile that accentuates the mesomorphic properties (i.e., very high muscularity, low linearity and low fat). These values are comparable to those recorded in elite taekwondo athletes [36], elite karate athletes [35] and elite amateur boxers [37]. As studies dealing with female kickboxers' body fat and somatotype are scarce, further investigations are recommended.

Physiological profile

To succeed in competition, kickboxers require well-developed technical-tactical skills and a high level of physical and physiological fitness [1,4,8,18]. Due to the specificity of combat in kickboxing (i.e., high-intensity movements during rounds, with short breaks that

TABLE 1. Body fat percentage (%) of amateur and elite kickboxers (data are presented as the mean \pm SD).

Athlete characteristics (n; level)	Body mass (kg) [mean \pm SD]	Body fat (%) [mean \pm SD]	Method (PER)	Reference
Male				
Canadian (4 elite)	72.6 \pm 5.4	8.1 \pm 2	SM (Jackson and Pollock [38])	[8]
Tunisian (30 amateur)	72.3 \pm 7.5	12.6 \pm 3.5	NR	[13]
Turkish (10 national and elite)	70.3 \pm 6.0	9.5 \pm 3.5	SM (Jackson and Pollock [38])	[14]
Turkish (15 national)	67.35 \pm 10.55	12.20 \pm 3.07	SM (NR)	[16]
Serbian (16 elite and 34 sub-elite)	69.73 \pm 14.02	11.42 \pm 5.81	NR	[17]
Caucasians (14 recreational)	75.4 \pm 8.9	14 \pm 5	SM (Parizkova [39])	[19]
Male and female				
Portuguese (13 elite)	73.9 \pm 11.34	9.72 \pm 5.7	NR	[23]

Note: PER: prediction equation reference; NR: not reported; SM: skinfold measurements.

are not enough to provide a full recovery), Zabukovec and Tiidus [8] showed that kickboxing requires moderate-to-high levels of aerobic/anaerobic power. The anaerobic metabolic pathway provides energy for short and intense attacks of maximal power during combat, while the aerobic system contributes to the kickboxers' ability to repeat attacks at the same strength and speed level during the total duration

of the combat, to optimize the recovery process during the brief periods of rest or reduced effort during the combat, and also for effective recovery between consecutive combats [2].

Since kickboxing taxes both the anaerobic and aerobic systems, the kickboxer should focus on optimizing each [3,20]. In addition to adequate rest, nutrition, cultivation of kickboxing skills, and psy-

TABLE 2. Maximum oxygen uptake ($VO_2\text{max}$) of amateur and elite kickboxers (data are presented as the mean \pm SD).

Athlete characteristics (n; level)	Ergometer	$VO_2\text{max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	Reference
Male			
Canadian (4 elite)	Cycle ergometer	61.5 \pm 7.5	[8]
Tunisian (30 amateur)	Cycle ergometer	51.9 \pm 4.3	[13]
Turkish (10 national and elite)	Multistage shuttle-run test	48.5 \pm 3.0	[14]
Serbian (16 elite and 34 sub-elite)	NR	49.81 \pm 10.86	[17]
Male and female			
Portuguese (13 elite)	Treadmill test	57.99 \pm 10.3	[23]

Note: NR: not reported.

TABLE 3. Lower and upper-body Wingate anaerobic test performance of kickboxers (data are presented as mean \pm SD).

Athlete characteristics (n; level)	Peak power ($\text{W} \cdot \text{kg}^{-1}$)	Mean power ($\text{W} \cdot \text{kg}^{-1}$)	Reference
Male			
Canadian (4 elite)			[8]
Arms	7.4 \pm 0.7	5.4 \pm 0.4	
Legs	18.1 \pm 4.6	10 \pm 0.7	
Tunisian (18 elite)			[12]
Arms	5.89 \pm 0.69	4.51 \pm 0.53	
Tunisian (30 amateur)			[13]
Arms	4.3 \pm 0.7	3.2 \pm 0.7	
Legs	9.8 \pm 2.1	6.7 \pm 1	
Caucasians (14 recreational)			[19]
Arms (F-v test)	NR	7.01 \pm 1.68	
Legs	NR	15.3 \pm 3.69	
Tunisian (18 elite)			[20]
Arms	ARG 5.85 \pm 0.83 PRG 5.93 \pm 0.52	4.56 \pm 0.56 4.45 \pm 0.48	
Tunisian (20 regional and national-level)			[21]
Arms	SKCTPG 5.8 \pm 1.3 Combat G 5.6 \pm 1.2	3.7 \pm 0.8 3.6 \pm 0.9	
Tunisian (20 regional and national-level)			[22]
Arms	5.6 \pm 1.2	3.6 \pm 0.9	

