MANUSCRIPT TITLE: Quantifying the Physical Response to a Contemporary Amateur Boxing Simulation

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ABSTRACT

This study examined the physical response to a contemporary Boxing Specific Exercise Protocol (BSEP), based on notational analysis of amateur boxing. Nine male senior elite amateur boxers completed a 3x3 minute BSEP, with 1minute passive recovery period interspersing each round. Average (HR_{ave}) and peak (HR_{peak}) heart rate, average (VO_{2ave}) and peak oxygen consumption (VO_{2peak}), Blood lactate (BLa) concentrations, rating of perceived exertion (RPE), and both tri-axial and uni-axial PlayerLoad™ metrics were recorded during the completion of the BSEP. Blood lactate concentration increased significantly in each round (Round 1 = 2.4 ± 1.3 mmol·L^{-1}; Round 2 = 3.3 ± 1.7 mmol·L^{-1}; Round 3 = 4.3 ± 2. 6 mmol·L^{-1}). Significantly lower HR_{ave} and HR_{peak} values were found in the 1st round (HR_{ave}: 150 ± 15 beats·min^{-1}; HR_{peak}: 162 ± 12 beats·min^{-1}) when compared to the 2nd (HR_{ave}: 156 ± 16 beats·min^{-1}; HR_{peak}: 166 ± 13 beats·min^{-1}) and 3rd (HR_{ave}: 150 ± 15 beats·min^{-1}; HR_{peak}: 169 ± 14 beats·min^{-1}). No significant differences were found in any of the VO_2 or PlayerLoad™ metrics recorded during the BSEP. The BSEP based on notational analysis elicited a fatigue response across rounds, confirming its validity. The BSEP can be used as a training tool for boxing specific conditioning with implications for reduced injury risk, and to assess the physical response to boxing-specific interventions. Moreover, the BSEP can also be manipulated to suit all levels of participants or training phases, with practical applications in performance monitoring and micro-cycle periodization.

Key words: Protocol, PlayerLoad™, Combat, Biomechanics, Physiology.

INTRODUCTION

The activity profile of amateur boxing is characterised by multi-directional, intermittent bouts of high intensity activity, interspersed by periods of active and passive recovery over a specific number of rounds (11, 13). This intermittent and multi-directional activity profile will inherently increase the complexity of both the physiological and biomechanical response; however, due to a number of practical constraints, the quantification of the physical demands of boxing has been afforded limited attention (14, 24). The physical response to sparring has received the greatest consideration (2, 20, 26, 33); however, although this method of simulating combat offers high ecological validity, there is limited experimental control, and the assessment of some physical measures are impractical when considering the impacts which occur to the head and body (12).

Similar issues have previously been identified in a number of other sports, thus leading to the development of a sport-specific simulation (30, 36, 37). These simulations offer a method of standardising the activity profile performed by the participants, whilst also increasing the mechanistic rigour and the opportunity to assess the physical demands beyond what is practical during competition (12, 35). Sport-specific simulations need to be validated on both the activity profile, and the physical response that they elicit (10), with a failure to do so bringing into question the integrity of the simulation and subsequently the efficacy of the practical applications. Where previous laboratory based assessments have been used to assess the physical demand associated with amateur boxing, they have typically been characterised by an activity profile that comprises an inappropriately high number of punches (19, 20), an ad hoc distribution of punches (2), or notational data recorded from a range of bout formats (35). The use of an invalid activity profile will almost certainly influence the physical demands and, as such, there currently does not exist a Boxing Specific Exercise Protocol (BSEP) that has been validated in relation to both the activity profile and the physical response associated with contemporary, male senior elite amateur boxing (3x3 minute bouts of activity, each interspersed by a 1 minute period of passive recovery) (1).

To date only a single paper has provided detailed notational analyses of male senior boxers competing in the contemporary 3x3minute amateur boxing format (11). Nevertheless, these notational data provide sufficient detail from which the activity profile of a BSEP can be developed. The notational data suggest that a total of ~60 punches are thrown per round, with the lead hand jab being the most frequently used punch, and that considerably more punches are thrown to the head when compared to the body. The notational data also suggests that combinations (2 or more punches in a cluster) of punches are regularly thrown in an attempt to be most effective during combat. When considering that a laboratory-based simulation will inherently elicit a conservative physical response when compared to actual combat (7), clustering of punches may offer a method of eliciting periods of temporary fatigue, and therefore a higher and more valid physical response, without invalidating the activity profile.

To monitor the internal response to boxing specific activity, previous literature has typically analysed physiological measures including oxygen consumption (VO2), heart rate (HR) and blood lactate (Blac) (32). The physical response could be extended to include an assessment of biomechanical efficiency, with contemporary measures of tri-axial accelerometry. Recently, PlayerLoad™ calculated from the tri-axial accelerometer function of global positioning system (GPS) devices has been identified as being sensitive enough to distinguish between specific combat movements, as well as offering a reliable method of quantifying the total external load associated with bouts of combat activity (25, 27,28).

The design of a valid BSEP has practical applications in performance monitoring, micro-cycle periodization, technique development, and the assessment of nutritional, training, and recovery interventions. Laboratory protocols also provide a reduced injury risk, negating physical contact. The aim of this current study was twofold. Firstly, to design a contemporary BSEP based on notational analysis of amateur boxing and, secondly, to validate both the activity profile, and the internal and external response that it elicits. It is hypothesised that a cumulative fatigue response would be observed across successive rounds of the BSEP, and that this response would be comparable to other boxing specific literature.

