Postactivation Performance Enhancement of Amateur Boxers' Punch Force and Neuromuscular Performance Following 2 Upper-Body Conditioning Activities

Article *in* International Journal of Sports Physiology and Performance · September 2022

DOI: 10.1123/ijspp.2022-0159

Mitchell Finlay
Edge Hill University

Craig A. Bridge
Edge Hill University

Richard Page
Edge Hill University

INTERNATIONAL JOURNAL OF SPORTS PHYSIOLOGY AND PERFORMANCE

Post Activation Performance Enhancement of Amateur Boxers Punch Force and Neuromuscular Performance Following Two Upper-Body Conditioning Activities.

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2022-0159.R1
Manuscript Type:	Original Investigation
Date Submitted by the Author:	17-Jun-2022
Complete List of Authors:	Finlay, Mitchell; Edge Hill University, Sport & Physical Activity Bridge, Craig; Edge Hill University, Sport & Physical Activity Greig, Matt; Edge Hill University, Sport & Physical Activity Page, Richard; Edge Hill University, Sport & Physical Activity
Keywords:	athletic training, biomechanics, isometric, kinetics, strength training, physical performance

Post Activation Performance Enhancement of Amateur Boxers Punch Force and Neuromuscular Performance Following Two Upper-Body Conditioning Activities.

Abstract

Purpose: The purpose of this study was to assess the efficacy of upper-body punch-specific isometric (ISO) and elastic resistance (ER) conditioning activities (CA), on the punch force and neuromuscular performance of amateur boxers. Methods: Ten male senior elite amateur boxers (19.7 ± 1.2 years; height 180.9 ± 7.0 cm; mass 78.7 ± 9.6 kg) visited the laboratory on four separate occasions. Initially, the participants performed baseline physical tests comprising bench press one repetition maximum (BP1RM), and counter-movement jumps (CMJ). On the other 3 occasions, the boxers performed maximal punches against a vertically mounted force plate, and maximal CMJ, prior to and following an ISO or ER CA, and a control trial. Results: No interactions between CA x Time were found in all performance variables. As observed by mean changes, effect sizes (ES) and signal:noise (S:N) ratio, both the ISO and ER, but not the control trial, consistently produced small-to-moderate, worthwhile increases in punch force and rate of force development (RFD), with the greatest increases in performance typically observed in the ISO trial. No meaningful improvements were observed in CMJ performance in all trials, indicative of a localised PAPE effect. Conclusion: In conclusion, the ISO and ER CA's may be implemented in an amateur boxers warm-up to acutely enhance punch force variables, though the isometric punch appears to be the superior CA to improve punch-specific performance. The CA's used in the present study may also be relevant to other combat sports inclusive of a striking element.

Keywords

Boxing; pre-conditioning; resistance activity; warm-up; kinetics

Introduction

The inclusion of preparatory exercise in the form of a warm-up has been shown to reduce injury risk, and enhance subsequent athletic performance.[1,2] Perhaps the most renowned warm-up protocol used in sport, is RAMP (Raise-Activate-Mobilise-Potentiate), popularised by Jeffreys.[2] Such protocols aim to stimulate blood flow, increase muscle temperature, increase muscle and tendon compliance, and enhance free-coordinated movement amongst other physiological and biochemical responses.[1] Performance benefits may include increased rate of force development (RFD), reaction time, muscular strength and power, and increased oxygen delivery.[1,2] The 'potentiate' segment is responsible for increasing the intensity to that expected in competition, and inducing post-activation performance enhancement (PAPE), a phenomena whereby athletes can acutely enhance neuromuscular performance for several minutes via prior voluntary muscle activity.[3-7] Previous research shows that prior performance of compound lifts, resisted sprints, isometrics, plyometrics, and ballistic activity may have beneficial effects on subsequent athletic performance, beyond that of the warm-up alone.[3-7] The PAPE phenomenon has been attributed to several mechanisms, including; increased muscle temperature, increased muscle and muscle fibre water content, and changes in muscle activation.[4] It should be noted that individual differences in athletes' responsiveness to PAPE exists[8], for example, strength levels have been shown to be a modulating factor,[5] whilst strength and power levels are highly correlated with punch force in amateur boxers.[10] Therefore, the application of PAPE may present an opportunity to improve desirable qualities of an effective punch, such as peak force and RFD in responding boxers.[9,10]

Whilst the application of PAPE is a widely adopted practice, a recent study highlighted a lack of CA's applied in a typical amateur boxers pre-bout warm-up.[11] In that particular study, a large focus on activity such as shadow boxing, padwork, stretching and mobility was evident; however, only 19% of boxers reported including what would be considered a CA, based on previous literature.[3,5,6] Elite competitors were more likely to include this practice prior to competition, potentially due to the increased access to the knowledge and resources of performance practitioners. Another likely reason for the limited use of CA's by amateur boxers, might be the logistical constraints within the pre-competition environment, such as inadequate warm-up space and lack of equipment. When we consider the quick turnaround in-between bouts, even quicker with the rare occurrence of a stoppage, warm-up structure and timing present a challenge for the practitioner and coach.

In recognition of the biomechanical specificity often required between a CA and a performance task,[5] and the potential localised effect of PAPE[12], CA's that are primarily upper-body may be more useful for the amateur boxer. However, research on upper-body CA's have primarily included free-weight or fixed (e.g smith or cable machine) resistance exercise, typically comprising heavy loads.[3,6] Although many of the above are effective, they would not be compatible with an amateur boxing competition warm-up environment. Therefore, alternative methods of inducing PAPE must be developed for the amateur boxer.

Researchers have attempted to overcome the logistical barriers in combat sports by utilising plyometric, or elastic resistance activity as the primary CA[13-15] with promising results. The use of elastic resistance may increase force production during the whole range of motion in a given movement,[14] whilst the added resistance should not alter the movement technique. Again, this may be of increased importance when we consider the biomechanical specificity often observed between a successful CA, and the performance test or sporting action.[3,5] Therefore, it could be postulated that elasticated punches may be an appropriate CA to improve punch-specific performance. Another popular form of resistance activity is isometric activity. This activity involves contraction of the skeletal muscles without any external movement,[16,17] and can induce longer-term gains in dynamic athletic performance, albeit perhaps limited to movements at specific joint angles.[16,17] There may also be merit in utilising isometric activity to induce PAPE where the CA and subsequent task is similar.[3] Considering the increased biomechanical specificity with perhaps lower fatigue,[16-18] the potential to improve peak force and RFD,[3,16-18] and its easy application to a warm-up environment, a punch-specific isometric CA may be an effective method to induce PAPE in boxers.