Note: F-v test: force-velocity test; ARG: active recovery group; PRG: passive recovery group; SKCTPG: specific kickboxing circuit training protocol group; Combat G: combat group.

chological preparedness, a critical determinant of a fighter's success is the degree to which he/she trains the metabolic pathways and skeletal muscles [1]. Relatively little is known regarding the physiological characteristics of kickboxing athletes. In order to gain a better understanding of the physical demands of the sport, the first step is to determine the basic physiological characteristics of individuals who have experience in practising kickboxing.

Aerobic profile

Cardiovascular fitness is one of the most important aspects of physical fitness conditioning in kickboxing [1]. In this context, well-developed aerobic fitness helps the kickboxer to maintain repetitive high-intensity actions within a kickboxing match, accelerate the recovery process and keep the kickboxer in a good physical condition until the last round and/or match [3]. Kickboxers' aerobic fitness has been established by measuring maximal oxygen consumption (VO₂max) in a continuous graded exercise test, using either a cycle ergometer or a treadmill in the laboratory [8,13,22] and a multistage shuttle-run test as a field test [14]. VO₂max mean values reported in the scientific literature vary between 54 and 69 ml·kg⁻¹·min⁻¹ for elite male kickboxers (Table 2). These values are comparable to those previously established with other striking combat sport disciplines such as amateur boxers (range from 49 to 65 ml·kg⁻¹·min⁻¹ for males) [33], elite karate athletes (range from 47 to 61 ml·kg⁻¹·min⁻¹ for males) [35], and elite taekwondo athletes (range from 44 to 63 ml·kg⁻¹·min⁻¹ and from 40 to 51 ml·kg⁻¹·min⁻¹ for males and females, respectively) [36]. These findings highlight that, as with other combat sports, kickboxing places a strong demand on cardiovascular and respiratory functions.

Anaerobic profile

High-intensity, intermittent sports rely mostly on anaerobic sources, as the decisive actions depend on powerful movements [33]. The ATP-PCr energy system, particularly, is very important for kickboxers because a powerful take-down or strike action often means the end of a competition [1]. The anaerobic evaluation is quite complex because there is no gold standard test available [35]. However, as it has been observed in other sports, the Wingate anaerobic test has been used to evaluate the anaerobic profile of kickboxers (Table 3). The main results determined through the Wingate anaerobic test are expressed in terms of peak and mean power output, and fatigue index [8,9]. These variables have been reported for both upper and lower-body actions in kickboxers [8,12,13,20-22]. The available studies showed that mean power output values for upper and lower body of male amateur kickboxers were about 3.2 ± 0.7 W·kg⁻¹ and 6.7 ± 1 W·kg⁻¹, respectively [13]. The latter are close to those previously established with amateur boxers' lower limbs (6.5 ± 0.5 W·kg⁻¹) [33]. In addition, in regional and national-level kickboxers, the mean anaerobic capacity recorded in upper limbs was about 3.6 W·kg⁻¹. However, the mean anaerobic capacities recorded in lower and upper limbs within elite male kickboxers were about 10.5 W·kg⁻¹ (range 8.2-11.8 W·kg⁻¹) and 4.7 W·kg⁻¹ (range 4.4-5.9 W·kg⁻¹), respectively [8,12,20]. This is similar to the lower limb anaerobic capacity value recorded in elite level male karate athletes (9.1 ± 1.1 W·kg⁻¹) [35] and greater than the value recorded in the upper limb with elite kung-fu athletes (4.1 ± 0.4 W·kg⁻¹) [40] and amateur kickboxers. These findings attest to the importance of anaerobic fitness development in kickboxing performance as in other combat sports.

TABLE 4. Strength performance of kickboxers (data are presented as mean ± SD).

