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REVIEW ARTICLE

Amateur Boxing: Physical and Physiological Attributes

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Abstract Boxing is one of the oldest combat sports. The aim of the current review is to critically analyze the amateur boxer's physical and physiological characteristics and to provide practical recommendations for training as well as new areas of scientific research. High-level male and female boxers show a propensity for low body fat levels. Although studies on boxer somatotypes are limited, the available information shows that elite-level male boxers are characterized by a higher proportion of mesomorphy with a well-developed muscle mass and a low body fat level. To help support the overall metabolic demands of a boxing match and to accelerate the recovery process between rounds, athletes of both sexes require a high level of cardiorespiratory fitness. International boxers show a high peak and mean anaerobic power output. 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 boxing. As boxing punches are brief actions and very dynamic, high-level boxing performance requires well-developed muscle power in both the upper and lower limbs. Albeit limited, the available studies reveal that isometric strength is linked to high-level boxing performance. Future investigations into the physical and physiological attributes of boxers are required to enrich the current data set and to help create a suitable training program.

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Key Points

- High-level boxers present low body fat and high muscle mass percentages.
- Elevated cardiorespiratory fitness is important to amateur boxers to support the metabolic demand of the combat and to provide a faster recovery between rounds.
- Well-developed muscle strength, muscle power and anaerobic power and capacity are key components to success in boxing.

1 Introduction

Boxing, which is called the "noble art" and is historically known as pugilism, is one of the oldest combat sports across all of human culture. According to the International Boxing Association, the first proof of boxing's appearance

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was discovered in Egypt and dates to approximately 3000 B.C. and boxing most likely appeared in Ethiopia as early as 6000 B.C. Historically, boxing first appeared as an Olympic sport at the ancient Olympic Games in 688 B.C. [1, 2]. The first amateur competition took place in 1860, and the Amateur Boxing Association appeared in London in 1880 [3]. Boxing consists of stand-up fist fighting and should therefore not be confused with other fighting styles such as kickboxing, Savate or French boxing, Muay-Thai or any other combat sport that allows the use of feet, elbows or knees to strike.

The Amateur International Boxing Association (AIBA), which is the official world organization of amateur boxing, has 196 affiliated national federations [3]. The most well-known AIBA events are the Olympic Games and the World Championship. Boxing was on the program of the Olympic Games for the first time in St. Louis in 1904, and, since 1920, boxing has been included in the program of the Olympic Games without interruption. A total of 286 boxing athletes, 36 of whom were women (competing for the first time at the Olympics), representing 79 countries, participated in the last Olympic Games [4]. As a full contact combat sport, the aim of amateur boxing is to succeed in delivering a clean and correct punch to the opponent without being punched in return [5]. During an amateur boxing match, opponents are only permitted to use their fists [6], with the knuckle area of the glove towards the target area (i.e., any part of the front and sides of the head or body above the belt) on the opponent. The scoring system in boxing is a function of the following criteria, which are analyzed by five judges: number of quality blows on the target area, domination of the bout, competitiveness, technical and tactical superiority and infringement of the rules [7].

As in almost all other types of combat sport, boxers are categorized into a series of weight classes that are intended to promote fair competition by matching opponents of equal body size, strength and agility [8–10]. According to the amateur boxing rules, there are ten weight categories, from less than 46 kg to more than 91 kg for youth boys and elite men, and from less than 45 kg to more than 81 kg for youth girls and elite women. For junior boys and girls, there are 13 weight categories from 46 to 80+ kg [11].

Olympic boxing rules have been subjected to several modifications of the bout formula. The duration, as well as the number of rounds, varies between categories: novice boxers compete in 3 rounds of 2 min each; intermediate boxers compete in 4 rounds of 2 min each; and open-class boxers compete in 3 rounds of 3 min or 4 rounds of 2 min each, by agreement of the coaches and boxers [12]. Between rounds, the recovery durations are always 1 min. Amateur boxing athletes can win by various types of decisions: points, referee stopping the contest (RSC), the compulsory count limit, injury (e.g., dangerous cut, fracture or dislocation), knockout (KO), referee stopping the contest because of a head blow (RSCH), walkover (i.e., the boxer presents himself in the ring and his/her opponent fails to appear) and disqualification [7].

To succeed in delivering a scoring blow and in return to avoid getting blows, boxers require well-developed technical-tactical skills and a high level of physical and physiological fitness [13]. It has been reported that a high anaerobic threshold and aerobic power level are necessary to succeed in boxing [5]. Amateur boxing is characterized by high-intensity movements during rounds, with short breaks that are not enough to provide a full recovery [14]. In this context, to properly train a boxer, knowledge of the metabolic requirements of a boxing match from the scientific literature seems to be extremely necessary.

Although amateur boxing is considered the most popular combat sport around the world, to our knowledge, there are no in-depth review papers that synthesize the physical and physiological characteristics of amateur boxers. A review of boxers' characteristics could improve coaches' and strength and conditioning trainers' knowledge concerning the physical and physiological profiles needed to reach high-level performance in this combat sport. Consequently, our goal is to provide a comprehensive review that will help scientists, coaches and athletes to better understand the physiological requirements of boxing.

2 Literature Search Strategies

A computerized search was performed in the MEDLINE, Web of Science, SPORTDiscus™, Google Scholar and Scopus databases (up to January 2014) for English-language, peer-reviewed articles. The key words used were as follows: "boxing," "boxing AND physiology," "boxing AND physical fitness," "boxing AND anthropometry," "boxing AND strength," "boxing AND muscular power," "boxing AND aerobic level," "boxing AND anaerobic level" and "boxing AND weight loss." References from the original studies were searched for further relevant investigations. Only scientific research dealing with the major fitness components of boxers (i.e., body composition and somatotype, aerobic and anaerobic profiles, muscular strength and power) and using accepted methods that provided relevant practical applications for a boxer's fitness training and/or performance were included in the current review.