Variations of ISO and ER activity in the development of punch performance is not uncommon in the physical preparation of boxers;[19] however, application to the pre-competition warm-up may present novel and logistically sound methods of enhancing punch-specific performance. Moreover, this method may not require substantial strength levels or experience in resistance training, both modulating factors.[5] The aim of this study, therefore, was to assess the acute performance enhancing effects of two punch-specific upper-body PAPE CA's (elastic resistance [ER]; isometric [ISO]), on the punch-specific performance of amateur boxers. A further aim was to explore whether the CA's could induce a non-localised PAPE effect on neuromuscular performance. It was hypothesised that the upper-body CA's would enhance subsequent punch performance to a greater extent than the control trial, and that performance enhancement would be limited to a localised effect.

Method

Design

This study comprised a within-subject repeated-measures cross-over design to assess whether two boxing-specific upper-body CA (ER and ISO), induce a PAPE effect on punch force variables and neuromuscular performance of male senior elite amateur boxers. Participants were required to attend the laboratory on four occasions, comprising an initial familiarisation and baseline physical testing session (Bench press and CMJ), followed by two separate experimental trials (ISO and ER), and a control trial (no CA). All experimental and control trials were randomised and interspersed by a minimum of 72-h Participants were asked to refrain from vigorous exercise and consumption of alcohol or stimulants for 48-h prior to each testing session.[20,21] In all trials, participants initially performed a standardised warm-up, immediately followed by the CA, or in the case of the control trial, rest. The dependent variables chosen to assess the efficacy of the CA's, were peak punch impact force, and RFD. To assess the potential global effects of the CA's, counter-movement jump (CMJ) height was also assessed. All the above have been used previously to assess boxers punch-specific and lower-body neuromuscular performance. [9,10,22]

Subjects

Ten male senior elite amateur boxers (19.7 ± 1.2 years; height 180.9 ± 7.0 cm; mass 78.7 ± 9.6 kg) took part in the study. Participant criteria required boxers to be over the age of 18, and currently competing as a senior elite boxer at the time of testing. The study was conducted during the amateur boxing season. Participants completed a comprehensive health screening procedure and confirmed that they were free of injury at the time of testing. All participants were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study. The current study was granted ethical approval by Edge Hill University (ETH2021-0058) and was conducted in accordance with the Helsinki Declaration.

Methodology

Initially, boxers completed a baseline physical testing and familiarisation trial, with the latter enabling the boxers to become accustomed to the two PAPE CA's, and performance tests. This trial also ensured the resistance load of the ER bands was individualised to each participant for the experimental trials, with visual observation of technique detriment (Classified as struggling to fully extend the band to end range at high velocity) monitored by the lead researcher. Thus, the ER band with the greatest resistance, where technique could be maintained, was chosen. For all trials, participants were advised to apply protective wraps in their typical way and wore their own, or were supplied with, velcro 12 Oz boxing gloves.[23] During all the experimental trials, participants initially performed standardised shadow boxing, dynamic activation and mobility exercises, and a single 3-minute round of the Boxing-specific Exercise Protocol (BSEP)[24] on a punch bag. Inclusion of a standardised warm-up in the intervention and control trials is recommended to determine whether the cause of the potential performance benefit was from the intervention itself. Inclusion of task-specific activity in the warm-up is also recommended to ensure ecological validity.[4] Prior to, and at every 1-minute interval of the BSEP round, participants performed punches at perceived progressive intensities (50%, 70%, 90%, and 100%)[9] to a vertically mounted force plate, with the latter used as baseline data. Baseline CMJ was also collected prior to the BSEP round.

Elastic resistance (ER) trial

The ER CA comprised 2 x 5 repetitions of maximal concentric jab and cross punches with ER, performed immediately at the end of the warm-up (Figure 2). Previous research has found similar frequency of elasticised combat CA enhances subsequent combat-specific performance.[13,14] The resistance band was anchored to a stationery object and wrapped around the participants hand (gloves off), with the band sitting between the thumb and index finger.

Isometric (ISO) maximal voluntary contraction (MVC) trial

The ISO CA comprised 3 x 3-second punch-specific MVC's against the force plate in both jab and cross stance (Figure 2). This duration was chosen as it may be an appropriate dosage to elicit PAPE, whilst minimising the risk of fatigue associated with longer durations.[25,26] Visual observation by the lead researcher ensured the participants were not leaning into the force plate, but applying maximum force in a ballistic manner, near end range.

Acknowledging the initial delayed presence of PAPE,[5] and anecdotal observations the time separating the end of a bout, and the ring walks for the subsequent bout, a period of 3-minutes interspersed the CA's and the performance tests. Likewise, 3-minutes rest followed the warm-up in the control trial. All performance tests were completed at baseline, 3-minutes post, and every 2-minutes thereafter until 13-minutes post, accommodating the typical PAPE time course found in the literature.[3,5] A schematic representation of the study design can be seen in figure 1.

Experimental measures

Punch force variables

Participants performed 2 repetitions of jab, cross, lead hook, and rear hook punches against a vertically mounted force plate (Bertec, Columbus, USA), with each punch type interspersed by 5s recovery. The force plate sampling at 2000 Hz, was vertically mounted to a custom-built steel apparatus and comprised custom high-density foam padding (72 x 42 x 10cm) enclosed in a rectangular case. The height of the force plate was manipulated according to each participants height. Force data was captured using a motion capture system (Qualysis, Inc. Sweden). Specifically, force signals were transferred to a AM6500 digital signal converter. Raw force data was exported to Visual 3D whereby a pipeline command identified the beginning and end of each punch with a minimum threshold of 200 N. Subsequently, data were exported to a large Microsoft Excel datasheet, whereby peak and mean impact forces, and maximal RFD for each punch type was analysed. Prior work by the current research group showed that the vertically mounted force plate demonstrates excellent within-session (ICC 0.955 - 0.991; 0.928 – 0.968) and good to excellent between-day reliability (ICC 0.894 – 0.981; 0.944 – 0.971) for absolute peak impact force and RFD variables, respectively. Data was less reliable when normalised to body mass, therefore absolute values were analysed in the present study.