Athlete characteristics (n; gender; level)	Strength test	Reference
Canadian (4; male; elite)	Knee extension peak torque For 60°/s 215 ± 21 N.m For 180°/s 168 ± 18 N.m	[8]
Brazilian (5; male; 2±1 training experience)	Extensor peak torque of the right lower limb 48.49±32.74 N.m Extensor peak torque of the left lower limb 146.02±31.67 N.m Flexor peak torque of the right lower limb 71.76±13.03 N.m Flexor peak torque of the left lower limb 68.94±14.93 N.m	[18]
Caucasians (14; male; recreational)	Force-velocity (F-v) test FO lower limbs 239.1 ± 73.8 N FO upper limbs 133.2 ± 39.7 N	[19]
Greek kickboxers (31; NR; 4.8 ± 3.1 training experience)	Handgrip muscle strength Dominant hand 53.7 ± 11.9 kg Non-dominant hand 50.0 ± 11.3 kg	[25]

Note: NR: not reported; FO: maximal force.

TABLE 5. Lower and upper-body explosive power test performance of kickboxers (data are presented as mean \pm SD).

Athlete characteristics (n; level)	SJ (cm)	CMJ (cm or ms)	MBT (m)	Reference
Male				
Tunisian (20 elite; 10 winners and 10 losers)	NR	Winners 35.45 \pm 2.21 cm Losers 33.51 \pm 2.29 cm	4.59 \pm 0.22* 4.18 \pm 0.24	[10]
Tunisian (18 elite)	27.92 \pm 3.84	29.8 \pm 5.33 cm	NR	[12]
Tunisian (30 amateur)	NR	36.5 \pm 5.9 cm	4.1 \pm 0.4	[13]
Tunisian (18 elite)	ARG 27.92 (3.84) PRG 28.86 (4.54)	29.80 \pm 5.33 cm 30.89 \pm 2.93 cm	NR	[20]
Tunisian (20 regional and national-level)	NR	SKCTPG 39.2 \pm 4.8 cm Combat G 39.3 \pm 4.7 cm	NR	[21]
Tunisian (20 regional and national-level)	NR	Overall 39.3 \pm 4.7 cm Winners 40.8 \pm 5.0 cm Losers 38.5 \pm 4.7 cm	NR	[22]
Male and female				
Portuguese (13 elite)	NR	0.79 \pm 0.10 ms	NR	[23]

Note: NR: not reported; SJ: squat jump; CMJ: countermovement jump; MBT: medicine ball throw; ARG: active recovery group; PRG: passive recovery group; SKCTPG: specific kickboxing circuit training protocol group; Combat G: combat group; *: significant difference compared with losers.

Physical profile

Strength

Muscle strength in both the upper and lower limbs is paramount for a fighter's victory and is one of the keys to success in kickboxing [8]. The striking battles experienced by kickboxers resemble those of karate, MMA and taekwondo and require, therefore, the expression of dynamic strength. However, the development of these characteristics can contribute to the performance success of a decisive kickboxing skill. Moreover, both isometric (i.e., hand grip strength) and isokinetic strength performances are largely accepted as indicators of an amateur kickboxer's level of strength [14,18,25], as is the case with amateur boxers [33]. The results provided in this review showed a value of 53.7 \pm 11.9 kgf for the dominant hand and 50.0 \pm 11.3 kgf for the non-dominant hand (Table 4). The strength levels of kickboxers evaluated through the knee extension peak torque (215 \pm 21 Nm for 60°/s and 168 \pm 18 Nm for 180°/s) [8] were less than those recorded in amateur boxers [33]. Consequently, kickboxers require strength and strength endurance to effectively perform and sustain the technical and tactical actions in a match including kicking, punching, blocking, holding and pushing [4,14]. Overall, the upper limb isometric strength is of particular importance for achieving high-level amateur and elite kickboxing performance. It should be noted that there is no research quantifying maximal dynamic strength through one-repetition maximum test (1RM). In addition, there are no studies dealing with the effects of sex, age group and weight categories, and so future studies are warranted

to clarify the effects of these factors on the strength condition of kickboxers.