METHODS

Experimental Approach to the Problem

This current experimental study was associated with the design and validation of a contemporary BSEP. Participants were required to attend the laboratory on three separate occasions, ensuring a minimum of 72 hours interspersed each of the 3 trials. The 3 trials included an incremental treadmill-based exercise test ($\dot{V}O_{2max}$ test), a familiarisation trial of the BSEP, and a single experimental trial of the BSEP. The activity profile of the BSEP was based on notational analysis of amateur bouts to ensure participants performed a valid and standardised activity profile. The current protocol allows for the assessment of additional physical parameters and enables increased mechanistic rigour when compared to previous boxing-specific literature. The dependant variables were chosen to quantify and validate the physical response to the protocol by using contemporary measurements, which are regularly used in an applied setting, and that have been previously used in boxing-specific literature

(32). The use of GPS-based triaxial accelerometry also offers a novel method of assessing the mechanical demand of Boxing-specific activity.

Subjects

Nine male senior elite amateur boxers (Mean ± SD; age 21 ± 4 yrs; height 176. 2 ± 4.3 cm; mass 69.7 ± 8.22 kg; previous contests 31 ± 12; VO_{2max} 55.03 ± 6.10 $ml\cdot kg^{-1}\cdot min^{-1}$; HR_{max} 189 ± 5 $beats\cdot min^{-1}$) participated in the study. All participants were aged between 18 and 31. A priori power calculation from pilot study data identified that a sample size of 8 was required to evaluate a time main effect (for statistical power >0.8; $P < 0.05$). Inclusion criteria specified that participants were completing boxing-specific training volumes of > 6 $h\cdot wk^{-1}$, had a fight scheduled within a month of the completion of the current study, had competed at regional level as a minimum, and were familiar with the 3 x 3 minute fight format. The current study was completed during the amateur boxing season (between January and March). Participants completed a comprehensive health screening procedure and were free of injury at the time of testing. All participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. The current study was granted ethical approval by an Institutional Review Board (IRB).

Procedures

The familiarisation trial comprised the completion of the warm up and first round of the boxing specific exercise protocol (BSEP) used in the experimental trials. The familiarisation trial was conducted to ensure that the participants were familiarised with both the BSEP and the equipment that would be worn in the experimental trial.

The $\dot{V}O_{2max}$ test was completed to determine the participant's maximal heart rate (HR_{max}), and maximal oxygen consumption ($\dot{V}O_{2max}$), aligned with end-point criteria guidelines of the British association of Sport and Exercise Sciences (39). Prior to this, participants were required to complete a brief warm up inclusive of self-directed, dynamic stretching and familiarising themselves with treadmill running technique. Participants were fitted with a heart rate monitor (Polar, Team system, Finland) and a breath-by-breath portable metabolic analyser (Cosmed K2, Rome, Italy) for the duration of the protocol.

The experimental trial comprised the completion of a standardised boxing specific exercise protocol (BSEP) based on contemporary notational analysis (11) from the 2012 London Olympic Games. Relevant to the demands of the modern boxer, and specific to the AIBA bout format, the BSEP consisted of 3x3 minute rounds of intermittent activity, with a 1 minute passive recovery period interspersing each of the three rounds. Table 1 identifies the punching profile associated with each round of the BSEP and the notational data upon which the protocol is based.

Due to the lack of defensive actions associated with the BSEP, the block and counter punches reported in the notational data (11) have been included within the other punch typologies. As identified in figure 1, the participants were required to deliver specific punches in accordance with standardised auditory signals. Speech dictation of each instruction was transferred from TextEdit v1.10 for Mac (Apple Inc. California, USA) to Garageband v10.0.3 for Mac (Apple Inc. California, USA) where they were organised according to the activity profile. The completed audio files were then subsequently uploaded to iTunes v12.3.1.23 (Apple Inc. California, USA) for playback. The auditory files comprised the following speech dictation instructions: jab, rear straight, rear hook, lead hook, and low. The low instruction (as illustrated in figure 1 as a white vertical bar) is used to instruct the boxer that the specific punch type should be delivered as a body punch. To facilitate orthodox and southpaw boxers, with exception to the jab (always conducted with the lead hand), punch instructions were defined as lead and rear, as oppose to left and right.

The audio file also features a sensor beep function to dictate to the participant when they should throw the previously instructed punches. In reference to figure 1, the example audio track begins with a beep to indicate the start of the round, then dictates a low jab, and then provides another beep at which point the participant should throw the punch. The second and third punches comprise a jab and a rear hand combination, with another beep following these instructions to inform the participant when to throw the aforementioned combination.

** Insert Table 1 about here **

** Insert Figure 1 about here **

The participants performed specific punching sequences on a 120 x 35cm, wall-mounted punch bag suspended at a height relative to each individual. Tape was applied to the bag to distinguish two areas that should be targeted for head and body punches. Participants were encouraged to throw punches and incorporate feints and slips in their normal fashion during the completion of the BSEP. Participants were advised to apply protective wraps in their typical way and wore their own competition boxing gloves. Prior to the start of each experimental trial, participants were required to complete a standardised four minute boxing-specific intermittent warm-up. This standardised warm-up routine was designed to acutely familiarise the participants with the auditory instructions, and to prevent differences in the warm-up intensity affecting the physiological response during the experimental trial (22).

