The reproducibility of the internal load and performance-based responses to simulated amateur boxing

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ABSTRACT

The aim of this study was to examine the reproducibility of the internal load and performance-based responses to repeated bouts of a three-round amateur boxing simulation protocol (BOXFIT). Twenty-eight amateur boxers completed two familiarisation trials before performing two complete trials of the BOXFIT, separated by 4-7 days. To characterise the internal load, mean (HR_{mean}) and peak (HR_{peak}) heart rate, breath-by-breath oxygen uptake ($\dot{V}O_2$), aerobic energy expenditure (EE_{aer}), excess carbon dioxide production ($CO_{2excess}$) and ratings of perceived exertion (RPE) were recorded throughout each round and blood lactate determined post-BOXFIT. Additionally, an indication of the performance-based demands of the BOXFIT was provided by a measure of acceleration of the punches thrown in each round. Analysis revealed there were no significant differences ($P > 0.05$) between repeated trials in any round for all dependent measures. The typical error (coefficient variation %) for all but one marker of internal load ($CO_{2excess}$) was 1.2 – 16.5% and reflected a consistency that was sufficient for the detection of moderate changes in variables owing to an intervention. The reproducibility of the punch accelerations was high (CV% range = 2.1 – 2.7%). In general, these findings suggest that the internal load and performance-based efforts recorded during the BOXFIT are reproducible and thereby offers practitioners a method by which meaningful changes impacting on performance could be identified.

KEY WORDS: Combat sports, physiological response, reliability.

INTRODUCTION

Attempting to circumvent the limitations of laboratory and field-based assessments of physical and physiological aptitude, researchers have sought to develop sport-specific *simulations* of competitive sports performance (10,12,14,24,29,38,44,45). Their use seeks to satisfy the requirement for specificity during training and testing (34) and increases the ecological validity of performer assessment by replicating the internal (physiological responses) and external (physical movements) loads of competition (14,45). However, attempting to replicate both the physiological and physical demands in sports typified by dynamic, intermittent exercise patterns, alongside the execution of frequent technical skills, with adequate reproducibility, is challenging (45).

In principle, simulations are realised following a detailed initial identification of the typical movement demands (including the type, intensity, duration, distance and frequency of movements; 14) of a sport (43) via appropriate time-motion techniques (video or global positioning systems). Thereafter, such simulations have been employed to regulate exercise intensity whilst permitting invasive and sensitive measurements that facilitate the identification of meaningful changes in performance (24). In this way, they can be used as part of an athlete's conditioning, offering a replication of the demands of competition (29). In amateur boxing, there have been two attempts (12,39) to simulate the competitive environment. However, these simulations did not adequately replicate the external demands of competition. That is, the attempts to quantify the locomotive movement patterns lacked thoroughness, and the offensive and defensive actions included were atypical of those encountered in competitive performance. Moreover, it appears the internal loads generated by the simulations were invalid, being lower than those recorded in studies documenting the physiological responses to sparring and actual boxing bouts (19,32,40). Accordingly, the 'boxing conditioning and fitness test' (BOXFIT) (42) was developed in the first instance as an externally valid replication of amateur boxing contests, eliciting physiological responses (internal load) shown to be the most valid recorded to date. These encouraging findings support its potential as an appropriate protocol for the scrutiny of boxers' conditioning and the impact of intervention-based changes.

Notwithstanding the importance of the validity of measurement tools such as sport simulation protocols, it is necessary initially to establish the consistency with which they can generate the movements and internal loads over repeated trials. Such information provides an estimate of their ability to monitor worthwhile changes (5) following purposeful interventions. Therefore, the aim of the study was to quantify the trial-to-trial reproducibility of the BOXFIT's key movements and the internal and performance-based responses they elicit.

METHODS

Experimental Approach to the Problem

A test-retest design was used to establish the reproducibility of the movements and the internal loads and performance-based responses to the BOXFIT simulation. Boxers attended three sessions (over a maximum of 10 days) in which they performed boxing-specific assessments. Specifically, participants underwent familiarisation trials which involved two complete attempts of the simulation protocol separated by 60 minutes, the first of which employed shadow boxing exercise, and the second included all its elements (i.e. punching handheld coaching pads). The boxers returned 72 hours later to perform the first of two actual test simulations, and then 4 – 7 days later for the repeat trial.