Muscular power

Muscle power represents the ability to generate high amounts of force in relatively short periods of time [41]. Kicking and punching are the key component of kickboxers. To be effective, they require a high level of both speed and power [10,42,43]. In this context, it has been suggested that the ability to produce high muscular power is one of the major fundamental prerequisites underlying successful performance among amateur and elite kickboxers [44]. As in MMA and boxing, punching and kicking in kickboxing are extremely dynamic and brief actions that occur over a very short period of time [45]; thus, they are mainly a function of the high-energy phosphate system [46]. Indeed, Aagaard *et al.* [47] noted that a punch is delivered in 50-250 milliseconds, thus, exceptional rate of force development (RFD) capabilities are required. These values are comparable to those recorded in other explosive combat sports such as karate [35] and kung-fu [48].

Upper-limb explosive power has been determined through the use of medicine ball throwing [10,12,13]. However, performance on vertical jump assessed via countermovement jump (CMJ) is largely accepted as an indicator of kickboxers' lower body muscular power [10,12,13,19-22] (Table 5). Results provided in this study were higher than those recorded in elite karate practitioners [35], but less than those reported in elite taekwondo athletes [36,49].

Speed and agility

Speed and agility have been characterized in kickboxers [1,13]. During a kickboxing match, the most important factor in scoring with an offensive and/or defensive technique is the timing, which is the execution of a technique at the right time to surprise the opponent and score [12]. Developing the proper timing requires the development of speed, reaction time and the understanding of the various sparring situations. The development of defensive techniques may even require further skills, such as timing and speed, factors developed through intensive practice, since one has to decide the proper technique to use that would be fast and effective to counteract and score [33]. Speed may be defined as the shortest time required for an object to move along a fixed distance and incorporates two important phases, acceleration (i.e., the rate of change in speed up to the point at which maximum speed is reached) and maintenance (i.e., the speed that is maintained for the remainder of the distance of interest) [50]. In contrast, agility may be defined as a rapid whole-body movement with a change of velocity or direction in response to a given stimulus (e.g. incorporating both deceleration and acceleration phases) [51]. In kickboxing matches, whether attacking or defending, agility skill requires the ability to perceive relevant information about an opponent's actions and react quickly and accurately. Only one study has examined the speed and agility characteristics of amateur kickboxers [13]. Researchers and sports scientists may therefore wish to consider developing valid, reliable and practical tests to assess the speed and agility of kickboxers.

Psychological characteristics

Elite kickboxers repeatedly have to perform under high pressure, and it is therefore not surprising that psychological characteristics often distinguish those successful at the highest standard from their less successful counterparts [10,15]. In addition to the psychological state necessary to attain peak performance, the athlete must have an appropriate physiological condition, which is directly associated with the optimal psychological state. Research identifies a number of psychological variables that are linked with enhanced performance in kickboxing [10,26]. These variables comprise psychological skills including concentration, relaxation and controlling anxiety, goal setting, visual search strategies, imagery and self-talk [6,7,15,26]. Other psychological variables comprise those personal characteristics that may impact upon performance including self-confidence, motivation and mental toughness [7,10,15]. Previous research evidence has already supported an association between psychological characteristics and sports performance [10,26]. Given the growing body of evidence linking mental and psychological skills to enhanced performance in kickboxing [6,7,15,10,26], an individualized mental skills training (MST) programme should be part of a fighter's training related to the activity intensities, tasks performance, phase of learning and psychological characteristics of athletes with different championship levels.

When comparing within competition level and match outcome, Slimani et al. [10] and Chen and Cheesman [52] noted that psycho-

logical skills (e.g., self-confidence, mental toughness) measures were a discriminator of successful performance in kickboxing and MMA, respectively. Particularly, compared to non-elite athletes, elite athletes reported that they were more motivated to do well in their sport, were more self-confident, experienced fewer problems with anxiety, relied more on internally referenced and kinaesthetic mental preparations, were more focused on their own performance than that of their team, and were more successful at deploying their concentration [10,52]. In fact, researchers and coaches have also distinguished successfully elite from non-elite athletes on the basis of their psychological skills.

Motivation

Once the competition is over, one of the primary psychological issues that kickboxers face concerns how to maintain motivation for intense, long-duration training regimens [15,26]. One of the major reasons for this is because emotions are a major source of motivation of behaviour and athletes need to deal with many different, fluid emotions in between competitions as well [15]. However, Vallerand [53] defines motivation as the construct used to describe the internal and/or external forces that produce the initiation, direction, intensity, and persistence of behaviour. Thus, the achievement of motivation is an important issue in sport psychology and is related to the rate of effort and perseverance in kickboxing [15].