Participants attended the laboratory for each trial in a 3-hour post absorptive state after a 48-hour period of abstinence from vigorous exercise and alcohol. Participants were also asked to refrain from consuming caffeine 24 hours before all experimental trials, consume standardised meals between trials, and wear similar apparel for each trial. In an attempt to ensure that the participants were sufficiently hydrated, participants were asked to consume 500 ml of water 2 hours prior to the start of each trial. On arrival at the laboratory, a portable refractometer (Osmocheck, Vitech Scientific, West Sussex, UK) was used to ensure participants were euhydrated (urine osmolality of <700mOsm./kgH2O).

In an attempt to control for circadian variation, (4) all experimental trials were completed between 1200 and 1400 hours. The face mask associated with the portable metabolic analyser restricted the consumption of water to pre- and post-trial. No alternative drinks or foods were allowed to be consumed during the completion of the experimental trials. In an attempt to minimise the influence of both the gender (38) and the number (31) of observers, only one male researcher and the participant were present during the completion of the experimental trials.

Experimental Measures

During the completion of the BSEP, the participants were fitted with a breath by breath portable metabolic analyser (Cosmed K4, Rome, Italy) and a heart rate monitor (Polar, Team system, Finland) to quantify values for mean ($\dot{V}O_{2ave}$) and peak oxygen consumption ($\dot{V}O_{2peak}$), and both mean (HR_{ave}) and peak (HR_{peak}) heart rate across each round of the BSEP (see figure 1). Capillary blood lactate concentrations (BLa; Lactate Pro, LT-1710, Arkray, Kyoto, Japan) were also recorded immediately following the completion of each round of the BSEP using a reliable (34, 5) and portable lactate analyser (Lactate Pro, Arkay, LT17-10, Japan). The participant's rating of perceived exertion (RPE) (6) was also recorded as a point reading following each round.

Tri-axial accelerometry data (Kionix KX94, Kionix, Ithaca, New York, USA) was continuously recorded during the completion of the experimental trial to quantify tri-axial (PL_{total}) and Uni-axial PlayerLoad™ in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}) and vertical (PL_{V}) movement planes. The triaxial accelerometer recorded at 100Hz, was contained within a global positioning system device (GPS; MinimaxX, S4, Catapult Innovations, Scoresby, Australia), and was housed within a standardised neoprene vest at the cervical region of the spine. The relative contributions of each uniaxial PlayerLoad™ vector to PL_{total} ($PL_{ML\%}$, $PL_{AP\%}$, and $PL_{V\%}$) were also quantified. All PlayerLoad™ measures were calculated using the Catapult Sprint software v5.0.9.2 (Catapult Innovations, Scoresby, Australia) for each of the three rounds.

Statistical analyses

Statistical analyses and the variables that were to be included were decided *a priori*. Prior to parametric analysis, the assumptions of the GLM were initially assessed to ensure model adequacy. Outliers were assessed via the inspection of box plots produced from the standardised residual values for each independent variable. It was identified that for all independent variables, none of the standardised residuals were greater than 3 box-lengths from the edge of the box in a boxplot. Normality of the stacked standardised residuals were assessed using a Shapiro-Wilk test with a significance value set at $P < 0.05$. The current data did not violate the assumptions of normality, and therefore inferential analyses were performed. A repeated-measures general linear model (GLM) was chosen as an appropriate parametric test to compare the cumulative fatigue response in the physical measures across successive rounds of the BSEP. Where significant main effects and interactions were identified, post hoc pairwise comparisons with a LSD correction were completed. For all significant main effects and interactions, 95% confidence intervals for difference (CI) and partial eta squared (η^2) values are reported. To assess between-session reliability, intraclass correlation coefficients (ICC) were calculated from the data recorded from the first round of both the familiarisation and experimental trials. These ICC values were then used to calculate standard error of measurement (SEM) of the independent variables. The ICC statistics will be interpreted as < 0.2 = slight, 0.21-0.4 = fair, 0.41-0.6 = moderate, 0.61-0.8 = substantial and > 0.8 = almost perfect reliability (29). All statistical analyses were conducted using PASW Statistics Editor 22.0 for Mac (SPSS Inc, Chicago, USA), with statistical significance set at $P \leq .05$. All data is reported as mean ± SD unless otherwise stated.

RESULTS

Table 2 summarises the heart rate response to the BSEP. The GLM identified significant differences across rounds for both the HR_{ave} ($P = 0.007$; $\eta_p^2 = 0.465$; ICC: 0.932; SEM: 3 beats·min^{-1}) and HR_{peak} ($P = 0.021$; $\eta_p^2 = 0.422$; ICC: 0.955; SEM: 2 beats·min^{-1}) data, with significantly higher values recorded in the 2nd and 3rd rounds when compared to the first.

The GLM also identified significantly (P = 0.004; η_p^2 = 0.635; ICC: 0.881; SEM: 0.6 mmol·L^{-1}) lower BLa data recorded during the 1st round (2.4 ± 1.3 mmol·L^{-1}) when compared to the 2nd (P= 0.003; 3.3 ± 1.7 mmol·L^{-1}; CI: -1.4 to -0.4 mmol·L^{-1}) and 3rd (P= 0.005; 4.3 ± 2.6 mmol·L^{-1}; CI: -3.1 to -0.8 mmol·L^{-1}). Significantly higher values were also recorded in the 3rd round when compared to the 2nd (P= 0.011; CI: 0.3 to 1.8 mmol·L^{-1}).