Countermovement jump

Immediately after the punch trials at each interval, participants performed 2 maximal effort countermovement jumps (CMJ) (no arm-swing) via a photocell system (Optojump, Microgate, Bolzano, Italy) to assess any potential global PAPE effects on jump height performance. This method has shown adequate reliability ICC 0.98 (0.95 – 0.99) when assessing lower body impulse in amateur boxers.[22] Conducting two, rather than three repetitions, has shown similar reliability and may be less time consuming,[27] whilst also potentially limiting fatigue from repetitive testing. Peak and mean jump height (cm) at each testing interval was obtained.

Insert figure 1 about here

Insert figure 2 about here

Statistical analyses

An a priori power calculation confirmed that a sample size of 9 would be required to establish a statistical power of 0.80, $p < 0.05$. Initially, a Two-way repeated-measures ANOVA 3-x-7 (conditioning activity [CA] x time) was chosen as an appropriate parametric test to firstly explore interaction effects between trials and time. Where significant main effects and interactions were identified, post hoc pairwise comparisons with a Bonferroni correction were completed. For all significant main effects and interactions, 95% confidence intervals (CIs) for difference and partial eta squared (η^2) values are reported. To further assess the efficacy of the acute interventions, mean changes against the smallest worthwhile change (SWC), effect size (ES), and ratio were also used to further identify any practical or 'real change' in performance. Specifically, change scores at each time interval of all 3 conditions were compared to a previously determined SWC. A signal:noise (S:N) ratio was also calculated,[28] whereby the mean difference between baseline and each time-point, was divided by the SWC. Any mean difference that was greater than the SWC, or where the S:N ratio was > 1, was deemed a worthwhile or meaningful change. Effect sizes (Cohens *d*) were calculated by dividing the mean difference between baseline and each time interval, by the pooled SD, with the following thresholds applied; small (0.2), medium (0.5) and large (0.8) effects. The above analysis was performed on a custom-made spreadsheet created by the authors. All data are reported as mean ± SD, or ratio, unless otherwise stated.

Results

Baseline physical testing

Boxers bench press 1RM and CMJ jump height was 91.0 ± 17.5 kg, and 38.1 ± 2.5 cm, respectively.

No significant interactions between CA and time were found in any performance variables, across all trials. However, main effects for time were observed in all punches, except for the jab, and also for CMJ height.

Cross

For peak force, a significant main effect was observed for time (F 6, 54) = 10.612, $p < 0.0001$ $\eta^2 = 0.541$), increasing significantly from baseline (2499 N) to 5-minutes (+111N; 95%CI = 7 to 216 N; p = 0.034), 7-minutes (+ 142 N; 95%CI = 31 to 254 N; p = 0.010) and 9-minutes post (+146 N; 95%CI = 54 to 238 N; p = 0.002), and from 3-minutes post (2538 N) to 7-

minutes (+103 N; 95%CI = 24 to 183 N; p = 0.009) and 9-minutes post (+107 N; 95%CI = 13 to 200 N; p = 0.021). For average force, a significant main effect was observed for time (F 6, 54) = 7.775, p = < 0.0001; η^{2} = 0.463), increasing significantly from baseline (2439 N) to 5-minutes (+101 N; 95%CI = 16 to 187 N; p = 0.016), 7-minutes (+135 N; 95%CI = 49 to 221 N; p = 0.002) and 11-minutes post (+123 N; 95%CI = 8 to 238 N; p = 0.033), and from 3-minutes post (2458 N) to 7-minutes post (+117 N; 95%CI = 10 to 224 N; p = 0.029). Significant main effects were observed for time in peak (F 6, 54) = 4.776, p = 0.001 η^{2} = 0.347) and average (F 6,54) = 3.802, p = 0.003 η^{2} = 0.297) RFD; however, post hoc tests did not identify any significant increases across time points.

L Hook

For lead hook peak force, a significant main effect was observed for time (F 2.893, 26.039) = 4.272, p = 0.015; η^{2} = 0.322); however, post hoc tests did not identify any significant increases across time points. For average force, there was a significant main effect for time (F 2.658, 23.923) = 6.098, p = 0.004; η^{2} = 0.404), increasing significantly from baseline (2544 N) to 7-minutes post (+95 N, 95%CI = 8 to 181 N, p = 0.028), and 9-minutes post (+124 N, 95%CI = 6 to 241 N, p = 0.036), and from 3-minutes post (2565 N) to 9-minutes post (+103 N, 95%CI = 7 to 199 N, p = 0.033). A significant main effect was observed for time in peak RFD (F 6, 54) = 6.320, p <0.0001 η^{2} = 0.413), increasing significantly from baseline (267217 $N.s^{-1}$) to 7-minutes post (+16232 $N.s^{-1}$, 95%CI 1993 to 30471 $N.s^{-1}$, p = 0.022), and from 3-minutes post (271784 $N.s^{-1}$) to 7-minutes post (+11665 $N.s^{-1}$, 95%CI 1086 to 22244 N.s-1, p = 0.027). A significant main effect was also observed for time in average RFD (F 6, 54) = 6.811, p <0.0001 η^{2} = 0.431), increasing significantly from baseline (257508 $N.s^{-1}$) to 7-minutes (+16133 $N.s^{-1}$, 95%CI 883 to 31382 $N.s^{-1}$, p = 0.035) and 9-minutes post (+15163 $N.s^{-1}$, 95%CI 2476 to 27850 $N.s^{-1}$, p = 0.016), from 3-minutes post (261739 $N.s^{-1}$) to 7-minutes (+11902 $N.s^{-1}$, 95%CI 2680 to 21123 $N.s^{-1}$, p = 0.009) and 9-minutes post (+10932 $N.s^{-1}$, 95%CI 1076 to 20788 $N.s^{-1}$, p = 0.026), and from 5 mins post (264948 $N.s^{-1}$) to 9 mins post (+7723 $N.s^{-1}$, 95%CI 1711 to 13734 $N.s^{-1}$, p = 0.009).