Self-confidence

The current review of the literature indicated that self-confidence is one of the most important determinants of peak athletic performance in kickboxing [7,15,26]. Researchers have also sought to develop models to predict performance in kickboxing from a psychological point of view [10]. Research into the relationship between mental toughness and performance has consistently shown that better competitive sport performance is associated with higher levels of self-confidence and mental toughness [10]. Thus, Slimani et al. [10] found that winners had higher scores for self-confidence than defeated kickboxers. Accordingly, Terry and Slade [54] studied male karatekas and found that winners score higher on pre-competition anger as well as self-confidence. Likewise, one of the most consistent findings revealed by this review is that successful elite kickboxers report greater self-confidence than do less successful ones.

Mental toughness

A review of the literature pointed to mental toughness as being one of the most important determinants of peak athletic performance in kickboxing and Wushu (kung-fu) [10,15,55]. Investigators have defined mental toughness as: "Generally, superior ability to cope better than your opponents with the many demands and related pressures that occur at the highest level in sport" [56]. Specifically, the mental toughness attributes include (a) self-confidence (i.e., belief that on we can perform well and be successful), (b) negative energy control (i.e., to cope with negative emotions such as fear,

anger, frustration and temper for achieving success), (c) attention control (i.e., to stay focused and to perform well), (d) visualization and imagery control (i.e., creating positive mental images), (e) motivation level (i.e., the energy and willingness to persevere), (f) positive energy control (i.e., energized with fun, joy and satisfaction), and (g) attitude control (i.e., habits of thought and unyielding) [57].

Rigorous scientific studies suggest that an individual's mental toughness will be determined by both inherited characteristics and by learning, experience, environment influences [57,58], skill mastery, competitiveness, successes, education and advice, the use of psychological skills, access to an understanding social support network, and reflective practice [57]. However, mental toughness appears to be multidimensional and most often associated with unshakeable self-belief, the ability to rebound after failures (resilience), persistence or refusal to quit, coping effectively with adversity and pressure, and maintaining concentration in the face of many potential distractions [59]. Research into the relationship between mental toughness and performance has consistently shown that better performances of both cognitive and motor skills are associated with higher levels of mental toughness and that winners have higher mental toughness than losers [10].

The effects of mental toughness training on both self-reported mental toughness and performance are currently unclear, but research concerning the related concept of hardiness suggests that successful interventions might be possible [10]. Since context-specific application of various mental skills programmes has appeared to be related to their intended outcomes, programmes geared to develop mental toughness may also require a sport-specific context. Also, MST has an important role in the mental toughness formation, maintenance and optimization in kickboxing.

Mental skills training

Mental skills are internal capabilities to effectively and consistently self-control the psychological factors that support the improvement of individual performance. For their formation and training, techniques, procedures and drills are used [15]. For instance, MST represents the systematic and consistent practice of psychological skills to improve performance, to increase the enjoyment or to obtain higher satisfaction from the sport activity [6,7,15,26]. The ultimate goal of MST is self-regulation, which is the ability of a person to work for achieving short and long term goals through monitoring and effective management of his/her thoughts, emotions or behaviours. The individual's ability to control mental and emotional processes supports task performance, creates the psychological foundation for self-confidence and personal wellbeing [6,7,15,26] and increases his/her motivation to continue making efforts for trying to improve his/her sport performance [15].

Four basic mental ability training methods, more exactly mental skill development techniques, are generally recognized in sports psychology: mental imagery, relaxation, self-talk and goal set-

ting [15,26]. The integration of these abilities in mental skills training programmes and further within physical training is very important from a practical point of view because "it may help ensure quality practice and facilitate the effective transfer of mental skills into competition" [15,26]. An effective interaction among physical, technical, tactical, and psychological preparations should exist within each of the critical phases of the training programme (preparatory, competition, and transition) to achieve a high level of proficiency [6,7,15,26].

A few applied sport psychology programmes have been provided to kickboxing coaches and athletes [6,7,15,26]. These programmes consist of psychological techniques aimed at coping effectively with psychological barriers. For example, Devonport [15] provided practical advice on staying motivated throughout and maintaining confidence. In addition, techniques such as imagery, relaxation and self-talk were introduced for the kickboxers to use before, during, and after practices and competition, as well as psychological advice for specific combat situations [6,7,15,26]. However, the effects of combining psychological techniques were deemed advantageous [26]. It might be that the combination of self-talk and mental imagery works to lower anxiety, promote task-relevant cognition, and possibly enhance motivation, self-efficacy and motor-skill performance, which would benefit kickboxing performance.

