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Published version

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Original Article

Physical profile of junior and senior amateur boxers

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Abstract:
Purpose: The purpose of this study was to profile the physiological characteristics of amateur boxers using a battery of tests designed to assess the physiological and physical demands required for performance. Fifteen junior amateur (age 14.9 ± 2.0 years; stature 164 ± 12 cm; body mass 50.9 ± 11.3 kg) and sixteen senior amateur boxers ($n = 16$; age 20.5 ± 4.0 years; stature 174 ± 9 cm; body mass 65.2 ± 10.7 kg) provided informed consent to participate in the study. Body composition, squat jump (SJ), countermovement jump (CMJ), 5- and 10 m sprint (5SP/10SP), press up (PU), right and left medicine-ball single-arm throws (MBR, MBL), repeated sprint test (RST) and Yo-Yo intermittent recovery test level 1 (YY) were performed. The likelihood (% chance) of between-group differences were assessed using a magnitude based approach, standardised-difference score (Cohen's d) and 90% confidence intervals [CI]. Linear regression (r) was used to examine the association between variables. **Results:** Senior boxers outperformed (79 to 99% chance) junior counterparts in PU, YY, CMJ, SJ, 10SP, MBL and MBR tests ($d \geq 0.50$ [-0.34 to 1.61]). There were very large ($r \geq 0.70$) correlations between fat free mass, upper-and lower body lean mass and medicine ball throw distance. There were large correlations ($r \geq 0.50$ to 0.69) between medicine ball throw distance and CMJ, SJ, PU, 5SP and 10SP. **Conclusions:** A simple and time-effective test battery was able to differentiate performance between junior and amateur boxers. These assessments could be useful when profiling junior and senior amateur boxers.
Key Words: **Boxing, Physiological Testing, Strength, Performance, Combat**

Introduction

Boxing is a combat sport that requires participants to strike the head and upper body whereby professional and amateur boxing are the two most widely practised forms. Amateur boxers are matched by ability, age and body mass using a weight classification system (48 kg to 91+ kg) (International Boxing Association, 2015) and historically have been decided via a number of different outcomes with the most common being the awarding of the highest points total. The International Boxing Association use the 'ten point must' system whereby each round is scored by the referee or three to five independent judges with 10 points being awarded to the victor of the round and their opponent 9 points or less (Amateur International Boxing Association, 2015), the winner of a bout is the boxer with the greatest number of points. Points are awarded for the number of quality blows on a target areas, which has been observed to be a predictor of Olympic standard performance (Devsa and Pons, 2020), domination of the bout by technical and tactical superiority and competitiveness. In addition, a boxer might also win by knockout, technical knockout, disqualification or retirement.

Elite standard amateur boxers initiate attacking or defensive actions every 1.4 seconds over a 3 minute round (Davis et al., 2015) with 77%, 19% and 4% energy derived from aerobic, phosphocreatine and anaerobic glycolysis energy pathways respectively during three semi-contact 2-minute rounds (Davis et al., 2014). A well-developed aerobic capability is a likely possible pre-requisite for success; aerobic capacities (VO_{2max}) in the range of 57.5 to 69.0 ml·kg^{-1}·min^{-1} have been reported for in senior amateur boxers (Smith, 2006). Senior boxers have around 21% greater VO_{2max} compared to junior-international standard boxers, suggesting aerobic capabilities of boxers might differ due to maturation and experience. Indeed, senior competitions are scheduled for 3 x 3 minutes, whereas junior bouts are limited to 3 x 2 minutes. The longer contest duration and training practices required for senior boxers might explain the differences between fighters. Blood lactate concentrations have been reported for both senior (13.5 ± 2.0 mmol·L^{-1}) and junior (14.1 ± 2.0 mmol·L^{-1}) boxers after four 2-minute rounds (Hanon et al., 2015; Smith, 2006). Many of these physiological qualities that are associated with high-performance are evaluated using specialist equipment, for example, high-speed treadmills, gas, and blood lactate analysers. Such equipment is costly, situated in specialist exercise physiology laboratories and requires

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specialist personnel to administer, analyse and interpret the data – this makes undertaking physiological assessments prohibitive to most practitioners, even at Olympic standard and certainly most amateur boxing coaches who prepare young and novice boxers for competition.