A similar response was identified for the RPE data, with significantly (P = 0.005; η_p^2 = 0.790; ICC: 0.791; SEM: 1 a.u) lower values recorded in the 1st round (11 ± 2 a.u) when compared to the 2nd (P= 0.002; 13 ± 2 a.u; CI: -3 to -1 a.u) and 3rd (P= 0.005; 14 ± 2 a.u; CI: -4 to -2 a.u). Significantly higher values were also recorded in the 3rd round when compared to the 2nd (P= 0.001; CI: 1 to 2 a.u).

As identified in table 2, the GLM did not identify any significant differences in the across rounds for either the $\dot{V}O_{2ave}$ (P = 0.490; ICC: 0.928; SEM: 1.09 ml·kg^{-1}·min^{-1}) or $\dot{V}O_{2peak}$ (P = 0.884; ICC: 0.934; SEM: 1.54 ml·kg^{-1}·min^{-1}) data.

** Insert Table 2 about here **

Table 3 summarises the biomechanical response to the BSEP. The GLM revealed no significant differences in PlayerLoad™ across successive rounds; PL_{Total} (P = 0.246; ICC: 0.973; SEM: 1.11 a.u), PL_{AP} (P = 0.193; ICC: 0.972; SEM: 0.38 a.u), $PL_{ML,}$ (P = 0.161; ICC: 0.897; SEM: 0.56 a.u), PL_V (P = 0.633; ICC: 0.989; SEM: 0.33 a.u). As identified in Figure 1, there was also no significant differences in the relative contributions of $PL_{AP\%}$ (P = 0.295; ICC: 0.955: SEM: 0.24%), $PL_{ML\%}$ (P = 0.341; ICC: 0.974; SEM: 0.58) and $PL_{V\%:}$ (P = 0.257; ICC: 0.926; SEM: 0.78%).

** Insert Table 3 about here **

** Insert Figure 2 about here **

DISCUSSION

The aim of this current study was twofold: to design a contemporary BSEP based on notational analysis of amateur boxing; and to validate both the activity profile, and the internal and external response that it elicits. In an agreement with the hypothesis, a cumulative fatigue response was observed for values of HR_{mean}, HR_{peak}, Bla, and RPE during the completion of the BSEP. In this respect, the BSEP appears to present a valid and considerable physiological challenge.

The HR_{mean} and HR_{peak} data elicited a response whereby significantly higher values recorded in the 2nd and 3rd rounds when compared to the first. The observed HR data was similar in magnitude to those reported previously during standardised pad protocols (2, 12), with the observed differences being greater than the SEM. When considering that pad based protocols have been previously shown to elicit a more elevated physiological response when compared to punch bag based protocols, it could be suggested that the current BSEP elicits a cardiovascular response that is elevated when considering what is normally expected from punch bag based activity. These data also suggest that the cardiovascular response associated with the BSEP may also be further enhanced by conducting the current protocol within a choreographed pad routine (2, 12). In contrast, the current HR response is lower than that previously observed during an alternative punch bag based protocol (19); however, these contrasting data may be due to methodological differences between studies. For example, the aforementioned punch bag protocol (19) only recorded HR data in the final minute of each round, with each round comprising an activity profile whereby the participants were instructed to throw as many punches as possible. The data collection period and invalid activity profile will inevitably result in an elevated cardiovascular response when compared to the current study.

In line with the fatigue induced changes in HR, the BSEP also resulted in an increased perception of exertion across each of the rounds. The Post-bout RPE values of 14 ± 2 (au) recorded in this current study are similar to those previously reported from other BSEPs (2, 35). These data therefore suggest that alongside an increased cardiovascular stress, the BSEP could also be used to assess the influence of pre- and within bout interventions on perceptions of exertion. The measurement of RPE also appears to be sensitive enough to detect fatigue induced changes in perception of exertion during boxing combat and, as such, RPE may offer an inexpensive method to monitor training with this population.

The temporal pattern of increased cardiovascular response as a function of exercise duration was mirrored in the BLa values, which increased each round at a rate (~1 $mmol \cdot L^{-1}$) greater than the SEM. This data confirms the requirement of high activation of anaerobic lactic metabolism in boxing specific activity (9, 15, 33). The BLa values of 4.3 ± 2.6 $mmol \cdot L^{-1}$ observed at the end of the 3rd round are similar to those found in a 3x2 minute pad routine (2); however, these values are lower in comparison to similar previous studies (19, 12). Again, direct comparison is limited due to differences in workload and methodological differences in acquiring blood samples, with some studies collecting blood samples up to 4 minutes post-activity (2) and others failing to detect this information (19). Blood lactate concentrations are inevitably influenced by sample time (3) and, thus, the delay post-exercise and intensity of activity during the latter stages of the round will influence the values recorded (24). To date, those studies that have quantified the physiological response to boxing specific activity have often required near maximal effort, (20, 26, 19) failing to validly replicate the activity profile of an amateur bout, thus, inflating the BLa concentrations. Comparable values have been reported from another laboratory-based study (2), and a lower physiological response in a laboratory setting when compared to a competition setting is to be expected (2, 7). The current BSEP elicits a fatigue induced change in Bla, thus suggesting that the protocol could be used for specific conditioning and the assessment of intervention efficacy.