R Hook

A significant main effect was observed for time (F 6, 54) = 6.262, p = <0.0001 η^{2} = 0.410), with absolute peak force increasing significantly from baseline (2673 N) to 7-minutes (+148 N; 95%CI = 25 to 270 N; p = 0.015), and 9-minutes post (+162 N; 95%CI = 61 to 262 N; p = 0.002). For rear hook average force, there was also a significant main effect for time (F 6, 54) = 5.304, p <0.0001 η^{2} = 0.371), with absolute average force increasing significantly from baseline (2620 N) to 9-

minutes post (+140 N, 95%CI = 37 to 244 N, p = 0.006). A significant main effect was observed for time in peak RFD (F 3.899, 35.088) = 6.767, $p < 0.0001$ $\eta^2 = 0.429$), increasing significantly from baseline (309181 $N.s^{-1}$) to 7-minutes (+23713 $N.s^{-1}$, 95%CI 6100 to 41325 $N.s^{-1}$, p = 0.007) and 9-minutes post (+19746 $N.s^{-1}$, 95%CI 600 to 38892 $N.s^{-1}$, p = 0.041). A significant main effect was also observed for time in average RFD (F 6, 54) = 7.152, $p < 0.0001$ $\eta^2 = 0.443$), increasing significantly from baseline (297117 $N.s^{-1}$) to 7-minutes (+21734 $N.s^{-1}$, 95%CI 5785 to 37683 $N.s^{-1}$, p = 0.006) and 11-minutes post (+16785 $N.s^{-1}$, 95%CI 1190 to 32380 $N.s^{-1}$, p = 0.031), and from 3-minutes post (300581 N.s-1) to 9-minutes post (+17121 $N.s^{-1}$, 95%CI 1148 to 33094 $N.s^{-1}$, p = 0.032).

Mean changes, ES, and S:N ratio

Mean changes from baseline, inclusive of effect sizes and S:N ratios for punch force and RFD, are presented in table 1, with the same data for CMJ presented in table 2. Further, changes from baseline in peak punch force and peak RFD are plotted against the SWC in figures 3 and 4, respectively.

Insert table 1 about here

Insert table 2 about here

Insert figure 3 about here

Insert figure 4 about here

Discussion

This study aimed to assess the efficacy of two upper-body CA's performed in the warm-up, in acutely enhancing punch-specific and neuromuscular performance of senior elite amateur boxers. In agreement with the studies hypotheses, both CA's typically produced worthwhile improvements in punch force and RFD. Overall, the ISO CA typically produced the greatest acute performance enhancement, and across a longer 'window'. The results from the ANOVA, and the ES and S:N data in table 1, suggest most performance variables peaked between 7 and 9-minutes, though this would be varied between individuals. The findings of this study suggest that a punch-specific ISO CA may be a more useful activity to perform during the warm-up to acutely enhance punch performance in amateur boxing. Regarding the secondary aim of the study, there were no instances where jump height exceeded the SWC, only a localised effect from the upper-body CA's was observed. Boxers in the present study produced the greatest punch force and RFD in hook punches (Rear hook range 2628 - 2898 N, 303132 - 354817 $N.s^{-1}$; Lead hook range 2556 - 2798 N, 262160 - 298520 $N.s^{-1}$), with the former consistent with previous literature on elite level boxers.[9,29]

The necessity for biomechanical specificity when choosing a CA is well established. [3,5,6] Both the ISO and ER CA's performed in the present study were chosen for their practicality and their specificity to a punching action. Both CA's induced acute performance benefits, consistent with previous research where the CA shares similar technique and intensity with the performance task.[3,13,14] The familiarity with the movement could also perhaps negate the issue of strength levels being a modulating factor to PAPE, often observed in more traditional forms of CA, such as weightlifting or powerlifting techniques.[5] The punch-specific ISO CA in the present study offers the opportunity for an MVC at specific joint angles in a ballistic manner, with such activity shown to potentially improve variables such as RFD and velocity in more long-term training research,[16,17] and acute improvements in ball striking sports.[3] The increases in punch force and RFD following the ISO CA in the present study, may be due to increased neural activity; however, this was not analysed in the present study. There is evidence of a double "peak" in muscle activity during striking techniques, whereby "stiffening" of the body at impact occurs, thus creating effective mass and reduced energy loss.[30] Previous authors have encouraged the use of isometric contractions to improve this end range "stiffening" in boxers.[19] Whilst this may relate to more longer-term adaptations, it could be plausible that the isometric punch CA in the present study, had an acute effect on the body's ability to stiffen upon impact, thus produce greater forces in subsequent punches. Interestingly, the largest changes in peak punch force and RFD following the ISO CA, as observed by the ES and S:N ratios, occurred in the cross punch. This may be attributed to the straight nature (Jab and cross) of the ISO punch holds, where participants were instructed to apply maximal force, quickly. Another interesting finding is the drop off in hook punch force and RFD at 13-minutes following the ISO CA, which was not observed in the straight punches. Again, this may be attributed to the straight punches used in the ISO CA.

It is not clear why the ISO CA induced improvements in punch performance of a larger magnitude, than observed in the ER CA. Indeed, attributing any increases in performance to specific mechanisms may be a difficult proposition, as the exact mechanisms of PAPE remain unclear. We know that whilst PAPE and fatigue may coexist, there is somewhat of a trade-off, often highlighted by varied results depending on the CA, intensity, and recovery time administered.[3-5] Likewise, the potentially lower energy demand and muscular fatigue associated with isometric activity, compared to dynamic activity[16,17], and specifically elastic resistance activity[18] has been established. Therefore, it could also be postulated that the ISO CA performed in the present study, resulted in a more favourable balance towards PAPE. Likewise, this may be due to increased neural activation or motor recruitment in the ISO CA, though this is speculative. Nonetheless, the ISO CA typically presented performance enhancement first, and consistently elicited a 'larger window' of PAPE, whereby worthwhile increases in punch force and RFD were observed across more time points. The latter point may have implications for sporting competition that comprises longer duration, longer rest periods from warm-up to competition, or where unexpected delays may occur.