A punching action appears to take approximately ~100 to 600 ms, dependent upon the method of analysis, with peak fist speeds ranging from 6 to 12 $m \cdot s^{-1}$ and peak punch forces of ~2500 N observed at impact (Nakano et al., 2014; Piorkowski et al., 2011; Smith, 2006; Smith et al., 2000; Stanley et al., 2018). It is important to note, however, that magnitudes of force will differ depending on punch type, weight classifications and skill level of the boxer. Accumulated punching forces of 388,113 ± 102,020 N during simulated boxing activity where 76 punches (single, 2- and 3-punch combinations) over 4 x 2-minute rounds were thrown suggests that reproducing forceful punches during competition is an important determinant of performance (Smith et al., 2000). Much like the characterisation of a boxers physiology, the determination of a boxers punch force requires access to force plates or dynamometers that are specially designed to assess punching force. For the majority of those working with amateur boxers, such access is not a possibility, yet the importance of characterising a boxers force generating capability remains.

Successful performance at amateur standard requires the boxer to develop the physical characteristics previously mentioned. These characteristics can be assessed by physiological testing, which can be used to inform and monitor training. In a review of boxing-related scientific literature (Chaabène et al., 2014) it was concluded that additional knowledge regarding the physiological and physical attributes of boxers is required. Moreover, this knowledge and understanding should not be solely focused on obtaining more laboratory-based data since many who are involved in the physical preparation of amateur boxers do not have access to specialist sport science laboratories equipped with physiological and biomechanical test equipment. It is important for coaches and athletes to utilise low-cost and simple field tests to indirectly assess the physiological and physical characteristics that underpin boxing performance, to have an understanding of the variability of these tests and have standards for performance to rank their own athletes. Accordingly, the purpose of this study was to develop a battery of ecologically valid and reliable physical tests to characterise performance of amateur boxers. This research will help coaches and scientists to benchmark performance, monitor athlete development, assist in talent-development, identify strengths and areas for improvement and plan and prescribe training. Moreover, the secondary purpose of this research was to determine the reliability of the tests employed so that future research and training interventions can be interpreted after accounting for test error.

Material & methods
Participants

A total of 31 male amateur boxers (age = 17.7 ± 4.1 years; stature = 169 ± 12 cm; body mass = 57.6 ± 13.0 kg; competitive experience = 4 ± 3 years) volunteered for the study, which was approved by the local Sport Research Ethics Committee and conducted according to the principles of the Declaration of Helsinki. The risks and experimental procedures were fully explained and all subjects provided written informed consent before commencing the study. The sample was divided into two groups; junior amateurs (n = 15; age = 14.9 ± 2.0 years; stature = 164 ± 12 cm; body mass = 50.9 ± 11.3 kg; competitive experience = 3 ± 3 years) and senior-amateurs (n = 16; age = 20.5 ± 4.0 years; stature = 173.5 ± 9.4 cm; body mass = 65.2 ± 10.7 kg; competitive experience = 5 ± 3 years). Group allocation was assigned by age, with boxers aged 18 years or older placed in the senior group according to amateur boxing association regulations. The sample contained English national, regional and local standard boxers.

Design

Each boxer visited the exercise physiology laboratory three times. The first visit served to accustom the boxers to the testing procedures before the main trial which were performed during the second visit. The third testing session was used to assess reliability of the testing procedures. Prior to data collection, a standardised dynamic warm-up was performed followed by a trial of each test to accustom the subjects to the experimental procedures. All tests were conducted in the same order and at the same time of day (0900 or 1300) in temperature-controlled environments (20°C and 45% relative humidity). This occurred over 4-weeks in the months of April and May as boxers were approaching their peak in physical performance. A minimum of 3 and maximum of 10 days separated visits.

Methodology
Anthropometric profiling – Bioelectrical impedance analysis

Skeletal muscle mass (SMM) (kg), body fat mass (kg) and percentage body fat (PBF) were estimated using multiple-frequency bioelectrical impedance (Inbody 720, BioSpace, South Korea). As boxers compete in weight categories, characterisation of body composition was important for determining tissue contribution to body mass. The InBody 720 has been reported to produce valid measures of body composition (Anderson et al., 2012).

---3453

Countermovement jump and squat jump

Jump height assessments were performed to assess lower-body impulsiveness (Ruddock & Winter, 2016), which is a component of force transmission during punching (Stanley et al., 2018). Countermovement jump (CMJ) and squat jump (SJ) height were calculated from flight time using a photocell system (Microgate, Bolzano, Italy), which provides a valid assessment of jump height (Glatthorn et al., 2011). Free shoulder extension was permitted.