There was however, no temporal change in mean or peak oxygen consumption across rounds, consistent with previous studies (19, 12). These studies reported a considerably higher fractional utilization of $\dot{V}O_{2max}$; however, this could be attributed to the averaging of physiological responses over 2 minute when compared to the contemporary 3 minute rounds as associated with the BSEP. The fighter's pacing strategy during a 2 minute round would most likely be higher, and the near maximal effort punch routine used by some previous literature (19) would elicit a higher physiological response. The consistency of the $\dot{V}O_{2ave}$ and $\dot{V}O_{2peak}$ data recorded in the current study also demonstrates the importance of high levels of aerobic fitness in maintaining workload during boxing specific activity (32). The current $\dot{V}O_{2ave}$ data was also similar to that reported previously from a 3x3 minute pad routine (35) completed with similar standard boxers. As discussed in relation to the HR data, the oxygen consumption data therefore supports the notion that the current punch bag based protocol elicits a response comparable to pad based combat. A somewhat conservative physiological response to simulations in comparison to competition (7, 17) must be balanced against the practical issues of engaging an opponent. As such, a more elevated response may be expected if the BSEP was modified to be pad based with a qualified instructor countering attacks similar to that in previous studies (2, 12).

As a result of the methodological issues associated with quantifying biomechanical measures during combat sports, it is difficult to evaluate the biomechanical response to the BSEP. In contrast to the current hypothesis, and also the findings of a recent Mixed Martial Arts (MMA) study, (28) there was no significant fatigue effect evident in the PlayerLoad™ data recorded across the rounds of the BSEP. It is worth noting however, that the MMA simulation consisted of 3x5 minutes of activity with an opponent during an unstandardized routine. As previously discussed in relation to the physiological data, the observed fatigue response will be dependent on the duration of activity, and will be inherently higher during actual combat. A comparable yet higher mean $PL_{total}{\cdot}min^{-1}$ was recorded during the BSEP (15.9 au) when compared to the MMA simulation (14.91 au) (28). These data therefore suggest that although the absolute external load may be higher from the MMA simulation, the relative external load is actually higher during the BSEP. When considering the location of the tri-axial accelerometer used in these studies, the higher relative external load elicited from the BSEP may be indicative of the increased number of punches and subsequent trunk rotations. These data therefore have implications for training design.

In the current study, the participants exhibited the highest PL_{Total} in round 2, with the second highest and the lowest value occurring in rounds 3 and 1 respectively. Although these differences were not significantly different the differences between round 2 and the other two rounds was greater than the SEM. This could possibly be attributed to the highest punch count occurring in round 2, followed by rounds 3 and 1. More specifically, there was a higher frequency of hooks and rear hand punches thrown during round 2 in comparison to other rounds. Previous investigation into PL_{Total} of punching in MMA sparring, revealed a higher external load was associated with the hook; left hook 2.48 ± .31 (au), right hook 2.54 ± .65 (au) when compared to the jab 2.04 ± .29 (au) and rear straight 2.25 ± .26 (au) (27). A boxer initiates more sideways movement when throwing hooks and rear straight punches as oppose to a jab. This is due to the twisting motion from the proximal to distal body segments, in particular at the trunk (16, 8). Further, it is known that punch force is heavily reliant on a boxer's ability to produce force at the lower limbs, more specifically transferring momentum from the rear foot to front foot (18, 21). Consequently, a boxer produces high vertical and medial-lateral force and accelerations once knee flexion and subsequent extension occurs. This is reflected in the mean relative contributions of $PL_{V\%:}$ $PL_{AP\%:}$ $PL_{ML\%}$ at 39:28:33. These contributions were also consistent across rounds, thus suggesting that although a fatigue response was evident in the physiological data, this had no detrimental effect on mechanical efficiency. When considering the similarity of the activity profile performed across the rounds of the BSEP, any change in the PL response could be attributed to a change in efficiency, indicative of a change in punching technique. As such, the consistency in the current PL data suggests an improvement in mechanical efficiency and technical proficiency even with the increased perceived and absolute physiological load. This observation may be indicative of a subconscious pacing strategy that boxers employ during early rounds in an attempt to maintain performance in the latter rounds. These data have both technical and tactical implications for coaches. It is however worth noting that as previously identified, the observed maintenance of mechanical efficiency may not exist during more prolonged activity, indicative of professional boxing or training.

This study is the first of its kind to use tri-axial accelerometry to determine the mechanical load associated with boxing-specific activity. The current data could therefore be utilised by conditioning coaches, athletes, and sport scientists alike to design and monitor the external load associated with training, and also the influence of interventions on mechanical efficiency. Tri-axial accelerometry could also be positioned in more functionally relevant locations, such as the lumbar region of the participant's spine. This position is closer to the participant's centre of mass and therefore may better reflect the rotation of the upper body when punching, as has been suggested in other sports (23). The current data also suggests that the PlayerLoad^{TM} metrics may be sensitive enough to monitor the efficiency of different isolated boxing punch techniques, as has previously been studied in MMA activity (27). An increased understanding of which boxing specific movements are performed with the greatest intensity could assist in fatigue and injury management for coaches and conditioners. Although boxers in this present study were encouraged to keep moving and slipping in such a way that they were facing a constant threat in the form an opponent, this facet of the BSEP was not standardised and could therefore possibly over/under-estimate the physical response associated with typical bout activity. Incorporating the defensive movements present in activity profiles of amateur bouts, could further increase the validity of the BSEP.

PRACTICAL APPLICATIONS

The BSEP elicits a valid physiological response, and therefore enables specificity in training without the risk inherent with sparring or other contact activities. As a conditioning session, the BSEP might be used to assess training status in preparation for a bout, as a rehabilitation tool where the injury prohibits full body contact, or as a method of maintaining fitness during periods where no competitive fights are scheduled. Coaches might also utilise the BSEP as a measure of intervention efficacy, such as, but not limited to, modifications to training practices or nutritional interventions. The BSEP also offers scope for coaches to consider interventions between rounds, either from a conditioning perspective in terms of reduced recovery, or alternate strategies between rounds.