3 Body Composition and Somatotype

Because amateur boxing is a weight-class combat sport, optimizing the body composition of boxers is considered relevant for high-level competitive performance. Prior to each match, athletes 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 amateur boxers of both sexes showed a propensity for low levels of body fat (Table 1). Amateur boxers are often stronger per kilogram of body weight than age-matched individuals. The mean range of body fat percentage extends from 9 to 16 % and from 14 to 26 % for male and female amateur boxers, respectively, in different practice and/or weight categories (Table 1). In light of the studies presented in Table 1, the mean body composition of international-level male boxers is approximately 12 % fat. Smith [15] reported higher body fat (mean ± SD 10.1 ± 2.6 %) and total skinfold (mean ± SD 23.8 ± 5.9 mm) among junior elite-level boxers than among senior elite-level ones (mean ± SD 9.1 ± 2.3 % and 22.3 ± 4.4 mm for body fat and total skinfold, respectively). The authors suggested that this difference may be related to the maturational status and/or the fact that senior boxers used weight loss procedures more frequently. It is important to note that studies on elite-level female boxers are lacking. Additionally, there are no studies that address body fat percentage in relation to the boxer's body weight class, except for that of Khanna and Manna [16] (Table 1).

Body fat percentage in male and female amateur boxers is comparable to that previously recorded in taekwondo [17], karate [18] and judo athletes [19] and slightly above the values established for elite-level wrestlers [20]. This observation suggests that low body fat percentage seems to be a prerequisite for boxer's high-level performance, similar to other combat sports. It has been reported that senior boxers have a higher total body mass, lean body mass and body fat compared with junior athletes [16]. This difference might be due to the training regimen differences between the two age categories; for example, senior boxers engage in more high-level strength training relative to their junior counterparts. Trutschnigg et al. [21] reported a similar body fat percentage between club-level female boxers and a group of physically active women, but a higher lean body mass index compared with the control group. These differences might be due to the training-related differences between the two groups (the female boxer group completed two muscular strength sessions per week).

From the studies presented in Table 1, it is clearly established that female amateur boxers have a propensity toward a greater body fat percentage compared with male boxers. This finding is consistent with the results established in the other combat sports such as karate [18], judo [19] and taekwondo [17]. This trend is also evident in male and female sedentary individuals [22].

Weight loss procedures are commonly practiced by combat sports athletes [9, 10, 23], but only one study was found about the prevalence of weight loss in Olympic-level boxers [24]. This study indicated that 100 % of Olympic-level boxers from the Brazilian national team reported losing weight before competition (for this group, the mean weight lost was 5.8 kg). Hall and Lane [25] reported that boxers typically reduce (mean ± SD) 5.6 ± 1.06 % of their body mass before competition. During the weight loss process, most athletes try to avoid decreasing lean body mass [23], and one important aspect during this process is the diet control [9, 10]. Iwao et al. [26] investigated the influence of the number of meals per day (two or six) with the same total energy intake during 2 weeks of body mass reduction and reported that despite the same total body mass reduction in both groups, the group consuming more meals per day reduced more body fat (mean ± SD 2.6 ± 0.4 kg) and reduced less lean body mass (mean ± SD 2.4 ± 0.3 kg) than the group that consumed only two meals per day (mean ± SD; body fat reduction 1.4 ± 0.4 kg; lean body mass reduction 3.5 ± 0.3 kg). All these results indicated that consuming meals more frequently can be important for boxers reducing their body mass. However, Iwao et al. [26] reported that the exact mechanism by which this phenomenon occurred, despite the same energy daily intake, could not be explained by their data.

When a group of boxers was submitted to a 5-day body mass reduction (mean ± SD 5.6 ± 1.7 %), body fat percentage determined via bioelectrical impedance decreased (mean ± SD) from 8.7 ± 1.7 % to 8.2 ± 1.6 %, while fat-free mass decreased (mean ± SD) by 4.9 ± 1.3 %, but no changes were observed in the control group [27]. For the group losing weight, most of the body mass reduction was obtained via dehydration, as decreases (mean ± SD) in total body water (6.0 ± 0.9 %), extracellular water (12.4 ± 7.6 %), total hemoglobin mass (5.3 ± 3.8 %), blood volume (7.6 ± 2.1 %) and plasma volume (8.6 ± 3.9 %) were observed in the group submitted to the weight loss procedures. One week after the competition, all variables had returned to baseline in the weight loss group [27].

Scientific research studies dealing with amateur boxer's somatotype are lacking, and there exists only one study conducted using elite-level male boxers from India, by Khanna and Manna [16]. The authors reported that senior elite-level amateur boxers have a somatotype that is characterized by a higher proportion of mesomorphy that reflects a well-developed muscle mass and low body fat. A comparison between amateur junior and senior boxers showed that the senior boxers have significantly higher endomorphy (mean ± SD 2.3 ± 0.6 vs. 1.8 ± 0.5) and mesomorphy (mean ± SD 4.9 ± 0.7 vs. 3.2 ± 0.6) characteristics compared with junior boxers, in whom a higher

Table 1 Body fat percentage of amateur boxing athletes (data are presented as the mean ± SD)

Athlete characteristics (*n*)	Body mass (kg)	Body fat (%) [range]	Method (prediction equation reference)	References
Males				
Indian national-level				Khanna and Manna [16]
Junior ($n = 30$)	53.6 ± 4.1	12.2 ± 1.1	Siri [29]	
Senior ($n = 30$)	76.7 ± 10.9	16.4 ± 3.8		
Indian junior national-level				Khanna and Manna [16]
Light-weight ($n = 7$)	53.1 ± 3.5	12.2 ± 1.1	Siri [29]	
Medium-weight ($n = 7$)	63.4 ± 3.2	11.6 ± 1.0		
Heavy-weight ($n = 7$)	74.6 ± 5.4	11.2 ± 1.2		
England international-level			Durnin and Womersley [30]	Smith [15]
Senior ($n = 23$)	NR	9.1 ± 2.3 [4.7–13.5]		
Junior ($n = 73$)	NR	10.1 ± 2.6 [5.0–17.7]		
Elite-level boxers from different nationalities			Durnin and Rahman [31]	Di Prampero et al. [32]
White boxers ($n = 9$)	NR	14.0 ± 1.1		
Black boxers ($n = 12$)	NR	11.4 ± 1.0		
Polish national-level ($n = 34$)	71.8 ± 15.1	9.4 ± 5.2	Durnin and Womersley [30]	Hübner-Woźniak et al. [33]
Malaysian national-level ($n = 7$)	56.9 ± 6.2	14.3 ± 2.0	Durnin and Womersley [30]	Ismail et al. [34]
Egyptian elite-level ($n = 17$)	73.8 ± 5.1	14.4 ± 1.9 [11.8–17.54]	NR	El-Ashker and Nasr [14]
American recreational-level ($n = 18$)	71.5 ± 12.6			Kravitz et al. [36]
Male ($n = 12$)		16.1 ± 7.3 [4.8–28.6]	Siri [29] for male	
Female ($n = 6$)		Value for both male and female	Lohman [35] for female	
South African novice-level ($n = 8$)	78.0 ± 5.4	14.4 ± 5.5 [8.1–24.8]	Durnin and Womersly [30]	Bellinger et al. [37]
Brazilian regional-level ($n = 6$) [two junior and four senior boxers]	56.9 ± 12.2	12.7 ± 5.3	Jackson and Pollock [38]	de Lira et al. [39]
Italian elite-level	77.4 ± 1.4	14.5 ± 1.5	Durnin and Womersly [30]	Guidetti et al. [5]
Caucasian club-level ($n = 12$)	77.9 ± 8.1	22.4 ± 3.9	Parizkova [40]	Giovani and Nicolaidis [28]
Polish national-level male ($n = 13$)	71.8 ± 15.1	9.4 ± 5.2	Near-infrared interactance instrument (Futrex 6100/XL, USA)	Hübner-Woźniak et al. [41]
Females				
Canadian club-level ($n = 11$)	58.7 ± 7.9	14.6 ± 2.0	Total body duel-energy X-ray absorptiometry scan	Trutschnigg et al. [21]
Brazilian regional-level ($n = 4$) [two junior and two senior boxers]	61.2 ± 6.6	22.0 ± 3.5	Jackson et al. [42]	de Lira et al [39]
Indian elite-level ($n = 20$)	57.6 ± 7.7	26.8 ± 2.8	NR	Chatterjee et al. [43]