Whilst the ER CA typically induced an inferior PAPE response than that observed following the ISO CA, our findings demonstrate its efficacy in bringing about worthwhile changes to punch force, and less so, RFD in senior elite amateur boxers. Previous research found a 3.3% significant increase in roundhouse kick velocity (measured as the linear velocity of the kicking foot's toe in taekwondo athletes) following an elasticated kicking CA of 10 efforts, compared to a control trial of kicking with no elastic resistance.[14] The authors also found a significant increase in rectus femoris activation following the elastic resistance condition, perhaps due to the increase of force production throughout a whole range of motion.[14] This increased neural activation may, again, partly explain the presence of PAPE. Likewise, in a study on judokas, resistance band pulls and standing broad jumps elicited significantly greater power output in the high pull test when compared to a control trial.[13] In the present study, worthwhile changes in punch force were observed in the cross and both hook punches following the ER CA, though RFD performance increases were limited to hook punches, and in those instances, RFD was only slightly above the SWC (0.2). Performance in most tests was maintained, or increased during the control trial, suggesting the prior standardised warm-up, or indeed the performance of the testing battery at regular intervals, may have at least preserved performance. It is worth noting that the repetitive testing at regular intervals may also have had a summation effect, thus supressing PAPE, though the authors aimed to minimise this as much as possible, by including only 2 repetitions of each test at each time interval. However, instances where the control trial elicited meaningful changes was extremely rare, again highlighting the efficacy of the two CA's in the present study.

The requirement for biomechanical specificity between the CA and subsequent activity is a common theme throughout this paper; however, we must also consider the substantial contribution of the lower limbs to force production in a punch.[10] Our findings showed no worthwhile increases in CMJ performance following both CA's, which would suggest that any performance enhancement is limited to a localised effect. In the aforementioned study in judokas,[13] broad jumps and resistance band pulls induced significant power output gains in a judo-specific pull test when compared to a control trial, whereas broad jumps in isolation yielded only non-significant increases. Further research is needed in this area to identify the efficacy of multiple CA's, both upper-body and lower-body in nature, on localised and non-localised PAPE.

The optimal recovery period following both CA's was seemingly between 7- 9 minutes, though as expected, this varied across individual boxers, and across trials. This optimal recovery time of a group of athletes falls within the range proposed by previous reviews.[3,5] Opposingly, the initial minutes following a CA may see little change, or even detriments to performance, [3-5] perhaps due to the presence of fatigue. Again, this is highly individualised.

Practical applications

We believe the two upper-body CA's in the present study can be easily applied in a competitive warm-up environment, thus, avoiding logistical difficulties often observed in PAPE research. Knowledge of the typical time intervals between bouts, and the PAPE time course of a responding individual athlete, may allow the practitioner to structure the CA more optimally within the warm-up. This may enable boxers to be at a 'peak' state at the start of a bout, or practitioners could aim for any performance enhancement to be present for as much of the bout as possible. Future research should apply a more individualised approach using the methods of the present study and apply this to a bout scenario, to progress the real-world application even further.

Conclusion

In conclusion, this study has shown that performing an ISO or ER CA in a warm-up, induces meaningful changes in the punch performance of senior elite amateur boxers. Consistently greater increases in performance, as observed by greater ES and S:N ratios, showed the ISO CA as the more efficacious CA in inducing acute performance benefits. Across all trials, no meaningful changes were found in CMJ performance, suggesting that whilst the ISO and ER CA were successful in improving performance, this was limited to a localised effect. The data suggest amateur boxers could perform isometric or elasticated punches in the pre-bout warm-up to acutely improve punch force and RFD. Findings from this study may also be relevant to other combat sports with a striking element. Future work by researchers and practitioners should focus on an individualised approach, in the context of an amateur bout.

References

1. Bishop D. Warm Up I. Sports Med. 2003; 33: 483-498.
2. Jeffreys I. Warm-up revisited: The ramp method of optimizing warm-ups. *Professional Strength and Conditioning*. 2007; 6: 12-18.
3. Finlay, M.J., Bridge, C.A., Greig, M and Page, R. M. Upper-Body Post-activation Performance Enhancement for Athletic Performance: A Systematic Review with Meta-analysis and Recommendations for Future Research. *Sports Med.* 2022; 52: 847–871.
4. Blazevich, A. J and Babault, N. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. *Front Physiol*. 2019; 10: https://doi.org/10.3389/fphys.2019.01359.
5. Seitz, L. B and Haff, G. Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: a systematic review with meta-analysis. *Sports Med.* 2016; 46: 231-240.
6. Ng, C. Y., Chen, S. E and Lum, D. Inducing postactivation potentiation with different modes of exercise. *Strength Cond J*. 2020; 42: 63-81.

7. Boullosa, D.A. Post-activation performance enhancement strategies in sport: a brief review for practitioners. *Hum Mov.* 2021; 22: 101–109.
8. Healy, R and Comyns, T. Application of postactivation potentiation methods to improve sprint speed. *Strength Cond J.* 2017; 39: 1-9.
9. Dunn, E., Humberstone, C., Iredale, K and Blazevich, A. A damaging punch: assessment and application of a method to quantify punch performance. *Transl Sports Med*. 2019; 2: 146-152.
10. Loturco, I., Nakamura, F. Y., Artioli, G. G., Kobal, R., Kitamura, K., Cal Abad, C. C., Cruz, I. F., Romano, F., Pereira, L. A and Franchini, E. Strength and Power Qualities Are Highly Associated With Punching Impact in Elite Amateur Boxers. *J Strength Cond Res*. 2016; 30: 109–116.
11. Finlay, M. J., Page, R. M., Greig, M and Bridge, C. A. The prevalence of pre-conditioning and recovery strategies in senior elite and non-elite amateur boxing. *The Physsportsmed*, 1–9. https://doi.org/10.1080/00913847.2021.1931525
12. Laskin, G., Talpey, S and Gregory, R. The effects of an upper body conditioning stimulus on lower body post-activation performance enhancement (PAPE): a pilot study. *International Journal of Strength and Conditioning*. 2021; 1. https://doi.org/10.47206/ijsc.v1i1.64.
13. Lum D. Effects of various warm-up protocol on special judo fitness test performance. *J Strength Cond Res*. 2019; 33: 459-465.
14. Aandahl, H. S., Von Heimburg, E and Van den Tillaar, R. Effect of postactivation potentiation induced by elastic resistance on kinematics and performance in a roundhouse kick of trained martial arts practitioners. *J Strength Cond Res*. 2018; 32: 990-996.
15. Santos, J. F., Valenzuela, T. H., and Franchini, E. (2015). Can different conditioning activities and rest intervals affect the acute performance of taekwondo turning kick? *J Strength Cond Res*. 2015; 29: 1640–1647.
16. Oranchuk, D. J., Storey, A. G., Nelson, A. R and Cronin, J. B. Isometric training and long-term adaptations: Effects of muscle length, intensity, and intent: A systematic review. *Scand J Med Sci Sports*. 2019; 29: 484–503.
17. Lum, D and Barbosa, T. M. Brief Review: Effects of Isometric Strength Training on Strength and Dynamic Performance. *Int J Sports Med*. 2019; 40: 363–375.
18. Grosprêtre, S., Gimenez, P., Mourot, L., and Coratella, G. Elastic band exercise induces greater neuromuscular