Sprint tests

The ability of a boxer to rapidly activate the neuromuscular system, shorten active musculature and rapidly produce force is an important characteristic of performance. Five and 10 m sprint times were assessed by running in a straight line through photocell timing gates (Brewer Timing Systems, USA). Boxers were instructed to form a 2-point sprint-start-stance 0.5 m behind the first photocell gate, ensuring a standardised starting point. The test began when the first photoelectric beam was broken, and boxers were asked to perform maximal-effort sprints as quickly as possible over 10 m.

Repeated Sprint Test

During competition boxers are required to produce repeated high-intensity efforts ((Davis et al., 2014)). This test was chosen to assess the ability to reproduce high-intensity efforts over 2 min duration. Two start lines were placed at either end of a 20 m running distance. Boxers returned the start line after 10 s active recovery and then repeated the 20 m maximal sprint; the process was repeated until the completion of 10 sprints. Repeated sprint performance was determined by calculating percentage sprint time decrement ($S_{dec}^{\%}$). The $S_{dec}^{\%}$ attempts to quantify fatigue by comparing repeated sprint performance to predicted 'ideal performance' (i.e. the best effort would be replicated in each sprint) (Bishop et al., 2001).

60 seconds press-up test

The ability of boxers to produce force and the rate at which force is developed is important for successful performance (Nakano et al., 2014; Stanley et al., 2018). This test was chosen to assess muscular strength-endurance, a surrogate of maximum voluntary force production. Boxers were required to start prone with hands positioned perpendicular to the shoulder joint; elbows and knees fully extended with the trunk parallel to the floor. Elbows were flexed until the chest and thighs contacted the floor. The participant returned to the start position by extending the elbows. This action counted as one repetition and participants repeated as many of these actions as possible in 60 s.

Medicine Ball Backhand Throw

This test was chosen to assess the ability of the boxers to develop force in a movement pattern similar to a rear-hand punch. Holding a 3 kg medicine ball positioned at shoulder height on the same side of the rear foot (e.g. right foot to the rear, medicine ball held in right hand) with the elbows flexed. Boxers were instructed to rotate their trunk and produce maximal effort to throw the ball as far as possible from a marked location on the floor. Each boxer was instructed to rapidly rotate their body proximal to distal whilst fully extending the elbow before releasing the ball. The first point of ball to ground contact was recorded as the distance thrown (m).

Yo-Yo Intermittent Recovery Test level 1

The Yo-Yo intermittent recovery test level 1 was chosen to assess the ability to recover from high-intensity aerobic exercise, similar to the demands imposed on a boxer during competition. The Yo-Yo intermittent recovery test level 1 is an incremental exercise test whereby running speed is increased each minute. Methods describing the test procedures are detailed elsewhere (Krustrup et al., 2003).

Statistical analysis

Gaussian distribution of data was assessed with the Kolmogorov-Smirnov test and homogeneity of variance using Levene's tests (release 11.0, SPSS Inc., Chicago, IL, USA). Data are reported as mean and standard deviation (±) in text and tables. Between group, differences were assessed using a magnitude-based approach (Hopkins et al., 2009) and analysed using a statistical spreadsheet that calculates group means, standard deviations, standardised effect sizes (Cohen's d pooled standard deviation method) and 90% confidence intervals for d. Effect size (d) was evaluated according to small (0.2), medium (0.5) and large (0.8) effects. Pearson's correlation coefficient (r) was used to examine associations between variables and interpreted as small (0.1), moderate (0.3), large (0.5) and very large (0.7) (Hopkins). 95% Limits of agreement (LOA), Coefficient of Variation expressed as a percentage (CV), Typical Error of Measurement (TE) and the Intraclass Correlation Coefficient (ICC) were calculated to assess absolute and relative reliability of the test procedures.

Results

Reliability data for each test is reported in table 1.