Activity profile

Time-motion analysis

A typical kickboxing match consists of 3 rounds of 2 min with 1-min recovery between rounds [2]. To overcome the opponent and win the combat, kickboxers have to obtain a greater number of points via kicking and/or punching, or by achieving a technical knockout during the match [2]. The activity pattern of the kickboxing match is intermittent and characterized by short-duration, high-intensity bursts of activity interspersed with periods of lower intensity and/or pauses caused by kickboxers' clinching and/or the referee's interruption [1,2,11]. The activity-to-rest ratio in amateur kickboxing matches has been ranging from 1:2, with an average of 6 seconds of effort and 12 seconds for pauses [2], to 1:5 in official and simulated amateur and national-level combats, respectively [22]. Likewise, Davis *et al.* [60] reported an activity-to-rest ratio of 9:1 (without including breaks between rounds) in amateur boxing combat. In regional MMA matches, Del Vecchio *et al.* [61] reported a ratio between high to low intensity actions (Hi:Lo) of 1:2 to 1:4. However, the activity to rest ratio in international full-contact kickboxing matches has been revealed to be 1:1 with an average of 2.2 ± 1.2 seconds of high-intensity actions (i.e., HIA: attack and/or defensive actions) interspersed by 2.2 ± 0.7 seconds of non-fighting activities (i.e., LIA: low-intensity activity) and 5.4 ± 4.5 seconds of pause decided by the referee [11]. Furthermore, the same authors reported that the mean time between two successive high-intensity actions was about 3.4 ± 1.2 seconds. Matsushigue *et al.* [62] reported a similar effort-pause ratio in international taekwondo athletes. Chaabène *et al.* [63] revealed that elite karatekas elicited an action-to-rest ratio of 1:1.5,

which increased to 1:10 when the high-intensity-action-to-rest ratio was considered. These differences may be mainly explained by the specificity of each sport in terms of technical and tactical requirements, duration of the match, and athlete's experience level.

Regarding the activity levels, the current review showed that official and simulated amateur kickboxing combats are less demanding compared with official international combats. When comparing winners and losers, Ouergui et al. [22] found no significant differences in the duration of the various activity phases (i.e., HIA time, LIA time and pause time) between them. They also reported that there was no significant difference in the effort to pause ratio between rounds with 1:4 during round 1 and 1:5 during rounds 2 and 3.

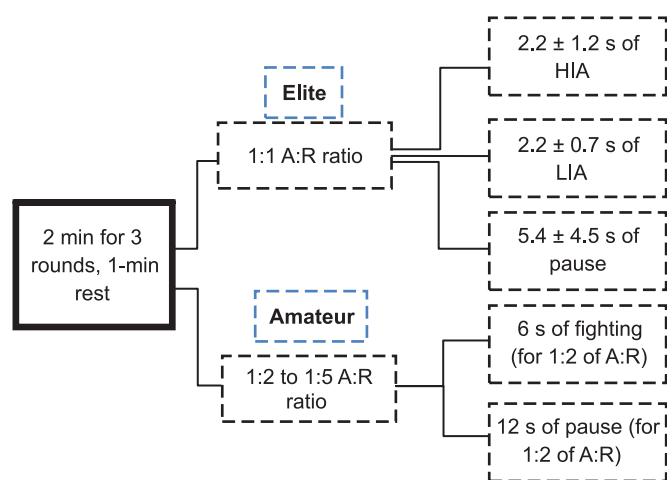


FIG. 1. The activity-to-rest ratio in elite and amateur level kickboxing matches.

Note: HIA: high intensity activity; LIA: low intensity activity; A:R: activity-to-rest.