In this study we consider a format based on amateur boxing, however elements of the BSEP could be modified to enable overload in the physiological response, for example by extending the duration of each round, or the number of rounds. Likewise, the BSEP could also provide coaches with a conditioning or technique drill for junior or novice boxers who are not yet competent enough to participate in full body contact. The BSEP therefore offers coaches the opportunity to modify performance monitoring and micro-cycle periodization strategies for a range of participants.

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REFERENCES

1. ABAE. (2015). *AIBA Technical Rules.* Available: http://www.abae.co.uk/aba/index.cfm/news/aiba-technical-rules-some-frequently-asked-questions/ Last accessed 22nd Nov 2015.
2. Arseneau, E, Mekary, S and Leger, L. A. VO_2 requirements of boxing exercises. *J Strength Cond Res* 25: 348-359, 2011.

3. Astrand, P, Rodahl, K, Dahl, H. A and Stromme, S. B. Physical Performance. In: *Textbook of Work Physiology: Physiological Bases of Exercise*. 4th ed. Champaign, IL: Human Kinetics. 2003. pp. 252-254.
4. Atkinson, G, and Reilly, T. Circadian variation in sports performance. *Sports Med* 21: 293-312, 1996.
5. Bonaventura, J. M, Sharpe, K, Knight, E, Kate L. Fuller, K. L, Tanner, R. K and Gore, C. J. Reliability and Accuracy of Six Hand-Held Blood Lactate Analysers. *J Sports Sci Med* 14: 203-214, 2015.
6. Borg, G. Perceived Exertion as an indicator of somatic stress. *Scand J Rehabil Med* 2: 92-98, 1970.
7. Bridge, C. A, Mcnaughton, L. R, Close, G. L and Drust, B. Taekwondo exercise protocols do not recreate the physiological responses of championship combat. *Int J Sports Med* 34: 573-581, 2013.
8. Cabral, S, Joao, F, Amado, S and Veloso, A. Contribution of Trunk and Pelvis Rotation to Punching in Boxing. In: Conference Proceedings of the Annual Meeting of the American Society of Biomechanics. 2010.
9. Chaabene, H, Tabben, M, Mkaoeur, B, Franchini, E, Negra, Y Hammami, M, Amari, S, Chaabene, R, and Hachana, Y. Amateur Boxing: Physical and Physiological Attributes. *Sports Med* 45: 337-353, 2015.
10. Currell, K and Jeukendrup, P. Validity, reliability and sensitivity of measures of sporting performance. *Sports Med* 13: 133-138, 2013.
11. Davis, P, Benson, P. R, Pitty, J.D, Connorton, A. J, and Waldock, R. The Activity Profile of Elite Male Amateur Boxing. *Int J Sports Physiol Perform* 10: 53-57, 2015.
12. Davis, P, Leithauser, R.M and Beneke, R. The Energetics of Semicontact 3x2-min Amateur Boxing. *Int J Sports Physiol Perform* 9: 233-239, 2014.

13. Davis, P, Wittekind, A and Beneke, R. Amateur boxing: activity profile of winners and losers. *Int J Sports Physiol Perform* 8: 84-91, 2013.

14. De Lira, C. A. B, Peixinho-Pena, L. F, Vancini, R. L, Fachina, R. J. F. G, De Almeida, A. A, Andrade, M. S and Da Silva, A. C. Heart rate response during a simulated Olympic boxing match is predominantly above ventilatory threshold 2: a cross sectional study. *Open Access J Sports Med* 4: 175-182, 2013.

15. Delvecchio, L. Profiling The Physiology of an Amateur Boxer. *J Aust Strength Cond* 19: 37-47, 2011.

16. Dyson, R, Smith, M.S, Martin, C and Fenn, L. Muscular recruitment during rear hand punches delivered at maximal force and speed by amateur boxers. In: Proceedings of Biomechanics International Symposium, Ouro Preto, Brazil. 2007. pp. 591-594.

17. Fernandez-Fernandez, J, Boullosa, D. A, Sanz-Rivas, D, Abreu, L, Filaire, E and Mendez-Villanueva, A. Psychophysiological stress responses during training and competition in young female competitive tennis players. *Int J Sports Med* 36: 22-30, 2015.

18. Filiminov, V. I, Koptsev, K. N, Husyanov, Z. M and Nazarov, S. S. Means of Increasing Strength of the Punch. *Natl Str Cond Assoc J* 7: 65-66, 1985.

19. Ghosh, K.A. Heart Rate, Oxygen Consumption and Blood Lactate Responses During Specific Training in Amateur Boxing. *Int J Appl Sports Sci* 22: 1-12, 2010.

20. Ghosh, A. K, Goswami, A and Ahuja, A. Heart rate & blood lactate response in amateur competitive boxing. *Indian J Med Res* 102: 179-183, 1995.

21. Giovani, D and Nikolaidis, P. T. Differences in Force-velocity Characteristics of Upper and Lower Limbs of Non-competitive Male Boxers. *Int J Exerc Sci* 5: 106-113, 2012.