3454---

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DANIEL C WILSON, ALAN D RUDDOCK, MAYUR K RANCHORDAS, STEPHEN W THOMPSON, DAVID ROGERSON

Table 1: Reliability data for performance tests

Test	Test 1 mean ± SD	Test 2 mean ± SD	Mean difference ± SD	95% Limits of agreement	Coefficient of variation (%)	Typical error of measurement	ICC (r) (90% CI)
Squat Jump (cm)	31.3 ± 7.7	31.5 ± 7.6	0.2 ± 2.5	4.9	5.2	1.8	0.95 (0.89 to 0.98)
Countermovement Jump (cm)	32.5 ± 7.6	33.3 ± 7.6	0.9 ± 1.3	2.6	3.2	1.0	0.98 (0.95 to 0.99)
5-m sprint test (s)	1.11 ± 0.11	1.11 ± 0.09	-0.01 ± 0.09	0.18	6.1	0.07	0.57 (0.24 to 0.78)
10-m sprint test (s)	1.82 ± 0.26	1.90 ± 0.21	0.09 ± 0.23	0.45	10.9	0.16	0.50 (0.14 to 0.74)
Repeated sprint test	4.7 ± 1.7	5.6 ± 2	-1.1 ± 1.5	2.9	29.5	1.05	0.63 (0.33 to 0.82)
60 s press-up test (reps)	49.0 ± 18.1	50.5 ± 16.8	1.5 ± 5.5	10.7	9.3	3.9	0.95 (0.89 to 0.98)
Medicine ball throw right hand (m)	8.20 ± 2.00	8.48 ± 2.15	0.28 ± 0.73	1.44	5.8	0.52	0.93 (0.85 to 0.97)
Medicine ball throw left hand (m)	6.85 ± 2.08	7.22 ± 1.96	0.37 ± 0.89	1.74	8.2	0.63	0.89 (0.78 to 0.95)
Yo-Yo Intermittent Recovery Test Level 1 (m)	1324 ± 508	1424 ± 595	100 ± 229	450	13.7	162	0.90 (0.80 to 0.96)

Anthropometrics

Table 2 and 3 details anthropometric characteristics. Senior boxers were very likely (98%) to have more skeletal muscle mass (difference = 7.4 kg; d = 1.04 (0.51 to 1.57)) and PBF was similar (37%) between groups (difference = 0.9 %; d = 0.18 (-0.44 to 0.80)).

Table 2: Body composition (mean ± SD)

	Seniors	Juniors
Body mass (kg)	65.3 ± 10.7	50.9 ± 11.3
Skeletal muscle mass (kg)	32.9 ± 5.2	25.5 ± 6.9
Body fat mass (kg)	57.7 ± 8.5	46.0 ± 11.3
Body fat (%)	12.0 ± 4.3	11.1 ± 5.7

Table 3: Segmental body composition data (mean ± SD)

Lean mass (kg)	Seniors	Juniors
Left Arm	3.34 ± 0.6	2.45 ± 0.86
Right Arm	3.24 ± 0.60	2.45 ± 0.85
Trunk	25.86 ± 3.5	20.70 ± 5.30
Left Leg	8.50 ± 1.26	6.76 ± 1.97

Senior boxers very likely (98%) performed better in 60 s press up test (difference = 17 reps; d = 1.04 (0.52 to 1.56), MBL (difference = 2.0 m; d = 0.93 (0.39 to 1.48), MBR (difference = 2.2 m; d = 1.10 (0.58 to 1.61), Yo-Yo IRT L1 (difference = 489 m; d = 1.05 (0.52 to 1.59). Seniors boxers likely (79%) jumped higher in CMJ (difference = 4 cm; d = 0.59 (-0.04 to 1.22)) and SJ (difference = 3 cm; d = 0.51 (-0.13 to 1.15)). Senior boxers likely (92%) ran faster over 5 m (difference = 0.06 s; d = 0.68 (-0.11 to 1.26) and 10 m (difference = 0.10; d = 0.89 (-0.34 to 1.44). RST (%S_{dec}) was likely similar (39%) between groups (difference = 0.0%; d = 0.02 (-0.63 to 0.67).

---3455

Table 4: Performance data (mean ± SD). MBTL = medicine ball throw left arm;
MBTR = medicine ball throw right arm; YY IRT L1 = Yo-Yo Intermittent Recovery Test Level 1;
CMJ = Countermovement jump; SQJ = Squat jump; RST = Repeated sprint test (% decrement)

	Press-up test (reps)	MBTL (m)	MBTR (m)	YY IRT L1 (m)	CMJ (cm)	SQJ (cm)	5 m sprint (s)	10 m sprint time (s)	RST (% dec)
Juniors	47 ± 18	6.7 ± 2.1	8.0 ± 2.0	1208 ± 410	33 ± 5	32 ± 5	1.15 ± 0.10	1.97 ± 0.12	4.5 ± 1.6
Seniors	64 ± 9	8.7 ± 1.5	10.2 ± 1.4	1697 ± 388	37 ± 8	35 ± 8	1.09 ± 0.05	1.87 ± 0.10	4.5 ± 2.3

There were very large correlations (table 5) between fat free mass, upper-and lower-body lean mass (sum of segments) and medicine ball throw distance (Explained variance = 49% (25 to 69%)). Percentage body fat had small to moderate correlations with most performance tests.