Subjects

Twenty-eight amateur boxers (4 novice, 12 intermediate and 12 open class) (mean ± SD; age 22.4 ± 3.5 years, body mass 67.7 ± 10.1 kg, stature 171 ± 9 cm, years of experience 6 ± 2 years, previous contests 15 ± 8; predicted $\dot{V}O_{2max}$ = 57 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in the study. Boxers were informed of the procedures and potential risks of participation, and subsequently provided written informed consent. Institutional ethical approval for the experimental procedures was granted by the Faculty of Applied Sciences Ethics Committee.

Procedures

Throughout both trials the boxers wore a portable gas analyser (mass = 450 g; Cosmed, K4b^2, Italy) and a heart rate monitor (Polar, Electro Oy, Kempele, Finland). In addition, they wore fabric hand-wrapping (450 cm length, 5 cm width; Adidas, Germany) and boxing gloves (284 g; Adidas, Germany) as required during actual competition. Following a 15-minute self-selected warm-up consisting of shadow boxing, jogging and punch bag exercise, the boxers performed the simulation protocol (see overview below) in a boxing ring (6.1 m^2) (temperature = 19.0 ± 3.4 °C; humidity = 41.3 ± 8.5 %). The analysed simulation comprised three rounds of three minutes' duration, interspersed with a one minute rest between rounds (50 s seated, 10 s standing). This structure mirrors that of non-novice amateur boxing bouts. Movements during the simulation were recorded using a digital camera (Canon MV700, Japan) positioned adjacent the boxing ring, and the data files were subsequently uploaded to

Dartfish TeamPro (Version 4.0, Switzerland) where the lead researcher identified deviations from the set protocol and coded them as either a *missed action* (i.e. the boxer completely failed to perform the required action) or an *incorrect action* (i.e. the boxer performed the wrong movement). Moreover, whether *missed* or *incorrect*, a note was made identifying whether the action was an offensive, defensive or motion-related error, and thereby enabled an assessment of the adherence to the commands of the BOXFIT.

Amateur boxing simulation protocol (BOXFIT). The external demands of the simulation protocol coincide with the mean contest demands of amateur boxing (41). Consequently, during each minute boxers covered 35.9 m using boxing-specific movements, performed 26 punches (consisting of 15 individual attacks) against handheld coaching pads and simulated 12 defences. For specific details of the movements and their chronological order, the reader is referred to Thomson (42). As the underpinning data of the simulation revealed no differences in the minute-by-minute technical and ambulatory demands of contests involving two- and three-minute rounds, the application of a standardised demand applicable to novice (c.f. regional), intermediate (c.f. inter-regional) and open class boxers (c.f. national standard) was justified. All movement routines were therefore repeated over one-minute cycles, three times per round, and controlled via instructive audio commands.

Internal load and performance-based measurements. Breath-by-breath gaseous exchange measurements of oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER) and minute ventilation ($\dot{V}_E$) were recorded throughout the simulation using a portable gas analyser (Cosmed K4b^2, Italy) and subsequently averaged over five-second periods. Based upon previous research (10), ventilatory data was used to calculate aerobic energy expenditure (EE_{aer}; expressed in kcal·min^{-1}) using:

$$EE_{aer} = 3.941 \times \dot{V}O_2 + 1.106 \times \dot{V}CO_2$$

An oxygen equivalent of 3.941 was used while the non-protein respiratory quotient (npRQ) was < 1. However, in the event npRQ became > 1, an oxygen equivalent of 5.04 kcal·min^{-1} was used and assumed all energy was derived from carbohydrate. An estimate of anaerobic glycolysis was also obtained by calculating excess CO_2 production ($CO_{2excess}$) (10) as follows:

$$CO_{2excess} = \dot{V}CO_2 - (0.817 \times \dot{V}O_2)$$

where 0.817 represented the resting RER (20).

Peak and mean heart rates were recorded using a 1 Hz frequency monitor (Polar, Electro, Finland) throughout. Established as the optimum time post-exercise to record peak lactate following boxing-specific exercise (12), capillary blood samples were collected one minute post-performance from the ear lobe and analysed for blood lactate using a portable analyser (Lactate Pro, Kyoto, Japan). Immediately following each round of simulated boxing, session ratings of perceived exertion (sRPE) were recorded using the category ratio scale (CR-10) (17).

To provide an estimate of the performance-based responses of the boxers, the punches were delivered to coaching pads held by a qualified boxing coach (Level 2, ‘full’ Amateur Boxing Association of England with over five years of coaching experience) equipped at the posterior aspect of each wrist with wireless three-dimensional accelerometers (Herman

Digital Trainer, USA). These devices quantified the acceleration delivered to the targets each round in units expressed as ‘g’ values with the sum of both monitors recorded.