In addition to these findings, the percentage of fighting (i.e., offensive and defensive actions) and non-fighting activities (i.e., low-intensity actions with pause time) was 40 and 60%, respectively, during an international competition [11]. These findings are not similar to those of Cappai et al. [24], who demonstrated that Muay Thai athletes spent 60% of the total combat duration in fighting activities (i.e., clinches or long distance attacks), whereas about 40% was spent in preparation phases. Del Vecchio et al. [61] reported that MMA athletes spent approximately 77% of the total match's duration in performing high-intensity striking and/or grappling sequences either in the standing position or on the ground, lasting between 8 and 14 seconds. Consequently, this time structure can be used to improve the technical, tactical, and physical preparation of kickboxers, allowing greater specificity in the tasks to be implemented. This type of action-to-rest pattern in kickboxing (Figure 1) requires a well-developed aerobic and anaerobic fitness level to meet the energy requirement of that activity appropriately, and requires training in an intermittent metabolism pattern during a kickboxer's

preparation [1,64]. Future investigations in performance analysis (technical/tactical and time motion analysis) during kickboxing competition (i.e., full-contact, low-kick and light contact styles) according to gender, participant levels, weight categories and match outcome are needed to support the findings presented in the current review.

Injury epidemiology in kickboxing

Despite the importance of developing the psychophysiological characteristics of kickboxers to achieve success in competition, it is worth noting that hard and prolonged periods of training each week and longer kickboxing careers might increase the risk of traumatic brain injury (TBI). TBI is a well-known public health problem around the world, and it is associated with increased morbidity, mortality and long-term disability [65]. For instance, kickboxing is well established to be associated with a risk of TBI [31]. It is worth noting that the terminology of TBI has evolved over time and the entity is now termed chronic traumatic brain injury (CTBI). However, chronic TBI may be caused by knock-out (KO) with loss of consciousness or by the cumulative effect of punches or kicks performed to the head. Kickboxers with long experience or kickboxers with limited defensive skills who repeatedly sustained heavy blows are at the greatest risk of developing this condition [32]. More specifically, kickboxing is associated with chronic repetitive head trauma that may cause brain injuries [27,32], unconsciousness and neurological abnormalities, mainly hypopituitarism [65]. Some studies have investigated pituitary functions in amateur kickboxers and demonstrated that kickboxing is a cause of TBI, and that growth hormone (GH) deficiency and adrenocorticotrophic hormone (ACTH) deficiency were also very common (22.7%, 9.1%, respectively) among 22 amateur kickboxers [31]. Accordingly, Tanriverdi et al. [66] reported that GH is the most common hormone lost after TBI, followed by ACTH, gonadotropins (luteinizing hormone (LH) and follicle-stimulating hormone (FSH)), and thyroid-stimulating hormone (TSH). The authors showed that the mechanisms responsible for pituitary dysfunction after TBI are not entirely clear; however, they suggest that genetic predisposition and autoimmunity may play a role. Thus, hypopituitarism following TBI may have a negative impact on degree of functional recovery and cognition performance and health as a whole [30,66].

Currently, as in Muay Thai all body targets are permissible in both amateur and professional kickboxing except for the groin [67]. Thus, it would be expected that the head, arms, and trunk would be the major targets/sites of injury for kickboxers [29,32]. Head injuries were found to be the second most common injury in both amateur and professional kickboxers [68]. Zazryn et al. [32] reported that the head/neck/face, followed by the lower extremities, were the most common body regions injured. The latter authors also reported that Australian kickboxers sustained more head injuries than those from the United Kingdom and Holland (51.6% vs. 42.5%), but fewer lower extremity injuries (39.8% vs. 53.4%, respectively). Romaine et al. [28] stated that the most common sites of injury for kickboxers

were the back, the knee, and the ankle; the most common types of injuries were strains followed by sprains, and tendinitis. Professional fighters were 2.5 times more likely to get injured compared with amateurs (rate ratio, 2.51), while defeated fighters were 3.5 times more likely to get injured compared with winners (rate ratio, 3.48) [27]. Zazryn *et al.* [32] reported an injury incidence rate of 109.7 injuries per 1000 athlete-exposures (AEs) in elite kickboxers competing in the state of Victoria, Australia.