Table 5: Correlation matrix (*r* (90% confidence interval)). CMJ = Countermovement jump; SQJ = Squat jump; 5 m = 5 m sprint test; 10 m = 10 m sprint test; PU = press-up test; MBTL = medicine ball throw left arm; MBTR = medicine ball throw right arm; YY IRT L1 = Yo-Yo Intermittent Recovery Test Level 1

	CMJ	SJ	5 m	10 m	PU	MBTL	MBTR	YY IRT L1
Age (years)	0.57 (0.32 to 0.75)	0.57 (0.32 to 0.75)	0.60 (0.36 to 0.77)	0.65 (0.43 to 0.80)	0.61 (0.37 to 0.77	0.69 (0.49 to 0.82)	0.74 (0.56 to 0.85)	0.71 (0.52 to 0.83)
FFM (kg)	0.48 (0.20 to 0.69)	0.52 (0.25 to 0.71)	0.56 (0.44 to 0.80)	0.61 (0.37 to 0.77)	0.56 (0.31 to 0.74)	0.86 (0.75 to 0.92)	0.86 (0.75 to 0.92)	0.46 (0.18 to 0.67)
PBF (%)	0.36 (0.06 to 0.60)	0.26 (-0.05 to 0.52)	0.20 (-0.11 to 0.48)	0.24 (-0.07 to 0.51)	0.38 (0.08 to 0.61)	0.15 (-0.16 to 0.44)	0.12 (-0.19 to 0.41)	0.29 (-0.02 to 0.55)
Upper body lean mass (kg)	0.51 (0.24 to 0.71)	0.55 (0.29 to 0.73)	0.66 (0.44 to 0.80)	0.63 (0.40 to 0.78)	0.59 (0.35 to 0.76)	0.88 (0.79 to 0.93)	0.86 (0.75 to 0.92)	0.49 (0.22 to 0.69)
Lower body lean mass (kg)	0.50 (0.23 to 0.70)	0.54 (0.28 to 0.73)	0.68 (0.47 to 0.82)	0.62 (0.39 to 0.78)	0.53 (0.27 to 0.72)	0.85 (0.74 to 0.92)	0.87 (0.77 to 0.93)	0.43 (0.19 to 0.68)

There were large correlations (*r* ≥ 0.50 to 0.69) between medicine ball throw distance and CMJ, SJ, Press-up test, 5 m sprint and 10 m sprint. When upper-body lean mass was scaled to fat free mass there were large correlations to medicine ball throw distance (*r* ≥ 0.50 to 0.69). There were moderate correlations between lower-body lean mass relative to fat free mass and medicine ball throw distance (*r* ≥ 0.30 to 0.49).

Discussion

The purpose of this study was to develop a battery of ecologically valid and reliable physical tests to characterise performance of amateur boxers. A secondary purpose of this research was to determine the reliability of the tests.

Anthropometrics

Junior boxers were slightly leaner than their senior counterparts, 11.1 ± 5.7 vs 12.0 ± 4.3 % body fat although this was not statistically meaningful. Previous research reported that junior boxer's were leaner than senior boxer's but differences between the groups was much greater than the present study with senior boxers having a body fat percentage of 16.4 ± 3.8% and the juniors 12.2 ± 1.1% (lal Khanna & Manna, 2006). Senior boxers very likely had more total skeletal muscle mass, upper-body lean mass and lower-body lean mass than juniors. Our data show smaller differences in lean mass in comparison to the findings by (lal Khanna & Manna, 2006) who reported that senior boxers had 10.6 kg greater lean body mass in comparison to junior boxers. Senior boxers might have more lean body mass because of greater maturity and it is likely that they have accumulated additional time training to gain superior levels of muscle mass in comparison to the junior counterparts. A low body fat percentage is crucial for successful boxing performance as it can help the athlete reach their desired weight category. In addition, a greater proportion of muscle mass will improve the potential for force production which is crucial for successful boxing performance. This is indicated by the large correlations (*r* = 0.86) between fat free mass and medicine ball throw test performances (table 4).