NR information not reported

propensity for ectomorphy (mean ± SD 4.0 ± 0.8 vs. 2.3 ± 0.8) was noted [16]. Giovani and Nicolaidis [28] revealed that club-level male boxers presented a somatotype dominated by both endomorphy/mesomorphy propensities, in line with the previous findings from elite boxers. No studies were found concerning body size and arm span in amateur boxers. Future studies that take into account the weight categories for both sexes are needed concerning somatotype, body size and proportionality in amateur boxers.

Because body fat percentage is mediated by numerous factors such as sex, level of competitiveness, weight category and age, future studies should take into account all of these parameters and interpret the body fat percentage accordingly. Skinfold-based methods for estimating the body mass percentage represent the tool used in most of the available studies (Table 1). Although the simplicity and the accessibility of such a tool makes it useful in the field, special attention should be taken by practitioners to recognize the limitations of the results from the different prediction equations for quantifying the body fat percentage through this method.

4 Aerobic Profile

Cardiovascular fitness is one of the most important aspects of physical fitness conditioning in Olympic boxing [12, 14, 15, 39, 44]. In this context, well-developed aerobic fitness helps the boxer to maintain repetitive high-intensity actions within a boxing match, accelerate the recovery process and keep the boxer fit until the last round and/or match [12, 14, 44]. Boxers' aerobic fitness level has been established by measuring maximal oxygen consumption (VO_{2max}) on a continuous graded exercise test, using either a cycle ergometer or a treadmill in the laboratory [45]. The overall VO_{2max} mean values reported in the scientific literature vary between 49 and 65 ml/kg/min for males and between 44 and 52 ml/kg/min for females (Table 2). Unfortunately, for some studies, there is a lack of information about the type of ergometer used and the sex, level and number of boxers included in the study. The broad range of VO_{2max} values established in both males and females might be due to the boxer's level of practice, training phase, mode of testing and the different weight categories. However, VO_{2max} mean values reported in amateur boxers are comparable with those previously established with other combat sport disciplines such as wrestling (range from 53 to 56 ml/kg/min) [20], karate (range from 47 to 61 ml/kg/min for males) [18], taekwondo (range from 44 to 63 ml/kg/min and from 40 to 51 ml/kg/min for males and females, respectively) [17] and judo (range from 50 to 60 ml/kg/min and from 40 to 50 ml/kg/min for males and females, respectively) [19]. These findings highlight that, as with other combat sports, amateur boxing places a strong demand on cardiovascular and respiratory functions. However, this range of VO_{2max} values is still under those established for elite and sub-elite endurance athletes [46].

It should be noted that no studies have compared boxers' different levels of practice, levels of training and/or competitive levels. In a study comparing ranking in amateur boxing competition performance with physical fitness attributes, Guidetti et al. [5] revealed that the levels of anaerobic threshold and VO_{2max} and/or aerobic power were the variables most related to a boxer's competitive ranking and the most decisive factors contributing to a successful performance. Thus, to withstand the high physiological demands of a boxing match, boxers should have a well-developed aerobic fitness level. Khanna and Manna [16] compared VO_{2max} between senior- and junior-level amateur boxers and reported that senior boxers showed a higher VO_{2max} compared with their junior counterparts. This fitness difference is likely due to training program differences between the two groups and/or the maturational level. Likewise, boxers presented higher aerobic power levels when compared with healthy, untrained individuals [47].

In a comparison of cardiorespiratory fitness between two groups of different age categories, Smith [15] reported that junior England elite-level amateur boxers presented lower VO_{2max} values when compared with elite senior boxers. This finding may be due to the competition level and/or training program differences between the two groups, age (i.e., junior boxers between 16 and 17 years old and senior boxers between 18 and 34 years old) and level of maturation. Ghosh et al. [48] reported that senior international amateur Indian boxers from the heavyweight category presented lower VO_{2max} levels relative to body mass compared with the other weight categories. This observation supports the need for developing an allometric scaling approach that will minimize the effects of anthropometric parameter differences between boxers in future investigations.

El-Ashker and Nasr [14] measured VO_{2max} in a group of national-level male amateur boxers before and after 8 weeks (32 sessions, ~53 h) of a boxing training program. They revealed that the VO_{2max} (mean ± SD) increased from 58.2 ± 6.9 to 64.6 ± 7.2 ml/kg/min (Table 2). This means that boxing exercises might be adopted for aerobic fitness development. With regard to female amateur boxers, similar findings have been established by Chatterjee et al. [43] after 6 weeks of boxing exercises.

Few studies have been conducted using female amateur boxers. The research of Chatterjee et al. [43] reported that the VO_{2max} values of elite-level Indian female boxers was (mean ± SD) 52.1 ± 6.9 ml/kg/min (Table 2), slightly above those established with females involved in other combat sports such as karate, taekwondo and judo. Kumar et al. [49] reported that national/international-level female amateur boxers had greater VO_{2max} values compared with their university-level counterparts.