22. Gray, S and Nimmo, M. Effects of active, passive or no warm-up on metabolism and performance during high-intensity exercise. *J Sports Sci* 19; 693-700, 2001.
23. Greig, M and Nagy, P. Lumbar and Cervico-Thoracic Spine Loading During a Fast Bowling Spell. *J Sports Rehabil. In press*
24. Hanon, C, Savarino, J and Thomas, C. Blood lactate and acid-base balance of world-class amateur boxers after three 3-minute rounds in international competition. *J Strength Cond Res* 29: 942-948, 2015.
25. Hurst, H.T, Atkins, S and Kirk, C. Reliability of a Portable Accelerometer for Measuring Workload During Mixed Martial Arts. *J Athl Enhanc* 3: 1-5, 2014.
26. Khanna, G. l and Manna, I. Study of Physiological Profile of Indian Boxers. *J Sports Sci Med* 5: 90-98, 2006.
27. Kirk, C, Hurst, T and Atkins, S. Comparison of the Training Loads of Mixed Martial Arts Techniques in Isolated Training and Open Sparring. *J of Combat Sports and Martial Arts* 6: 1-6, 2015.
28. Kirk, C, Hurst, T and Atkins, S. Measuring the Workload of Mixed Martial Arts using Accelerometry, Time Motion Analysis and Lactate. *Int J Perform Anal Sport* 15: 359-370, 2015.
29. Landis, J and Koch, G. G. The Measurement of Observer Agreement for Categorical Data. *Biometrics* 33: 159-174, 1997.
30. Page, M. R, Marrin, K, Brogden, M. C and Greig, M. Biomechanical and Physiological Response to a contemporary Soccer Match-Play Simulation. *J Strength Cond Res* 29: 2860-2866, 2015.
31. Rhea, M. R, Landers, D. M, Alvar, B. A and Arent, S. M. The effects of competition and the presence of an audience on weight lifting performance. *J Strength Cond Res* 17: 303-306, 2013.

32. Slimani, M, Chaabene, H, Davis, P, Franchini, E and Chamari, K. Performance Aspects and Physiological Responses in Male Amateur Boxing Competitions: A Brief Review. *J Strength and Cond Res In press.*

33. Smith, M.S. Physiological Profile of Senior and Junior England International Amateur Boxers. *J Sport Sci Med* 5: 74-89, 2006.

34. Tanner, R. K, Fuller, K. L and Ross, M. L. Evaluation of three portable blood lactate analysers: Lactate Pro, Lactate Scout and Lactate Plus. *Eu J Appl Physiol* 109: 551-559, 2010.

35. Thompson, E and Lamb, K. The reproducibility of the internal load and performance-based responses to simulated amateur boxing. *J Strength Cond Res In press.*

36. Waldron, M, Highton, J and Twist, C. The reliability of a rugby league movement-simulation protocol designed to replicate the performance of interchanged players. *Int J Sports Physiol Perform* 8: 483-489, 2013.

37. Williams, J. D, Abt, G and Kilding, A. Ball-sport Endurance and Sprint Test (BEAST90): validity and reliability of a 90-minute soccer performance test. *J Strength Cond Res*. 24: 3209-3218, 2009.

38. Winchester, R, Turner, L. A, Thomas, K, Ansley, L, Thompson, K. G, Mickelwright, D, and St Clair Gibson, A. Observer effects on the rating of perceived exertion and affect during exercise in recreationally active males. *Percept Mot Skills* 115: 213-227, 2012.

39. Winter, E, Jones, A, Davidson, R, Bromley, P and Mercer, T. Amateur Boxing. In: *Sport and Exercise Physiology Testing Guidelines: Volume I -Sport Testing. The British Association of Sport and Exercise Sciences Guide*. London, Taylor & Francis, 2006. pp. 155-159.

FIGURE AND TABLE LEGENDS

Figure 1 Schematic representation of the experimental design and measures. Vertical arrows depict point measurements, and horizontal arrows depict values recorded across rounds. The zoomed image depicts a representation of a single 3 min bout of the BSEP, with the black bars denoting an auditory signal, and the white bars denoting a body shot of the specific punch type.

Figure 2 The relative contributions of the uniaxial PlayerLoad™ measures (■= $PL_{V\%}$; ■= $PL_{ML\%}$; ■= $PL_{AP\%}$) across rounds.

Table 1 The activity profile associated with the BSEP and the notational data upon which it is based (10).

Table 2 The absolute and relative physiological response to the BSEP. * denotes a significant difference with round 1.

Table 3 The PlayerLoad™ response to the BSEP.

Figure 1 Schematic representation of the experimental design and measures. Vertical arrows depict point measurements, and horizontal arrows depict values recorded across rounds. The zoomed image depicts a representation of a single 3 min bout of the BSEP, with the black bars denoting an auditory signal, and the white bars denoting a body shot of the specific punch type.