Countermovement jump and squat jump

Reliability data (table 1) indicates that both jump tests have an adequate test-re-test error. Senior boxers performed better in both jump tests (table 4). We observed moderate to large correlations between anthropometric assessments and jump height, however, explained variance was low (r^2 = 7 to 33%). We are the first to report data regarding jumping performance of boxers, however, literature from other sports such as soccer also demonstrate differences between senior and junior athletes. More specifically, CMJ heights of 33 ± 5 reported in the present study are similar to those reported by (Malina et al., 2004) on youth soccer players (age range 13 - 15 years old), but less than 14-year-old regional standard soccer players (≈ 53 cm) (Wong et al., 2009). Our findings indicate that amateur boxers rank poorly for countermovement jump height in comparison to other sports. This is surprising given that forceful punching requires vertical impulses from the lower-limbs. Although, there are technical elements inherent within jump tests which might contribute to the observed results.

Sprint Tests

The coefficient of variation for the 5 m and 10 m sprint tests were 6.1% and 10.9%, respectively. Senior boxers ran faster in both tests and fat free mass and upper and lower body lean mass were large predictors of sprint performance (see table 5). Cross-sectional area is related to force production which could be an explanation for why the senior boxers performed better than their junior counterparts. It should be noted that we are the first to report sprint data on amateur senior and junior boxers. Senior boxers produced performances similar to junior Premier League Academy soccer players (1.85 ± 0.05 s) for 10 m sprint test whilst junior boxers performed to similar standard as similar aged school children over 10 m (1.97 ± 0.08 s) (Wrigley et al., 2014). Speed and acceleration are important attributes for boxers as punching requires rapid rates of force development, however, the 5 and 10m sprint tests demonstrated test re-test reliability that might compromise its ability to detect differences between senior and junior boxers as well as changes due to training. Nevertheless, speed and acceleration are important attributes for boxers, and these tests are simple to administer and low cost.

Repeated sprint test

There were no differences between senior and amateur boxers in RST performance. The lack of differentiation between groups might be due to the poor test-retest reliability (CV 29.5%). An important limitation of the RST is that this measurement required boxers to repeat 20 m sprints 10 times with 10 s recuperation which might not best-represent the activity patterns of amateur boxing. Future research might need to incorporate exercise-to-rest ratios that accurately reflect boxing competition. Nevertheless, to our knowledge this is the first study that has profiled RST in junior and senior amateur boxers and provides important, new data for coaches and scientists about performance decay during repeated high intensity exercise bouts.

Press-up Tests

The coefficient of variation for the 60 s press-up test was (9.3%). Senior boxers outperformed the juniors and outperformed press-up requirements of Boxing Australia, where senior boxers are expected to perform 50 press ups during the 60 s test (Boxing Australia, 2011). Forceful punching is a complex movement that depends on the coordinated, forceful action of the lower, trunk and upper body musculature. Weighted barbell exercises are commonly used tools to determine upper-body maximal strength, however maximal strength testing has been contraindicated in novice strength trainees (Braith et al., 1993). This test battery was developed to be applicable for boxers of all standards and who might have variable strength training experience. The 60 s press-up test was therefore chosen to provide a safe estimate of upper body strength-endurance. Press-up tests might lack reliability, however, due to the potential for repetitions to be performed incorrectly.

Yo-Yo IRT LT1

The coefficient of variation for the Yo-Yo IRT L1 was 13.7% and is larger than the ~9% previously reported (Krustrup et al., 2003). To our knowledge, we are the first to report the results of a Yo-Yo test conducted on amateur boxers. Senior boxers performed better than juniors by 29% and age was a very large predictor of Yo-Yo test performance, similar to that reported in previous research (Krustrup et al., 2003). Although not a direct measure, the Yo-Yo test is considered a test of aerobic capacity (VO_{2max}) (Krustrup et al., 2003). (Armstrong & Welsman, 2001) found that increases in FFM explained the observed increase in VO_{2max} from 11 to 17 years and both chronological age and stage of maturation were identified as explanatory variances in the development of VO_{2max}. (Smith, 2006) reported that senior international boxers had an aerobic capacity of around 21% larger than junior internationals which is similar to the between-group difference in Yo-Yo performance reported in our study. Differences might also be due to the competition round and total fight duration, where senior amateur boxers perform at high heart rates (90% maximum heart rate) for extended periods of time compared to juniors (Smith, 2006) . A well-developed aerobic capacity is important for amateur boxers to be able sustain high-intensity activities during competition and is highlighted by (Smith, 2006) who reported a VO_{2max} of 69.1 ml·kg^{-1}·min^{-1} in a British Olympic medallist (n = 1; Athens 2004). Practitioners and