Despite the availability of well-developed measurement tools such as portable metabolic devices (i.e., K4b^2, Cosmed, Rome, Italy), measuring oxygen consumption during a match remains difficult. Recently, Davis et al. [12] tried to challenge this problem by directly measuring oxygen consumption during a semi-contact boxing match. The authors revealed that overall metabolism is predominantly

Table 2 Maximum oxygen uptake of amateur boxing athletes (data are presented as the mean ± SD)

Athlete characteristics (*n*)	Ergometer	$\dot{V}O_{2max}$ (ml/kg/min) [range]	References
Males			
Indian national-level	Treadmill		Khanna and Manna [16]
Junior ($n = 30$)		54.6 ± 4.6	
Senior ($n = 30$)		61.7 ± 9.0	
Junior light-weight ($n = 7$)		58.3 ± 2.2	
Junior medium-weight ($n = 7$)		56.8 ± 2.1	
Junior heavy-weight ($n = 7$)		51.5 ± 2.1	
England international-level	NR		Smith [15]
Senior ($n = 23$)		63.8 ± 4.8 [53.1–70.0]	
Junior ($n = 26$)		49.8 ± 3.3 [43.2–56.2]	
Elite-level boxers from different nationalities ($n = 21$)	Estimated from the indirect method of Margaria et al. [51]		Di Prampero et al. [32]
White boxers ($n = 9$)		49.9 ± 2.6	
Black boxers ($n = 12$)		49.0 ± 2.0	
		(both values measured at 2,300 m above sea level)	
French elite-level ($n = 16$)	Treadmill	62.2 ± 3.1	Vallier et al. [52]
English novice boxers ($n = 10$)	Treadmill	59.8 ± 4.3 [56.7–62.9]	Davis et al. [12]
Indian elite-level ($n = 6$)	Treadmill	59.5 ± 4.7	Ghosh [53]
Indian national-level senior boxers ($n = 26$)	Treadmill	54.5 ± 4.5	Ghosh et al. [48]
Greek national-level ($n =$ NR)	NR	55.8 (SD = NR)	Sevas et al. [54]
Hungarian boxers ($n =$ NR)	Treadmill	56.6 (SD = NR)	Joko [55]
Egyptian elite-level ($n = 17$) [VO_{2max} recorded before and after 8 weeks (32 sessions, ∼53 h) of a training program]	Treadmill	58.2 ± 6.9 (before) 64.6 ± 7.2 (after)	El-Ashker and Nasr [14]
American recreational-level ($n = 18$); male ($n = 12$), female ($n = 6$)	Treadmill	41.0 ± 6.5 [29.4–52.3] (value for both male and female)	Kravitz et al. [36]
International male boxers ($n =$ NR)	NR	65.0 (SD = NR)	Astrand and Rodahl [45]
Turkish elite-level ($n = 5$)	Cycle ergometer	60.6 ± 3.9	Baltaci et al. [56]
German elite-level boxers training at moderate altitude; male ($n = 16$)	Treadmill		Friedmann et al. [57]
Experimental group ($n = 9$)		61.0 ± 4.9 (before) 63.1 ± 3.6 (after)	
Control group ($n = 7$) (values before and after a training program of 18 days at moderate altitude)		62.1 ± 3.6 (before) 61.6 ± 5.7 (after)	
German elite-level boxers training at low altitude; male ($n = 13$) (values before and after a training program of 14 days at low altitude)		60.5 ± 7.5 (before) 58.8 ± 6.0 (after)	
Indian national-level ($n = 8$)	Treadmill	49.3 ± 6.1	Garg and Ghosh [58]
Indian national-level ($n = 7$)	Treadmill	57.9 ± 2.4	Ghosh et al. [48]
French national-level ($n = 13$)	Treadmill	64.7 ± 6.3	Jousselin et al. [59]
Novice-level ($n = 10$) (nationality = NR)	Cycle ergometer	52.4 (SD = NR)	Khedr [60]
Indian male national-level ($n =$ NR)	NR	58.3 (SD = NR)	Majumdar [61]
National-level ($n = 7$) (nationality = NR)	Treadmill	54.2 ± 4.5	Martos and Joko [62]
National-level ($n = 33$) (nationality = NR)	Treadmill	55.8 ± 4.9	Tokmakidis et al. [63]

Table 2 continued

Athlete characteristics (*n*)	Ergometer	$\dot{V}O_{2max}$ (ml/kg/min) [range]	References
Canadian experienced-level ($n = 9$)	Treadmill	62.2 ± 4.1 [53.6–66.2]	Arseneau et al. [50]
Brazilian regional-level ($n = 10$); male ($n = 6$), female ($n = 4$)	Treadmill	52.2 ± 7.2 (value for both male and female)	de Lira et al. [39]
Italian elite-level male ($n = 8$)	Treadmill	57.5 ± 4.7	Guidetti et al. [5]
Females			
Indian elite-level ($n = 45$) (VO_{2max} recorded before and after 6-week training camp)	Treadmill	48.6 ± 6.8 (before) 50.9 ± 7.4 (after)	Chatterjee et al. [43]
Indian elite-level ($n = 20$)	Treadmill	52.1 ± 6.9	Chatterjee et al. [43]
Indian national and university-level ($n = 11$)	VO_{2max} estimated from RHR and MHR [$VO_{2max} = 15.3*(MHR/RHR)$]	44.4 ± 3.3	Kumar et al. [49]

$\dot{V}O_{2max}$ maximum oxygen uptake, *MHR* maximal heart rate, *NR* information not reported, *RHR* resting heart rate

aerobic (mean of 85 %), highlighting the relevance for considering the aerobic fitness level as one of boxing's determining performance factors. Although amateur boxing is a full contact combat sport, the results of Davis et al. [12] were important and represent the first step that should be reinforced by future studies. It should be noted that although an amateur boxing match is predominantly aerobic, the decisive actions (e.g., offensive score or KO actions) are essentially maintained through anaerobic metabolism [39].

Arseneau et al. [50] reported that aerobic fitness is one of the key components of a boxer's physical fitness. They demonstrated the importance of aerobic demand [mean values of ~70 % peak oxygen consumption (VO_{2peak})] during boxing exercises (i.e., sparring and pad works, or punching on a partner's pads or mitts). Though the study is not conclusive, heavier boxers tended toward a lower VO_2 cost, and boxers with a higher VO_{2peak} tended toward a higher VO_2 cost as well as more engagement during sparring [50].