fatigue than phasic isometric contractions. *J Electromyogr Kinesiol*. 2019; 47: 113-120.

19. Ruddock, A. D., Wilson, D. W., Thompson, S. W., Hembrough, D., Winter, E. M. Strength and Conditioning for Professional Boxing. *Strength Cond J*. 2016; 38: 81-90.
20. Tunnicliffe, J. M., Erdman, K. A., Reimer, R. A., Lun, V and Shearer, J. Consumption of dietary caffeine and coffee in physically active populations: physiological interactions. *Appl Physiol Nutr Metab*. 2008; 33: 1301-1311.
21. Shirreffs, S. M and Maughan, R. J. The effect of alcohol on athletic performance. *Curr Sports Med Rep*. 2006; 5: 192-196.
22. Wilson, D. C., Ruddock, A. D., Ranchordas, M. K., Thompson, S. W and Rogerson, D. Physical profile of junior and senior amateur boxers. *J Phys Edu Sport*. 2020; 20: 3452-3459.
23. England Boxing 2022. *England Boxing Rule Book - England Boxing*. 2022 [online] Available at: https://www.englandboxing.org/rules-regs-resources/rule-book/. [Accessed 2 February 2022].
24. Finlay, M., Greig, M., Page, R. Quantifying the physical response to a contemporary amateur boxing simulation. *J Strength Cond Res*. 2018; 32: 1005-1012.
25. French, D. N., Kraemer, W. J and Cooke, C. B. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J strength Cond Res*. 2003; *17*: 678–685.
26. Rixon, K. P., Lamont, H. S and Bemben, M. G. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *J strength Cond Res*. 2007; 21: 500–505.
27. Roe, G., Darrall-Jones, J., Till, K., Phibbs, P., Read, D., Weakley, J and Jones, B. Between-Days Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. *Int J Sports Physiol Perform*. 2016; 11: 581–586.
28. Fitzpatrick, J. F., Akenhead, R., Russell, M., Hicks, K. M and Hayes, P. M. Sensitivity and reproducibility of a fatigue response in elite youth football players. *Science and Medicine in Football*. 2019; 3: 214-220.
29. Smith M. S. Physiological profile of senior and junior England international amateur boxers. *J Sports Sci Med*. 2006; *5*(CSSI): 74–89.
30. McGill, S. M., Chaimberg, J. D., Frost, D. M and Fenwick, C. M. Evidence of a double peak in muscle activation to enhance strike speed and force: an example with elite mixed martial arts fighters. *J Strength Cond Res*. 2010; 24: 348–357.

Figure Captions

Figure 1 Schematic representation of the experimental measures across 3 trials. CA = Conditioning activity; ISO = Isometric; ER = Elastic resistance; CON = Control; MVC = Maximal voluntary contraction.

Figure 2 Figure 2 Example techniques of the ISO (left) and ER CA's (right). CA = Conditioning activity; ISO = Isometric; ER = Elastic resistance.

Figure 3 Changes from baseline in peak punch impact force for all punches (a = jab, b = cross, c = lead hook, d = rear hook) under all 3 conditions, across 6 time-points. Grey dash lines represent SWC = Smallest worthwhile change thresholds (0.2) and (0.6); N = Newtons.

Figure 4 Changes from baseline in peak RFD for all punches (a = jab, b = cross, c = lead hook, d = rear hook) under all 3 conditions, across 6 time-points. Grey dash lines represent SWC = Smallest worthwhile change thresholds (0.2) and (0.6); $N.s^{-1}$ = Newtons per second.

Table 1 Mean differences, ES, and S:N ratio of punch force variables between pre-CA, and at several time points post-CA.