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coaches should note that the Yo-Yo test has a poor test-re test reliability that might compromise its ability to detect small but worthwhile changes in performance. However, it is simple to administer and has a high ecological validity based upon movement and physiological profiles of amateur boxing (Davis et al., 2015). Scientists and coaches wishing to assess the aerobic capacity of amateur boxers might consider the Yo-Yo test as a suitable alternative to laboratory based assessments if they can improve the reliability of the test.

Medicine Ball Throw

The magnitude of punching force can differ due to weight classification, skill and punch type. Punching force has been assessed by striking a force plate, however, an aim of the current study was to investigate practical field-based methods for scientists and coaches to infer punch force. Accordingly, we chose a medicine ball throw test; the coefficient of variation for the MBR and MBL tests were 5.8% and 8.2% respectively. Senior boxers performed better in both tests and a possible explanation for this could be that Junior amateur's body mass was around 14 kg less than senior amateurs. Indeed, we found that fat free mass, upper body lean mass and lower body lean mass explained 72 to 77% of the variance in the medicine ball throwing distance, suggesting that boxers who had greater muscle mass performed better in this surrogate test of punch force. We did not analyse throwing technique but procedures were controlled to limit variation by ensuring all medicine-ball throws were performed with the rear hand, irrespective of preferred fight stance. Therefore, when considering the overall effectiveness of a punch, medicine-ball throw tests might only account for muscle activity prior to ball-release and not the interaction between momentum and impulse or isometric force production at impact (Nakano et al., 2014; Piorkowski et al., 2011; Stanley et al., 2018). We recommend the medicine ball tests be validated by kinematic analysis of punching in future studies in order to elucidate its usefulness.

Conclusions

The purpose of this study was to develop a battery of ecologically valid and reliable physical tests to characterise performance of amateur boxers using a range of physical tests. A secondary purpose of this research was to determine the reliability of the tests. We observed large correlations ($r = 0.86$) between fat free mass and medicine ball throw test performances suggesting the importance of enhancing muscle mass within weight categories. Our findings also indicate that amateur boxers rank poorly for countermovement jump height in comparison to other sports, which is surprising given that forceful punching requires vertical impulses from the lower-limbs, but nevertheless should be an important tool to monitor the lower-body impulsiveness of boxers, especially given the low test-retest error for jumping. The coefficient of variation for the 5 m and 10 m sprint tests were 6.1% and 10.9%, respectively, suggesting the 5 m sprint test might be preferable over the 10 m sprint test based on the ability to determine error-free changes in performane. However, over such short duration this test might not provide any additional physiological insight over a jump test, therefore coaches should consider the inclusion of this test in their battery carefully. Similarly the repeated sprint test utilised in this research identified a magnitude of test-retest reliability that makes it difficult to provide a strong rationale for inclusion in test battery for boxers. The 60 s press-up test requires repeated forceful activation of the upper body and might be a useful assessment method if the reliability of test can be improved but the more punch specific medicine ball throw should be considered before the press-up test due to its slightly better reliability and stronger correlations with anthropometrical variables. A well-developed aerobic capacity and the capability to repeat high-intensity activity is a pre-requisite for successful boxing performance. Practitioners should be aware that although the Yo-Yo IRT L1 assesses the aforementioned qualities, the reliability of the test in boxers is generally poor, possibility because boxers are unaccustomed to high-speed turning that is required repeatedly within this test. This research will help coaches and scientists to benchmark performance, monitor athlete development, assist in talent-development, identify strengths and areas for improvement and plan and prescribe training. Future research should continue to quantify the physiological and physical characteristics of varying standards and weight classifications of amateur boxers in both laboratory and field settings, and develop tests to assess boxing specific endurance (L'uboslav et al., 2020). Amateur boxers appear to rank poorly for jump height compared to previous research in other sports; future research should investigate whether improving lower body impulsiveness (thus jump height) contributes to improved punch effectiveness.

Conflicts of interest - none

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