Overall, from the studies presented above, it can be suggested that the cardiorespiratory fitness level should be considered by coaches and sport scientists as the first benchmark toward improving and monitoring a boxer's training regimen. Because all of the testing protocols presented above (i.e., running on a treadmill and/or cycle ergometer) were far from being specific to amateur boxing matches, further studies considering oxygen consumption measurement using a sport-specific boxing test that respects the particular mechanical actions and metabolic requirements of this sport are necessary.

5 Anaerobic Profile

The activity pattern of the amateur boxing match is intermittent and characterized by short-duration, high-intensity bursts of activity interspersed with periods of lower intensity and/or pauses caused by boxers' clinching and/or the referee's interruption [12, 43, 64, 65]. The activity-to-rest ratio has been revealed to be approximately 3:1 [16]. The mean ratios between work and rest during the three boxing match formats, i.e., 3 × 3, 4 × 2 and 3 × 2 min, were 9:2, 8:3 and 6:2, respectively [12]. This type of action-to-rest pattern requires a well-developed anaerobic fitness level [16, 39, 43, 49, 66] to meet the energetic requirement of that activity appropriately. The 30-s Wingate anaerobic test is widely established as the most valid method for assessing working capacity using both the adenosine triphosphate and phosphocreatine (ATP-PCr) and glycolytic systems [67]. The few studies presented in Table 3 showed that the peak and mean power output values of male boxers were comparable to those previously established for judo [19], taekwondo [17] and karate [18], but slightly lower than the values recorded in high-level male wrestlers [20]. In this context, Hübner-Woźniak et al. [41] suggested that relative maximum and average upper and lower limb muscular power evaluated via the 30-s Wingate anaerobic test were significantly higher in wrestlers compared with boxers. Although amateur boxing performance is anaerobic dependent, wrestling seems to be slightly more anaerobic. Overall, these findings attest to the importance of anaerobic fitness development in boxing performance as in other combat sports.

Table 3 Anaerobic test performance of amateur boxing athletes (data are presented as the mean ± SD)

Athlete characteristics (*n*)	Peak power (W)	Peak power (W/kg)	Mean power (W)	Mean power (W/kg)	References
Indian male national-level (Wingate 30-s test)					Khanna and Manna [16]
Junior ($n = 30$)	NR	NR	NR	4.9 ± 0.7	
Senior ($n = 30$)	NR	NR	NR	6.5 ± 0.5	
Serbian male elite-level ($n = 14$) (Wingate 30-s test)	715.1 ± 90.3	9.3 ± 1.2	517.3 ± 56.8	6.7 ± 0.9	Popadic Gacesa et al. [70]
Polish male national-level ($n = 34$) (Wingate 30-s test)					Hübner-Woźniak et al. [33]
Upper limb	NR	8.4 ± 0.9	NR	6.3 ± 0.5	
		P_{peak} (W/kg $_{(FFM)}$) = 9.3 ± 0.7	NR	P_{mean} (W/kg $_{(FFM)}$) = 6.9 ± 0.4	
Lower limb	NR	9.8 ± 0.5	NR	8.6 ± 0.6	
		P_{peak} (W/kg $_{(FFM)}$) = 10.8 ± 0.3	NR	P_{mean} (W/kg $_{(FFM)}$) = 9.5 ± 0.4	
Caucasian club-level male ($n = 12$) (force–velocity test)					Giovani and Nicolaidis [28]
Upper limb	445.0 ± 80.0 (P_{max})	5.8 ± 1.1 (P_{max})	NR	NR	
Lower limb	910.0 ± 138.0 (P_{max})	11.8 ± 2.0 (P_{max})	NR	NR	
Polish national-level male ($n = 13$) (Wingate 30-s test); upper limb	NR	8.0 ± 0.9	NR	6.2 ± 0.6	Hübner-Woźniak et al. [41]

FFM fat-free mass, *NR* information not reported, P_{max} maximal power output, P_{mean} mean power output, P_{peak} peak power output

Mean power output has been established to be higher in male senior boxers (mean ± SD 6.5 ± 0.5 W/kg) compared with junior ones (mean ± SD 4.9 ± 0.7 W/kg) (Table 3) [16]. Authors have attributed this observation to the fact that senior boxers were more highly exposed to anaerobic training compared with junior boxers. These results are in agreement with previous findings for taekwondo [17] and judo athletes [19], as well as non-athletes [68]. There is a lack of studies dealing with female boxers' anaerobic profiles. Chatterjee et al. [43] reported that female elite-level boxers presented a good anaerobic level as measured through O_2 debt compared with their male counterparts.

In light of the fact that the main aim of boxers is to succeed in delivering clean, correct and powerful punches to the opponent, the assessment of upper limb muscular power is very important. Only a few studies exist that have quantified peak and/or maximal upper limb muscular power (Table 3). The values presented in Table 3 were comparable to those established in judo athletes [19] and Olympic wrestlers [69].

Because anaerobic power is well-established as being linked with performance in amateur boxing [28], further research studies evaluating anaerobic performance level differences across the various weight divisions and/or boxers' levels of success are warranted. Additionally, comparisons between the anaerobic capacities of winners and losers are needed.

6 Strength and Power

To effectively manage the physical and/or technical-tactical requirements of an amateur boxing match, boxers should have well-developed muscle strength and power [5, 36, 44, 66, 71–73]. Within this section of the manuscript, boxers' strength characteristics, including maximal strength, muscular power and isometric strength, will be critically reviewed.