Statistical analyses

The participants’ ability to follow the commands of the BOXFIT under test-retest conditions, was assessed via the statistical approach advocated by Cooper, Hughes, O’Donoghue and Nevill (9). Focussing upon punching (‘offensive’), simulated defences (‘defence’) and boxing-specific ambulation (‘locomotion’) individually, the frequency of the desired action was quantified for each 10-second period of a performance. A median sign test was computed to assess the null hypothesis of no significant systematic bias between the test-retest frequency counts of each action ($P \leq 0.05$). Subsequently, the observed proportion of agreement (PA) was calculated using the sum of agreeing 10-second periods expressed as a proportion of the total number of time periods (a 9-minute simulation = 54 periods). Additionally, the PA was calculated when a reference value of ± 1 frequency count was applied to reflect a permissible margin of error. This value was selected given the need to replicate the commands of the BOXFIT as closely as possible as wider margins would likely affect the accuracy of the internal load and performance-based responses. Approximate confidence intervals (CI) were then calculated for these proportions of agreement (upper 95% CI = PA + (1.96 x SE(PA)); lower 95% CI = PA - (1.96 6 SE(PA)); where ‘SE’ represented the standard error (9,43).

For subsequent analyses, descriptive statistics (mean ± SD) were calculated for all dependent variables and the normality of their distributions was checked using the Shapiro-Wilk test. A 2 x 3 (trial x round number) repeated measures factorial ANOVA was employed to assess the variability of the internal load and performance-based measures due to the independent variables. Equality of variance and covariance was assessed using Mauchly's test of sphericity. Where a significant ($P < 0.05$) Mauchly's test was identified, corrections to the degrees of freedom were made accordingly (35). Post-hoc Bonferroni-adjusted *t*-tests were employed to identify pairwise differences where appropriate. The typical error (TE) was calculated to provide an indication of the within-subject variability in the dependent variables between trials. Expressed as CV%, the TE was also related to the smallest worthwhile change (SWC%) using 0.2 x pooled standard deviation (25). Moderate (MWC%), large (LWC%) and very large (VLWC%) changes were calculated as 0.6, 1.2 and 2.0 x pooled standard deviation, respectively. These were converted to percentages to facilitate a comparison of the CV% with potential changes in performance. Alpha was set at $P \leq 0.05$ throughout. All data analyses were performed using either Microsoft Excel (Version 2010, Redmond, WA) or SPSS (Version 17.0; Chicago, IL).

RESULTS

There was strong agreement on a test-retest basis for the actions performed by the boxers during the simulation, with agreement being > 97% for offensive, defensive and locomotive actions (Table 1). For defensive actions, perfect agreement was not established owing to occasional incorrect movements being performed at the allotted time, though no action during the BOXFIT was missed altogether.

Table 1 placed about here

The reproducibility of the internal load of BOXFIT performance is presented in Table 2. Generally, the round of interest did not modify the consistency of the measurements, with most variables yielding variability smaller than the calculated moderate changes in responses. Between trials, no significant main effects or interactions were observed ($P > 0.05$) in the cardiovascular responses (HR_{mean} and HR_{peak}) to BOXFIT performance across any round. Moreover, the CV% was 1.2 to 2.5% and thus sufficiently low enough to permit identification of MWC% in all rounds. There were also no systematic differences ($P > 0.05$) between test-retest trials in any round for all ventilation-related measurements ($\dot{V}O_{2mean}$, EE_{aer} and $CO_{2excess}$). However, the consistency of the measurements of $\dot{V}O_{2mean}$ (CV% range = 6.2 – 13%) and EE_{aer} (CV% range 8.9 – 16.5%) were notably better than those of $CO_{2excess,}$ which evidenced the poorest reproducibility (CV% ≈ 30% across rounds). Importantly, the stability of $\dot{V}O_{2mean}$ and EE_{aer} was sufficient to detect small or medium changes, whereas $CO_{2excess}$ was consistent enough to detect only large changes in performance.

Mean values for sRPE indicated no systematic bias between trials ($P > 0.05$) and the CV% resided between 2.3 – 6.5%. Notably, better consistency was seen in rounds two and three compared to round one and was sufficiently low to identify SWC% (whereas the response during round one was less than MWC%). Mean post-simulation B_{lac} values did not vary significantly between trials, and the CV% for the measure was 12%; again smaller than the associated MWC%.