	Variable	Trial	SWC (0.2; 0.6)	Pre	Δ pre-3; ES	Δ pre-5; ES	Δ pre-7; ES	Δ pre-9; ES	Δ pre-11; ES	Δ pre-13; ES	S:N pre-3 (0.2; 0.6)	S:N pre-5	S:N pre-7	S:N pre-9	S:N pre-11	S:N pre-13
JAB	PF Peak (N)	ISO	112;	1714	-02; 0.00	-12; -0.02	31; 0.05	69; 0.11	41; 0.06	61; 0.10	-0.02; -0.01	-0.11; -0.04	0.27; 0.05	0.61; 0.20	0.37; 0.12	0.55; 0.18
		ER	336	1723	-36; -0.07	01; 0.00	24; 0.04	59; 0.11	64; 0.12	53; 0.10	-0.32; -0.11	0.01; 0.00	0.22; 0.07	0.53; 0.18	0.57; 0.19	0.47; 0.16
		CON		1756	-05; -0.01	01; 0.00	10; 0.02	13; 0.02	54; 0.10	14; 0.03	-0.04; -0.01	0.00; 0.00	0.09; 0.03	0.12; 0.04	0.48; 0.16	0.13; 0.04
	PF Ave (N)	ISO		1616	30; 0.05	29; 0.05	75; 0.13	95; 0.16	72; 0.11	53; 0.09	0.27; 0.09	0.26; 0.09	0.67; 0.22	0.85; 0.28	0.64; 0.21	0.48; 0.16
		ER		1673	-28; -0.05	07; 0.01	37; 0.07	61; 0.11	51; 0.09	39; 0.07	-0.25; -0.08	0.06; 0.02	0.33; 0.11	0.54; 0.18	0.45; 0.15	0.35; 0.12
		CON		1700	12; 0.02	07; 0.01	22; 0.04	24; 0.04	59; 0.10	22; 0.04	0.10; 0.03	0.06; 0.02	0.20; 0.07	0.21; 0.07	0.52; 0.17	0.19; 0.06
	RFD Peak ($N.S^{-1}$)	ISO	7714;	119869	-886; -0.02	2768; 0.07	2074; 0.05	2051; 0.05	1923; 0.05	8208; 0.20	-0.11; -0.04	0.36; 0.12	0.27; 0.09	0.27; 0.09	0.25; 0.08	**1.06**; 0.35
		ER	23143	125578	-4001; -0.09	1026; 0.02	-1664; -0.03	834; 0.02	-149; 0.00	-1102; -0.02	-0.52; -0.17	0.13; 0.04	-0.22; -0.07	0.11; 0.04	-0.02; -0.01	-0.14; -0.05
		CON		129809	2111; 0.04	-1021; -0.02	2962; 0.06	2288; 0.04	4927; 0.09	-1454; -0.03	0.27; 0.09	-0.13; -0.04	0.38; 0.13	0.30; 0.10	0.64; 0.21	-0.19; -0.06
	RFD Ave ($N.S^{-1}$)	ISO		112782	2102; 0.06	4422; 0.12	4174; 0.11	3655; 0.09	4626; 0.12	9190; 0.23	0.27; 0.09	0.57; 0.19	0.54; 0.18	0.47; 0.16	0.60; 0.20	**1.19**; 0.40
		ER		120568	-1593; -0.04	337; 0.01	-673; -0.01	667; 0.02	-96; 0.00	-781; -0.02	-0.21; -0.07	0.04; 0.01	-0.09; -0.03	0.09; 0.03	-0.01; 0.00	-0.10; -0.03
		CON		124311	4138; 0.09	1003; 0.02	5742; 0.12	3147; 0.06	4817; 0.10	1710; 0.04	0.54; 0.18	0.13; 0.04	0.74; 0.25	0.41; 0.14	0.62; 0.21	0.22; 0.07
CROSS	PF Peak (N)	ISO	115;	2452	105; 0.18	167; 0.29	226; 0.42	211; 0.38	198; 0.36	199; 0.36	0.91; 0.31	**1.46**; 0.49	**1.97**; 0.66	**1.84**; 0.61	**1.73**; 0.58	**1.73**; 0.58
		ER	344	2532	-63; -0.11	85; 0.16	136; 0.24	157; 0.30	109; 0.21	38; 0.07	-0.55; -0.18	0.74; 0.25	**1.19**; 0.40	**1.37**; 0.46	0.95; 0.32	0.33; 0.11
		CON		2513	75; 0.16	81; 0.18	64; 0.14	68; 0.15	119; 0.27	67; 0.15	0.65; 0.22	0.70; 0.24	0.55; 0.19	0.59; 0.20	**1.03**; 0.35	0.58; 0.19
	PF Ave (N)	ISO		2389	78; 0.14	153; 0.26	208; 0.39	156; 0.29	177; 0.33	153; 0.30	0.68; 0.23	**1.33**; 0.44	**1.81**; 0.61	**1.35**; 0.45	**1.54**; 0.52	**1.33**; 0.44
		ER		2461	-55; -0.10	80; 0.15	134; 0.24	152; 0.29	103; 0.19	37; 0.07	-0.48; -0.16	0.69; 0.23	**1.17**; 0.39	**1.32**; 0.44	0.90; 0.30	0.32; 0.11
		CON		2469	32; 0.07	72; 0.16	62; 0.13	49; 0.11	88; 0.20	58; 0.13	0.28; 0.09	0.62; 0.21	0.54; 0.18	0.43; 0.14	0.77; 0.26	0.50; 0.17
	RFD Peak ($N.S^{-1}$)	ISO	12758;	195853	17754; 0.29	36842; 0.51	43594; 0.75	48472; 0.76	39947; 0.66	41813; 0.71	**1.39**; 0.46	**2.89**; 0.96	**3.42**; **1.14**	**3.80**; **1.27**	**3.13**; **1.04**	**3.28**; **1.09**
		ER	38275	209753	-11011; -0.16	6234; 0.09	7436; 0.11	10161; 0.16	-807; -0.01	538; 0.01	-0.86; -0.29	0.49; 0.16	0.58; 0.19	0.80; 0.27	-0.06; -0.02	0.04; 0.01
		CON		212520	12736; 0.19	16482; 0.25	10462; 0.16	12008; 0.18	6704; 0.11	7498; 0.12	1.00; 0.33	**1.29**; 0.43	0.82; 0.27	0.94; 0.31	0.53; 0.18	0.59; 0.20
	RFD Ave ($N.S^{-1}$)	ISO		186552	15309; 0.28	33413; 0.50	36525; 0.68	34080; 0.60	37768; 0.68	33474; 0.64	**1.20**; 0.40	**2.62**; 0.87	**2.86**; 0.95	**2.67**; 0.89	**2.96**; 0.99	**2.62**; 0.87
		ER		199457	-8759; -0.13	7420; 0.12	8537; 0.13	9506; 0.16	-1050; -0.02	437; 0.01	-0.69; -0.23	0.58; 0.19	0.67; 0.22	0.75; 0.25	-0.08; -0.03	0.03; 0.01