6.1 Strength

It has been well established that punching force is paramount to a fighter's victory and one of the key indicators of amateur boxing performance [15, 44, 74]. Across the available research studies, there exist several tools that have been used for monitoring punching force. The most-used device was the piezoelectric force transducer embedded in the target [65, 75, 76]. It should be noted that the broad range of values for maximal punching force in Table 4 might be attributed to the different measurement devices used between the different studies. In his study,

Table 4 Maximal punching performance of amateur boxers (data are presented as the mean ± SD)

Athlete characteristics (n)	Boxing punch type	Absolute performance (N or kg)	Relative performance (N/kg)	Force measurement equipment	References
English elite-level male boxers ($n = 29$)	Straight lead hand to head	1,722.0 ± 700.0	25.0 ± 9.0	NR	Smith [15]
	Straight rear hand to body	1,682.0 ± 636.0	25.0 ± 8.0		
	Straight rear hand to head	2,643.0 ± 1,273.0	39.0 ± 17.0		
	Straight rear hand to body	2,646.0 ± 1,083.0	39.0 ± 15.0		
	Lead hand hook to head	2,412.0 ± 813.0	36.0 ± 11.0		
	Lead hand hook to body	2,414.0 ± 718.0	35.0 ± 9.0		
	Rear hand hook to head	2,588.0 ± 1,040.0	38.0 ± 13.0		
	Rear hand hook to body	2,555.0 ± 926.0	37.0 ± 12.0		
English male boxers				Wall-mounted force plate (4 triaxial piezoelectric force transducers) with a boxing manikin cover	Smith et al. [65]
Elite-level ($n = 7$)	Rear hand straight punch	4,800.0 ± 227.0	NR		
	Lead hand straight punch	2,847.0 ± 225.0	NR		
Intermediate-level ($n = 8$)	Rear hand straight punch	3,722.0 ± 133.0	NR		
	Lead hand straight punch	2,283.0 ± 126.0	NR		
Novice-level ($n = 8$)	Rear hand straight punch	2,381.0 ± 116.0	NR		
	Lead hand straight punch	1,604.0 ± 97.0	NR		
Professional heavy-weight boxer ($n = 1$)	NR	4,096.0 (PF)	NR	Padded pendulum equipped with a piezoelectric force transducer	Atha et al. [75]
Australian Olympic boxers weighing from 48 to 109 kg ($n = 7$)	Straight punch	3,336.0 ± 559.0 (MF)	NR	Hybrid III dummy equipped with a 6-axis load cell in the neck, a Tekscan's pressure sensor in the dummy's face, and Endevco accelerometers on the boxer's hands	Walilko et al. [72]
Flyweight		2,910.0 ± 835.0 (MF)			
Light welterweight		2,625.0 ± 543.0 (MF)			
		4,345.0 ± 280.0 (MF)			
Middleweight		3,427.0 ± 811.0 (MF)			
Super heavyweight					
Overall					
Professional American male boxers weighing 59.0–98.9 kg ($n = 12$)	NR	5,358.0 (PF)	NR	Bestshot force sensor imbedded in boxing gloves	Pierce et al. [44]
Male boxers	NR		NR	NR	Joch et al. [88]
Elite-level ($n = 24$)		3,453.0			
National-level ($n = 23$)		3,023.0			
Intermediate-level ($n = 23$)		2,932.0			
Polish heavyweight amateur boxer male ($n = 1$)	NR	2,697.0	NR	Fluid-filled systems	Karpilowski et al. [89]

Table 4 continued

Athlete characteristics (*n*)	Boxing punch type	Absolute performance (N or kg)	Relative performance (N/kg)	Force measurement equipment	References
Lithuanian elite-level male boxers ($n = 10$); values recorded after 2 microcycles (i.e., 2 weeks) of athletic training	Rear hand punch			Kiktest-100	Cepulénas et al. [90]
	Straight blow (after)	235.5 ± 40.1 kg			
	Straight blow (before)	253.4 ± 31.1 kg			
	Side blow (after)	292.5 ± 72.4 kg			
	Side blow (before)	297.0 ± 45.1 kg			
	Low blow (after)	259.1 ± 54.6 kg			
	Low blow (before)	303.6 ± 42.2 kg			
	Lead hand punch				
	Straight blow (after)	179.9 ± 49.6 kg			
	Straight blow (before)	184.9 ± 37.7 kg			
	Side blow (after)	250.2 ± 77.7 kg			
	Side blow (before)	255.1 ± 25.5 kg			
	Low blow (after)	207.6 ± 45.2 kg			
	Low blow (before)	299.5 ± 75.5 kg			

MF mean force, *NR* information not reported, *PF* peak force

Smith [15] evaluated the punching force relative to straight and hook punches to the head and body within senior elite-level amateur boxers. His results demonstrated that straight punching at both the head and the body was more powerful when performed by the rear hand compared with the lead one (Table 4). The difference in punching force seems to be due to the additional force generated by the leg during the rear-hand punch when compared with the lead-hand one [77, 78]. Other possible explanations behind this difference are the degree of trunk rotation and the longer distance over which the punch is performed [79]. Concerning hook punches, similar findings were recorded for the rear and lead hand [15] (Table 4). The lower punching force values in the straight lead-hand punch compared with the lead-hand hook punch might be attributed to the higher degree of body rotation in conjunction with the technique for throwing the lead-hand hook punch [79]. These punching force values were lower than those recorded by Smith et al. [65] and Walilko et al. [72] (Table 4). The differences were likely due to the heterogeneity in boxers' weight categories between the studies and/or to the number of boxers used. Future research in this area should detail the boxers' strength levels according to their weight categories and provide relative values of punching force to normalize performance.

Mean maximal punch force for the rear hand was significantly higher than that of the lead hand regardless of the boxer's level of expertise (i.e., elite, intermediate and novice level). Additionally, the maximal punching force was greater in the elite than the intermediate group, and higher in the intermediate than the novice group [65]. This finding indicates that apart from the punching type (i.e., rear vs. lead), the maximal punching force is a function of the boxer's competitive level. This is consistent with previously published results for elite, national and intermediate boxers [80] (Table 4). Additionally, these results are in agreement with those established by Neto et al. [81], who revealed that punching force was greater in advanced male kung-fu players compared with their intermediate-level counterparts. Smith et al. [65] attributed this difference in maximal punching force not only to the greater level of expertise but also to the emphasis on the production of a forceful rear-hand straight punch in competitions that use computer scoring. However, intermediate and novice competitions use a subjective method of judging, where the punch force is not as important. Filimonov et al. [78] suggested that skilled-level boxers have greater contributions from their legs to the punch compared with the other factors (i.e., arms and trunk). Experienced boxers presented a leg contribution of 38.6 % (mean) of the total punching force compared with 32.2 and 16.5 % (mean values) for intermediate- and the novice-level boxers, respectively [78]. Mack et al. [82] noted contradictory results and found a greater contribution of punching force on the pre-impact hand velocity rather than the force generated by the boxer's lower limb. The different results between the former authors and Filimonov et al. [78] may be due to the different methodological approaches adopted. Overall, it seems that the force generated by both the upper and lower limbs is a key determinant of punching force.