Table 2 placed about here

Between trials, no significant main effects or interactions were observed ($P > 0.05$) in the punch accelerations produced during BOXFIT performance. The CV% for punch accelerations (Table 3) ranged between 2.1 – 2.7% and although it was not lower than the SWC% at any point, during rounds one and three it was lower than moderate changes, and during round two it was lower than the LWC%.

Table 3 placed about here

DISCUSSION

The present study sought to examine whether an amateur boxing-specific simulation protocol is capable of generating reproducible movements, internal loads and performance-based responses such that it could detect ecologically valid intervention-based changes in a boxer's physiology and performance. The results warrant a largely favourable interpretation insomuch that the majority of movements and measures were replicated with sufficient consistency that would enable the detection of moderate (or even small) changes in performance across all rounds. These findings represent a considerable advance from what has been published so far. In particular, previous studies attempting to induce boxing-specific physiological demands have not assessed the reproducibility of any component (i.e. internal physiological response or external demands) and doubt exists about the representativeness of their data.

Indeed, the protocol of Davis, Wittekind and Beneke (12), which included 2.5 times the number of typical defences, revealed a significant difference in the number of offensive actions performed between rounds two and three even though they were meant to be identical

(13). Moreover, that the protocol they used demonstrated an increase in physiological responses across rounds suggests a low internal consistency. Given the regulated external demand dictated by BOXFIT, it is perhaps not surprising that the reproducibility of the actions performed within it was seen to be high, with perfect test-retest agreement achieved for the offensive and ambulatory actions, and near perfect agreement for the defensive movements. Thus, when the boxers are fully familiarised, the BOXFIT offers a means by which the external demand can be controlled, facilitating the assessment of various physiological and performance-based measures.

Throughout the three rounds, a consistent pattern emerged where the reproducibility was sufficient to enable the detection of at least moderate changes in performance. HR_{mean}, HR_{peak} and punch acceleration presented good consistencies with CV% < 2.5%, whilst measures of $\acute{V}O_2$, EE_{aer}, Blac and sRPE ranged between 2.3 – 16%. Previous research employing mean and peak heart rate as measures of physiological strain during sports simulation protocols have reported similar CV% or lower (i.e. < 2%) (44,45). Likewise, those for sRPE and Blac scores are similar to those reported previously (44). Employing such statistics support the BOXFIT's efficacy given the large variations often evident in sports (or bout) performances (22).

To provide realistic analytical goals, previous research appraising the impact of interventions (e.g. training, hypo-hydration or energy restriction) upon cardiovascular, glycolytic responses and the development of power during exercise was consulted. Moreover, the approach whereby the CV% of a measurement (referred to as 'noise') is related to a desirable systematic change (considered the 'signal') (5,8,25) was utilised to confirm the consistency of the measurements. That is, analytical goals were dependent upon the consistency of the BOXFIT measurements in relation to the expected percentage changes owing to interventions (8) and the expected change (%) must exceed the BOXFIT CV% to therefore support its reproducibility. As an example, boxers frequently undergo rapid weight loss (31,40) and it is plausible they might experience reductions in blood volume, and hence stroke volume for a given exercise intensity, resulting in a concomitant elevation in heart rates during aerobic exercise of ≈ 5 - 9% following 2.89 - 4% dehydration (21,23). The current between-trial CV % for mean and peak heart rates (2.4 and 2.0%) suggest the BOXFIT could be used to identify dehydration-related increases in cardiovascular demand, given the expected change in heart rate exceeds 2.4%. Likewise, dehydration is known to increase sRPE (1) and it would seem likely that the worst-case variability reported herein (6.5%) is lower than the typical increases (>10%; 11,21) in perceived exertion following dehydration of 3% body mass. Consequently, boxers engaged in weight loss practices could employ the BOXFIT to identify undesirable increases in heart rate (i.e. those > 2%) and perceived exertion (i.e. those > 6.5%) that imply they ought to taper their training and consider a fluid replacement plan incorporating electrolytes and carbohydrate intake (2). It might also be that a forthcoming contest is cancelled, or at least postponed, allowing the boxer to rehydrate before undergoing a more gradual approach to weight loss (30).

Furthermore, as decrements of 15% in an athlete’s ability to produce (peak) powerful upper-body movements are associated with 3% hypohydration (28), power in punching could be considered a function of force and velocity (7) and the recorded punch accelerations within the BOXFIT are influenced by the ability of a boxer to produce force (i.e. acceleration = force/mass) and velocity (i.e. acceleration = (change in velocity)/time), the expected decrements of 15% could plausibly transfer to the punching performance during the simulation. Thus, given a sensitivity of < 6.5% and expected changes of 15%, the BOXFIT could also be used to identify power-related declines in boxing-specific movements owing to hypo-hydration.