Some interesting data come from a specific type of fist/foot boxing or Muay Thai, which is similar from a technical and fighting styles point of view to kickboxing. Indeed, Muay Thai rules allow the fighters not only to fight with their feet and fists but also with their knees and elbows. For this specific type of sport, hard and prolonged periods of training each week and longer Muay Thai kickboxing careers might have increased the risk of developing foot and ankle problems, especially plantar forefoot callosities and wounds, as well as toe deformities including tight heel cord [69]. Recently, it has been reported that the overall injury incidence rates in Muay Thai fighters were 390.1 injuries per 1000 AEs and 39.7 injuries per 1000 minutes of exposure [67]. The most commonly injured anatomic regions were the head (57.8%) followed by the lower extremity (26.1%), while the most common types of injury were laceration (70.6%) and fracture (20.6%). An interesting study showed that in Muay Thai the injury risk depends on the fighters' weight category [68]. Gartland *et al.* [68] investigated prospectively the type and rate of injuries sustained during a total of 588.5 minutes of Muay Thai competition time over 10 events. They found that injury rates were 1.3 injuries per 100 minutes of competition in the lightweight category, 2.25 per 100 minutes of competition in the middleweight category, 30 per 100 minutes of competition in the heavyweight category, and 2.54 per 100 minutes of competition in the super heavyweight category. We believe that this type of study should also be conducted in regular/classical kickboxing, to allow the injury risk to be determined according to the fighters' weight categories.

Finally, it is worth noting that injuries in kickboxing are frequent and often significant, and better injury surveillance is strongly recommended. From a therapeutic point of view, limiting the number of kickboxing sessions per week may help to reduce injury rates [28], and the coach should adapt specific training/competition contests for young and children kickboxers (e.g., light contact kickboxing in both simulated and official combats) by avoiding a full-contact kickboxing competition.

CONCLUSIONS

The KPDGs described the extent of formative and relevant evidence to understand potential approaches presented in kickboxing articles. Physiological and psychological characteristics of athletes influence performance and guidance regarding the nature of training. However, successful kickboxers have a very low percentage of body fat for both males and females. Mesomorphy is the most predominant

somatotype component in male athletes, while females have similar components of mesomorphy and endomorphy. Moreover, high-level competitive kickboxers present highly developed strength, anaerobic power and capacity as well as aerobic power. These variables seem to be similar in the upper and lower limbs, since kickboxers used both punching and kicking techniques. In brief, this review highlights that elite kickboxers need specific anthropometric characteristics, psychological skills, high levels of explosive power and anaerobic capacity combined with high technical and tactical proficiency. These variables are critical for coaches, who could benefit from relevant information to direct their decision in establishing a kickboxing team roster, especially when the selection process is limited in time. Therefore, physical preparation should focus on improving muscular power and capacity in both upper and lower extremities of the body. Since kickboxing taxes both the anaerobic and aerobic systems, the kickboxer should focus on optimizing each. Anaerobic capacity may be improved through high-intensity interval training, other forms of power training and strength training. Interval training can improve anaerobic and aerobic systems concomitantly; therefore, it should be a mainstay of the fighter's training regimen.

Research from a broad range of perspectives (e.g., cognitive-behavioural, psychophysiological, developmental) is likely to advance the understanding of psychological characteristics, such as self-confidence, self-efficacy, motivation and mental toughness, and its importance in kickboxing. If practitioners are to intervene effectively and enhance these skills, then a better understanding of mental techniques is necessary. Furthermore, this study has demonstrated that among kickboxers, the best achievers can be discriminated from lower achievers on the basis of their psychological characteristics. The findings indicate that the most successful athletes were more confident, used more frequently relaxation strategies, self-talk, imagery, attentional control and emotional control and pursued a performance-approach goal more and a performance-avoidance goal less. In terms of application, this result contributes to the identification of the most efficient mental skills.

The present review shows a higher activity-to-rest ratio in male elite compared with amateur and national-level kickboxers. Also, there were no significant differences between winners and losers in the time of different activity phases. Finally, Muay Thai and kickboxing are characterized by chronic repetitive head trauma, which causes hypopituitarism due to TBI. Hypopituitarism following TBI may have a negative impact on degree of functional recovery, cognitive performance and consequently on physical performance aside from the obvious health consequences.

There is a lack of studies concerning the anthropometric, physical, physiological, psychological characteristics and performance aspects of kickboxers in relation to age, sex, level of competitiveness and success and weight categories across different kickboxing styles (i.e., light contact, full-contact and low kick). Thus, further research using novel technology as a means to differentiate between performance levels according to athletes' age and experience, and give specific

consideration to developing a specific testing and training protocol for kickboxers, is highly recommended.

Conflict of interests: The authors declared no conflict of interests regarding the publication of this manuscript.

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