Pierce et al. [44], quantifying punching force within a live boxing match, revealed that almost all punches were delivered at forces clearly lower than those recorded in the laboratory setting [15]. This observation may be due to the dynamic nature of the ring (i.e., the opponent is a moving target who can avoid, block, and partially evade the punch) [44]. Additionally, they reported that the boxer delivering the greater cumulative force and the greater number of punches won by unanimous decision regardless of their weight category class [44]. The mean punch force did not differ between the lead and rear hand within both the junior lightweight and heavyweight boxers, which was not consistent with the findings from the laboratory setting. Generally, heavyweight boxers delivered a greater force per punch and more punches per round compared with the junior lightweight boxers. It is interesting to note that the two strongest punches delivered were in non-heavyweight bouts, rather than in heavyweight ones. This is due, according to Pierce et al. [44], to the speed and technique of the punch, as well as size and muscle mass, which could influence the force.

The study by Walilko et al. [72] compared punching force between different weight categories and revealed that the punching force was higher in the heavier weight categories. The authors attribute this difference to the greater effective mass of the punch, which is due primarily to the higher body mass. Walilko et al. [72] reported that flyweight boxers presented a higher punching force compared with their light welterweight and middleweight counterparts. Although the authors did not discuss this observation, it can be attributed to the small number of boxers included in this study and/or to the different training strategies adopted between boxers, which can increase the effective mass of punching. This finding confirms that of Pierce et al. [44], who attributed the inter-group differences to the speed and technique of the punches.

In a comparison of punching force of amateur boxers with other types of combat sports, Wilk et al. [83] reported similar mean values in experienced male karatekas (ranging from 2,400 to 2,800 N). Voigt [84] identified a peak impact force of 3,334 N (range from 2,345 to 4,866 N) in well-trained karatekas. In a study conducted with kung-fu athletes, a lower punch force value was reported (mean ± SD 837 ± 245 N) [85]. This observation reflects the differences among the punching techniques used in combat sports.

No studies have been conducted with amateur female boxers with respect to punch impact, and future research should consider punching force in females and the differences in the type of punching technique, related to their male counterparts. Overall, punching force is fundamental for achieving high-level boxing performance. Accurately identifying the level of contribution from upper and lower limb strength as well as trunk rotation toward the maximal punching force requires further exploration.

The effect of body mass reduction on boxing performance was investigated in two experiments [86, 87]. Smith et al. [86] submitted seven male amateur boxers to a simulated bout in a boxing ergometer under two conditions, an euhydrated state and following exercise-thermal dehydration that resulted in a significant (mean ± SD) reduction in body mass (3.8 ± 0.3 %, from 77.3 ± 11.29 to 74.4 ± 10.72 kg), and reported no significant change in performance. However, the authors suggested that the

Table 5 Muscular power performance of amateur boxing athletes (data are presented as the mean ± SD)

Athlete characteristics (*n*)	Upper limb shot put test (m)		Lower limb (cm)	References
	Right hand	Left hand		
Lithuanian elite-level male boxers (*n* = 10) [values recorded before and after 2 microcycles (i.e., 2 weeks) of specific boxing training]	9.8 ± 1.4 (before) 10.2 ± 1.5 (after)	9.1 ± 2.0 (before) 9.4 ± 1.8 (after)	SLJ_1: 225.7 ± 11.2 SLJ_2: 239.7 ± 12.7 CMJ_{arm1}: 41.7 ± 3.0 CMJ_{arm2}: 43.6 ± 4.3	Cepulénas et al. [90]
Polish national-level male boxers				Obmiński et al. [93]
Male (*n* = 7)	9.2 ± 6.8	7.7 ± 5.5	NR	
Female (*n* = 7)	6.8 ± 3.8	5.9 ± 4.1	NR	
Polish national-level female boxers (*n* = 7) [values recorded before and after 2 microcycles (i.e., 2 weeks) of specific boxing training]	6.81 ± 0.76 (before) 7.28 ± 0.77 (after)	6.26 ± 0.83 (before) 6.63 ± 0.82 (after)	NR	Obmiński and Błach [95]

CMJ_{arm1} counter movement jump with arm swing after 2 weeks of athletic training, CMJ_{arm2} counter movement jump with arm swing after 2 weeks of specific training, *NR* information not reported, SLJ_1 standing long jump after 2 weeks of athletic training, SLJ_2 standing long jump after 2 weeks of specific training small sample size and the presence of an outlier may have affected the results. When the outlier boxer was removed a mean decrease of 26.8 % in the boxing performance task was observed. When two 5-day periods under normal energy and fluid intake or under restricted energy and fluid intake (resulting in a mean ± SD decrease of 2.95 ± 1.08 % in body mass) were investigated [87], no significant differences (mean ± SD) in boxing punching performance were found between normal (bout 1 = 6,428 ± 852 N; bout 2 = 6,780 ± 814 N) and restricted conditions (bout 1 = 6,225 ± 749 N; bout 2 = 6,472 ± 667 N). Thus, neither acute nor short-term body mass reduction seem to affect boxing performance when the reduction is less than 4 %. Hence, studies analyzing higher body mass reductions normally used by boxers (i.e., ~5 %) should be conducted to establish the impact of typical body mass reduction on performance.

6.2 Power

Muscular power is the ability to generate high amounts of force in relatively short periods of time [91, 92]. Punching is the key component of amateur boxing. To be effective, it requires a high level of both speed and power [44, 71]. In this context, it has been suggested that the ability to produce high-level muscular power is considered one of the major fundamental prerequisites underlying successful performance among elite amateur boxers [74]. A punch is an extremely dynamic and brief action that occurs over a very short period of time [75]; thus, it is mainly a function of the high-energy phosphate system [93]. The same researcher suggested that the mean impact velocity reached by the fist during a boxing punch was 8.9 m/s. This value is comparable to other explosive combat sports such as karate [83] and kung-fu [85].