A meta-analysis appraising the change in $\dot{V}O_{2max}$ owing to high-intensity interval training reported increases of ≈ 6 - 9 $ml \cdot kg^{-1} \cdot min^{-1}$ (3). The consistency of the $\dot{V}O_2$ and EE_{aer} responses during the BOXFIT resulted in CV% of 7.5% and 8.9%, respectively. Assuming increases in $\dot{V}O_{2max}$ are also reflected at the intensities associated with BOXFIT performance (≈ 42 $ml \cdot kg^{-1} \cdot min^{-1}$) owing to an enhanced efficiency (increased arterio-venous difference and haemoglobin content) (27), a ≈ 6 - 9 $ml \cdot kg^{-1} \cdot min^{-1}$ increase would exceed the 'noise' of the measurement (i.e. 7.5% of 42 $ml \cdot kg^{-1} \cdot min^{-1}$ = 3.15 $ml \cdot kg^{-1} \cdot min^{-1}$). Still, the proposed change of ≈ 6 - 9 $ml \cdot kg^{-1} \cdot min^{-1}$ in $\dot{V}O_{2max}$ might not be consistent with those expected in amateur boxers given such a finding was based upon recreationally active participants (defined as $\dot{V}O_{2max}$ < 55 $ml \cdot kg^{-1} \cdot min^{-1}$) (3). Nonetheless, knowing the sensitivity of the measurement (3.15 $ml \cdot kg^{-1} \cdot min^{-1}$) within the BOXFIT, it could remain a useful measurement for amateur boxers given the extent of training-induced improvements in $\dot{V}O_{2max}$ recorded in elite and well-trained distance runners (>5%) who possess maximal values (61-71 $ml \cdot kg^{-1} \cdot min^{-1}$) higher than the current sample of boxers (57 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$). Following a period of high-intensity interval training the BOXFIT could therefore be used to identify genuine changes in markers of boxing-specific aerobic fitness.

Previous research employing the K4b^2 gas analyser on a test-retest basis, particularly in an applied environment, is scarce, but the findings presented herein do not compare favourably to laboratory-based assessments of respiratory gas analysis (37). That is, during a 1,000 m upper-body ergometry assessment, 95% ratio limits of agreement for $\dot{V}O_2$ data revealed test-retest variability of 9%. Employing the CV% statistic, the variability of the $\dot{V}O_2$ recorded herein was 6 - 13% and estimates of EE_{aer} demonstrated lower consistency still. Such findings must cast doubt on all the previous findings of the energetic demands of combat simulations that have not reported the test-retest consistency of $\dot{V}O_2$ values produced. Indeed, research suggests the accuracy and consistency of the K4*b*[2] is compromised at higher intensities (15,26). The acyclic, short duration, high-intensity nature of the BOXFIT and its reliance upon upper-body exercise might explain the degree of variability owing to a weaker locomotor-respiratory coupling during such exercise (4,37) and greater variability in the oxygen kinetics (15). Nonetheless, that the K4*b*[2] gas analyser was able to detect moderate, and on occasion small, changes in $\dot{V}O_2$ and EE_{aer} suggests these measurements could remain practically useful when monitoring boxing-specific fitness. Finally, as the measure of $CO_{2excess}$ demonstrated poor reproducibility (CV% ≈ 30%), its usefulness in this context has to be questioned. Whilst it is known that such a measure has considerable inter-individual variance (18,36), no prior reports of its reproducibility have been published. The use of an estimated npRQ likely reduced the consistency of the measure as resting npRQ is also known to vary considerably between athletes (20), owing to factors such as nutrition and training status (6). Future research could focus on re-evaluating the consistency of $CO_{2excess}$ responses to high intensity exercise when npRQ has been quantified pre-exercise, enabling an appraisal of within-subject variability.

Post-performance decrements in blood lactate of 11 - 26% compared to control trials have been associated with low (insufficient) carbohydrate intake, and by inference low muscle glycogen stores (33,38). With a blood lactate CV% of 12% post-BOXFIT, it is possible such a measure is reproducible enough to allow the identification of a boxer experiencing low muscle glycogen, and hence an over-reliance on aerobic pathways of energy provision. As this situation would yield a lowered sustainable exercise capacity and premature fatigue during a bout (16), identifying its occurrence pre-competition appears pertinent.