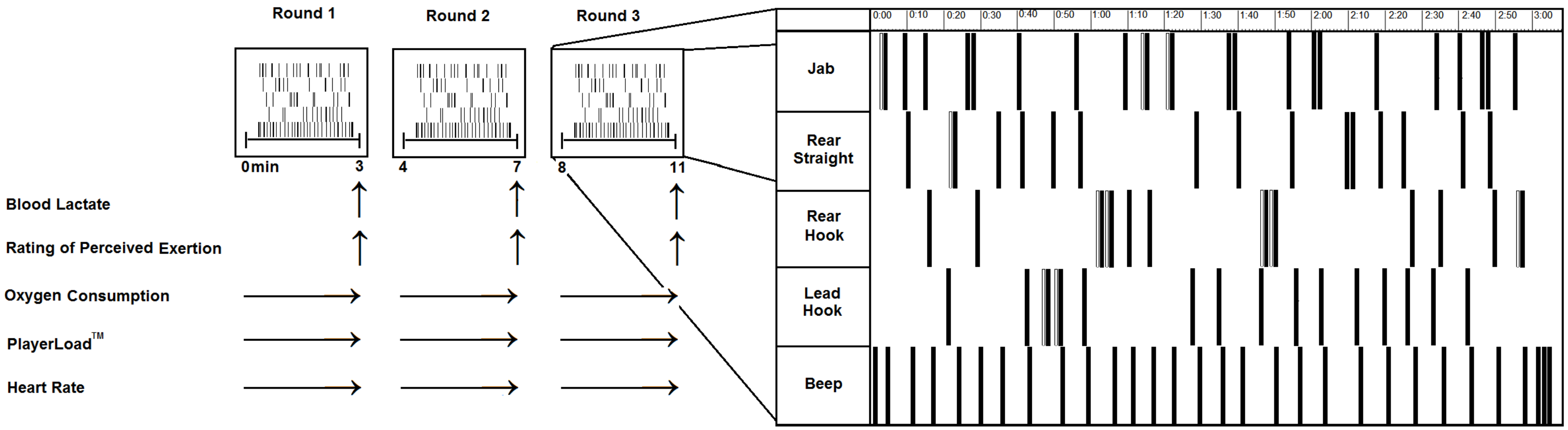

Figure 2 The relative contributions of the uniaxial PlayerLoad™ measures (■= $PL_{V\%}$; ■= $PL_{ML\%}$; ■= $PL_{AP\%}$) across rounds.

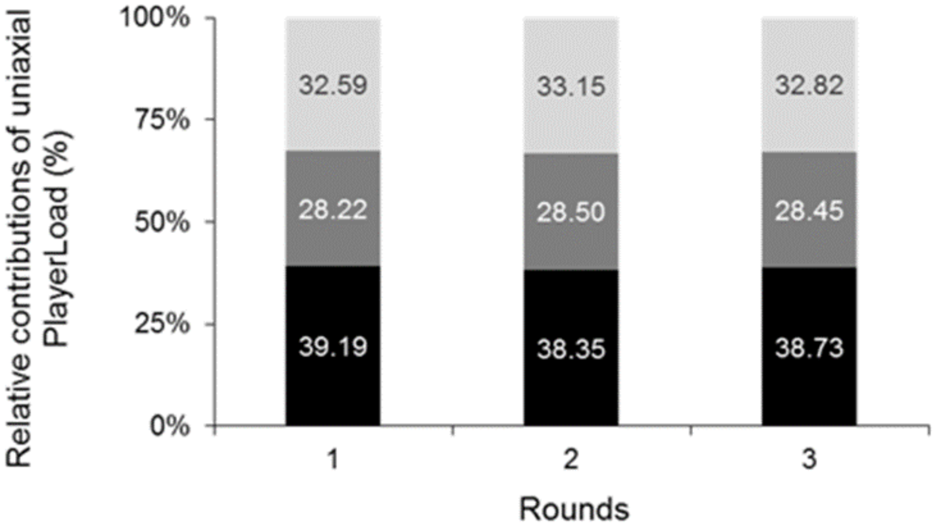

Table 1. The activity profile associated with the BSEP and the notational data upon which it is based.

	Round One		Round Two		Round Three	
	Notational data	BSEP	Notational data	BSEP	Notational data	BSEP
Total punches	61.0 ± 20.5	61	70.8 ± 23.5	71	63.8 ± 21.4	64
Total to head	50.9 ± 20.1	51	59.3 ± 22.5	59	53.4 ± 20.2	53
Total to body	10.1	10	11.5	12	10.4	11
Jab	20.6	21	21.7	23	19.8	21
Rear hand	12.0 ± 7.7	13	14.7 ± 8.8	17	14.6 ± 9.3	16
Lead hook	13.8	15	16	17	14.1	15
Rear hook	11.0 ± 7.0	12	13.2 ± 8.0	14	11.1 ± 7.4	12

Table 2. The absolute and relative physiological response to the BSEP. * denotes a significant difference with round 1.

	HR_{ave} (beats·min^{-1})	$\%HR_{max}$	HR_{peak} (beats·min^{-1})	$\%HR_{max}$	$\dot{V}O_{2ave}$ (ml·kg^{-1}.min^{-1})	% $\dot{V}O_{2max}$	$\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1})	% $\dot{V}O_{2max}$
Round 1	150 ± 15	79	162 ± 12	86	32.36 ± 4.94	59	43.77 ± 7.34	80
Round 2	156 ± 16* (CI: -9 to -3)	83	166 ± 13* (CI: -8 to -1)	88	32.99 ± 5.81	60	43.31 ± 8.18	79
Round 3	157 ± 18* (CI: -13 to -1)	83	169 ± 14* (CI: -12 to -1)	89	32.65 ± 6.04	59	43.50 ± 8.50	79

Table 3. The PlayerLoad^{TM} response to the BSEP.

	Round 1	Round 2	Round 3
PL_{Total} (au)	46.85 ± 6.88	48.69 ± 7.02	47.56 ± 6.13
PL_{V} (au)	18.68 ± 3.48	18.92 ± 3.44	18.55 ± 3.55
PL_{AP} (au)	13.26 ± 2.28	13.92 ± 2.40	13.54 ± 1.91
PL_{ML} (au)	14.91 ± 1.64	15.86 ± 1.64	15.47 ± 1.38