The shot put test is largely accepted as informative about amateur boxer's upper-level muscular power [93]. It has been reported that the results of the shot put test conducted in boxers are closely related to the power of the straight blow ($r = 0.83$) [94]. The values for shot put performance, albeit limited, are presented in Table 5 and are similar to performance values within elite-level male boxers [90, 93]. Female elite-level boxers presented lower explosive performance values in the shot put test compared with their male counterparts. Lower-limb explosive power has been determined through the use of both vertical and

Table 6 Hand-grip isometric strength performance of amateur boxing athletes (data are presented as the mean ± SD)

Athlete characteristics (*n*)	Hand grip strength performance (kg)		Measurement equipment	References
	Right hand	Left hand		
Mexican high-level male boxers ($n = 22$) (values are for the right and left hands)			Harpenden manual dynamometer graduated for kilogram-force	Ramirez Garcia et al. [96]
Light-weight	G: 36.1 ± 3.6	36.2 ± 1.7		
	S: 38.4 ± 4.2	36.6 ± 3.8		
	C: 36.5 ± 7.4	34.3 ± 7.4		
Middle-weight	G: 41.6 ± 2.3	42.0 ± 5.5		
	S: 44.0 ± 3.6	42.9 ± 4.1		
	C: 48.1 ± 3.9	46.4 ± 4.1		
Heavy-weight	G: 52.2 ± 8.4	49.6 ± 9.0		
	S: 55.0 ± 6.4	52.0 ± 9.5		
	C: 53.5 ± 7.6	50.7 ± 9.4		
Total boxers	G: 43.3 ± 8.6	42.6 ± 8.1		
	S: 45.8 ± 8.4	43.8 ± 8.9		
	C: 46.0 ± 1.6	43.9 ± 10.0		
Lithuanian elite-level male boxers ($n = 10$)			NR	Cepulènas et al. [90]
Values recorded after 2 microcycles (i.e., 2 weeks) of athletic training	53.9 ± 10.5	52.5 ± 9.2		
Values recorded after 2 microcycles (i.e., 2 weeks) of specific training	58.5 ± 12.1	56.7 ± 9.4		
Italian elite-level male ($n = 8$)	58.2 ± 6.9 [dominant hand]		Spring device hand-grip dynamometer	Guidetti et al. [5]

C competitive preparation phase, *G* general preparation phase, *NR* information not reported, *S* specific preparation phase horizontal jump tests [90] (Table 5). Results provided in this study were lower than those recorded for karate [18] and judo [19].

A very interesting study by Giovani and Nicolaidis [28], conducted within club-level male amateur boxers, suggested that the maximal power of the upper and lower limbs, as measured by the force-velocity test, are significantly associated with each other ($r = 0.70$). This finding means that boxers with higher maximal power in the lower limbs also present higher maximal power in the upper limbs [28]. This finding was supported by previous investigations that revealed a higher punching strength with the rear punch due to the additional role of the lower limb compared with the lead one [77, 78]. These observations reflect the importance of training programs that tend to develop both the upper and lower limb muscular power of boxers. Scientific investigations dealing with female boxers are lacking.

In light of the fact that muscular power is a determinant of success during an amateur boxing match, future research into the relationships among age, weight category and the boxer's level of expertise and/or success are highly necessary to create proper preparation strategies for boxers.

6.3 Isometric Strength

Table 6 presents the hand-grip isometric strength results from different groups of amateur boxers. A boxer's hand-grip isometric strength is an important index of physical fitness level [5, 73, 94]. In a sample containing Italian elite-level male amateur boxers, Guidetti et al. [5] established that isometric muscle contraction, particularly that of the upper limb (i.e., the dominant arm), is highly related to boxing competition ranking. Additionally, Bružas et al. [94] revealed that hand-grip strength performance of the main hand correlates with both the power of the straight and the side blow ($r = 0.74$ and $r = 0.63$, respectively). These findings have particular importance for coaches and can help with the establishment of proper training strategies for amateur boxers.

Ramirez Garcia et al. [96] suggested that hand-grip dynamometry represents an indirect indicator of the upper limb's degree of strength. In this context, it has been revealed that one of the basic factors linked to amateur boxing performance is the level of upper body strength [5]. Ramirez Garcia et al. [96] investigated both left and right hand-grip isometric strength performance by weight category and reported that a significant difference exists between the lightweight, middleweight and heavyweight categories. The same authors suggested that, within the whole group, there was a tendency toward increasing the hand-grip isometric strength of the left and right hand across the training phases (i.e., general, specific and competitive phase).

Cepulėnas et al. [90] investigated the effect of two boxing microcycles on hand-grip strength performance and found no significant effect. This observation might be due to the very short training duration that seems to be insufficient for increasing hand-grip strength performance. There is no research evaluating the effects of sex, age group and level of boxing practice, and future studies are warranted. Overall, on the basis of the available scientific investigations, it appears that upper limb isometric strength is of particular importance for achieving high-level amateur boxing performance.

7 Conclusions and Future Research

Elite-level amateur boxers of both sexes showed a propensity for low levels of body fat similar to other combat sport athletes (i.e., karate, taekwondo, judo and wrestling athletes). However, there is a need for further research about boxers' somatotype. The available data suggest that well-developed aerobic power is essential for maintaining repetitive high-intensity actions within an amateur boxing match to accelerate the recovery process and to help support the overall metabolic demand of the fight. It is well established that anaerobic power is linked with performance success in amateur boxing. Muscle strength in both the upper and lower limbs is paramount for a of the boxer's level of expertise. Because the boxing punch is a brief action and extremely dynamic, high-level amateur boxing performance requires well-developed muscular power. Upper and lower limb muscular power are positively correlated in boxers. From the available research, it appears that isometric strength is linked to high-level amateur boxing performance.

The present review might provide tangible guidelines for understanding the particular physical and physiological requirements for amateur boxing. However, studies on the physical/physiological characteristics of boxers in relation to age, sex, level of competitiveness and success and weight categories are very scarce. Thus, in view of the particular importance of such research in designing an adequate training program, additional investigative work is needed. An aerobic boxing-specific test that respects the particular physical/technical characteristics of amateur boxing activities seems to be needed. As studies dealing with boxing anaerobic level are limited, more extensive research in this area is warranted. Punching force measurements recorded at live boxing matches, while currently limited, are of great importance for designing proper training strategies. Future research addressing the contributions of the upper and lower limbs could be conducted with the proper training program development in mind. Additionally, studies about the years of specific boxing training necessary to achieve an international competitive level and the common boxing-specific training modalities used by Olympic-level boxers are needed.

Finally, we believe that the current critical review will not only provide readers with the available literature related to amateur boxers' physical and physiological characteristics, but will also stimulate novel ideas, experiments and further advances in this research field.

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