PRACTICAL APPLICATIONS

The BOXFIT described in this study permits the collection of a number of physical and physiological measurements that could be used to identify the preparedness of boxers, derive training intensities and monitor intervention-based changes in physiology or punching performance. Though the BOXFIT has been used to previously to determine the importance of a well-developed aerobic and anaerobic ability (42), the reported reproducibility further supports the application of the BOXFIT in the applied amateur boxing context. Not only would it enhance the specificity of assessment, but, knowing the sensitivity of the test, it appears justified that the BOXFIT be used to monitor the conditioning status (fitness) of boxers and determine the impact of certain body mass manipulation strategies (i.e. hypo-hydration and/or glycogen depletion) upon them given the prevalence and dangers of this practice (31).

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Table 1. Summarised reproducibility of the total actions performed during the BOXFIT simulation.

Performance indicator	**Median (sign test)**	**PA (%)**	**95% CI (%)**	**PA ± 1 (%)**	**95% CI (%)**
Offence	*P* = 1.00	100	100 to 100	100	100 to 100
Defence	*P* = 1.00	97	92 to 100	100	100 to 100
Locomotive	*P* = 1.00	100	100 to 100	100	100 to 100

P = exact p-value; PA = proportion of agreement; PA ± 1 = proportion of agreement where reference value resided within a single frequency count; CI = confidence interval.

Table 2. Reproducibility of internal load during the BOXFIT protocol (by round).

	Round	Trial 1 (mean ± SD)	Trial 2 (mean ± SD)	CV%
HR_{mean} (b·min^{-1})	1	165 ± 11	162 ± 11	2.4 $^{\downarrow MWC}$
	2	172 ± 10	172 ± 11	1.8 $^{\downarrow MWC}$
	3	175 ± 10	175 ± 9	1.2 $^{\downarrow MWC}$
HR_{peak} (b·min^{-1})	1	178 ± 13	178 ± 12	2.0 $^{\downarrow MWC}$
	2	187 ± 8	184 ± 13	2.5 $^{\downarrow MWC}$
	3	189 ± 11	188 ± 10	1.5 $^{\downarrow MWC}$
$\acute{V}O_{2mean}$ (ml·kg^{-1})	1	126.2 ± 16.2	122.2 ± 16.4	7.5 $^{\downarrow MWC}$
	2	131.0 ± 17.7	126.1 ± 15.0	6.2 $^{\downarrow MWC}$
	3	122.0 ± 22.8	126.1 ± 15.2	13.0 $^{\downarrow MWC}$
EE_{aer} (kcal·min^{-1})	1	30.7 ± 16.8	30.9 ± 16.5	8.9 $^{\downarrow SWC}$
	2	33.23 ± 17.9	30.20 ± 17.1	13.3 $^{\downarrow MWC}$
	3	32.1 ± 19.0	32.1 ± 16.5	16.5 $^{\downarrow MWC}$
$CO_{2excess}$ (ml·min^{-1})	1	498.2 ± 203.4	539.1 ± 281.3	30.1 $^{\downarrow LWC}$
	2	584.4 ± 220.3	672.5 ± 242.8	30.2 $^{\downarrow LWC}$
	3	625.2 ± 218.4	686.3 ± 237.6	29.5 $^{\downarrow LWC}$
sRPE (AU)	1	5.8 ± 1.4	5.8 ± 1.5	6.5 $^{\downarrow MWC}$
	2	6.8 ± 1.1	6.9 ± 1.1	2.7 $^{\downarrow SWC}$
	3	8.1 ± 1.1	8.2 ± 1.1	2.3 $^{\downarrow SWC}$
Blood lactate (mmol·l^{-1})	Post	4.6 ± 1.3	4.7 ± 1.2	12.0 $^{\downarrow MWC}$

CV% smaller than associated small ($^{\downarrow SWC}$), moderate ($^{\downarrow MWC}$) and large ($^{\downarrow LWC}$) change in performance.

Table 3. Reproducibility of punch accelerations by round.

	Punch acceleration (g)		
	Round one	**Round two**	**Round three**
Trial 1 (mean ± SD)	2697.3 ± 134.3	2768.1 ± 107.7	2782.0 ± 100.1
Trial 2 (mean ± SD)	2678.7 ± 106.2	2731.2 ± 96.3	2763.3 ± 125.4
CV%	2.1 [↓MWC]	2.7 [↓LWC]	2.1 [↓MWC]

CV% smaller than associated moderate ([↓MWC]) and large ([↓LWC]) change in performance.