		CON		199539	9791; 0.17	14908; 0.25	11858; 0.20	11104; 0.19	7320; 0.13	8045; 0.14	0.77; 0.26	**1.17**; 0.39	0.93; 0.3	0.87; 0.29	0.57; 0.19	0.63; 0.21
L HOOK	PF Peak (N)	ISO	114;	2556	30; 0.06	91; 0.17	167; 0.33	157; 0.29	140; 0.26	105; 0.20	0.26; 0.09	0.80; 0.26	**1.46**; 0.49	**1.38**; 0.46	**1.23**; 0.41	0.92; 0.31
		ER	343	2627	21; 0.04	48; 0.10	31; 0.06	171; 0.35	98; 0.19	08; 0.01	0.18; 0.06	0.42; 0.14	0.27; 0.09	**1.50**; 0.50	0.86; 0.29	0.07; 0.02
		CON		2639	25; 0.06	31; 0.07	42; 0.10	56; 0.13	55; 0.13	14; 0.03	0.22; 0.07	0.27; 0.09	0.37; 0.12	0.49; 0.16	0.48; 0.16	0.13; 0.04
	PF Ave (N)	ISO		2488	18; 0.03	110; 0.20	179; 0.33	146; 0.26	155; 0.28	115; 0.21	0.16; 0.05	0.95; 0.32	**1.56**; 0.52	**1.27**; 0.42	**1.35**; 0.45	1.00; 0.34
		ER		2562	23; 0.04	48; 0.09	52; 0.09	160; 0.31	93; 0.18	36; 0.07	0.20; 0.07	0.42; 0.14	0.45; 0.1	**1.39**; 0.46	0.81; 0.27	0.31; 0.10
		CON		2582	22; 0.05	45; 0.11	53; 0.13	65; 0.15	59; 0.14	45; 0.10	0.19; 0.06	0.39; 0.13	0.46; 0.16	0.57; 0.19	0.51; 0.17	0.39; 0.13
	RFD Peak ($N.S^{-1}$)	ISO	17971;	269568	3079; 0.04	13881; 0.17	28952; 0.34	15902; 0.18	19713; 0.23	14773; 0.17	0.17; 0.06	0.77; 0.26	**1.61**; 0.54	0.88; 0.29	**1.10**; 0.37	0.82; 0.27
		ER	53912	262388	7962; 0.10	4930; 0.06	15032; 0.18	20955; 0.27	13962; 0.18	-228; 0.00	0.44; 0.15	0.27; 0.09	0.84; 0.28	**1.17**; 0.39	0.78; 0.26	-0.01; 0.00
		CON		269694	2661; 0.03	3277; 0.04	4712; 0.06	7228; 0.09	7983; 0.10	-1543; -0.02	0.15; 0.05	0.18; 0.06	0.26; 0.09	0.40; 0.13	0.44; 0.15	-0.09; -0.03
	RFD Ave ($N.S^{-1}$)	ISO		258073	5713; 0.06	14905; 0.17	30066; 0.35	21096; 0.24	19897; 0.23	18161; 0.20	0.32; 0.11	0.83; 0.28	**1.67**; 0.56	**1.17**; 0.39	**1.11**; 0.37	**1.01**; 0.34
		ER		255553	5857; 0.07	3637; 0.05	12861; 0.16	19139; 0.24	9990; 0.12	2651; 0.03	0.33; 0.11	0.20; 0.07	0.72; 0.24	**1.07**; 0.36	0.56; 0.19	0.15; 0.05
		CON		258897	1123; 0.02	3779; 0.05	5470; 0.07	5254; 0.07	7522; 0.10	316; 0.00	0.06; 0.02	0.21; 0.07	0.30; 0.10	0.29; 0.10	0.42; 0.14	0.02; 0.01
R HOOK	PF Peak (N)	ISO	120;	2661	55; 0.10	128; 0.24	231; 0.44	185; 0.34	227; 0.44	62; 0.11	0.46; 0.15	**1.07**; 0.36	**1.92**; 0.64	**1.54**; 0.52	**1.89**; 0.63	0.51; 0.17
		ER	359	2690	58; 0.10	177; 0.32	177; 0.30	208; 0.36	114; 0.19	77; 0.13	0.48; 0.16	**1.47**; 0.49	**1.47**; 0.49	**1.73**; 0.58	0.95; 0.32	0.64; 0.21
		CON		2668	17; 0.03	118; 0.22	35; 0.07	91; 0.18	59; 0.12	64; 0.13	0.14; 0.05	0.98; 0.33	0.29; 0.10	0.76; 0.25	0.49; 0.16	0.54; 0.18
	PF Ave (N)	ISO		2620	35; 0.06	106; 0.19	177; 0.32	164; 0.28	133; 0.24	23; 0.04	0.29; 0.10	0.89; 0.30	**1.48**; 0.49	**1.37**; 0.46	**1.11**; 0.37	0.19; 0.06
		ER		2628	42; 0.07	112; 0.19	151; 0.25	196; 0.33	123; 0.21	65; 0.11	0.35; 0.12	0.94; 0.31	**1.26**; 0.42	**1.63**; 0.55	**1.02**; 0.34	0.54; 0.18
		CON		2612	15; 0.03	79; 0.15	12; 0.02	61; 0.12	58; 0.11	67; 0.13	0.12; 0.04	0.65; 0.22	0.10; 0.03	0.51; 0.17	0.48; 0.16	0.56; 0.19
	RFD Peak ($N.S^{-1}$)	ISO	21422;	311258	6020; 0.06	28650; 0.30	43560; 0.46	26545; 0.28	29332; 0.32	10539; 0.11	0.28; 0.09	**1.34**; 0.45	**2.03**; 0.68	**1.24**; 0.41	**1.37**; 0.46	0.49; 0.16
		ER	64266	311063	-1813; -0.02	7900; 0.08	16851; 0.17	17553; 0.18	11954; 0.12	1273; 0.01	-0.08; -0.03	0.37; 0.12	0.79; 0.26	0.82; 0.27	0.56; 0.19	0.06; 0.02
		CON		305223	-2091; -0.02	15375; 0.17	10727; 0.12	15140; 0.17	3383; 0.04	10895; 0.12	-0.10; -0.03	0.72; 0.24	0.50; 0.17	0.71; 0.24	0.16; 0.05	0.51; 0.17
	RFD Ave ($N.S^{-1}$)	ISO		298412	9393; 0.09	30633; 0.32	37813; 0.39	29293; 0.30	26433; 0.28	7462; 0.07	0.44; 0.15	**1.43**; 0.48	**1.77**; 0.59	**1.37**; 0.46	**1.23**; 0.41	0.35; 0.12
		ER		294485	4026; 0.04	11210; 0.11	21980; 0.21	25638; 0.25	20120; 0.20	5784; 0.06	0.19; 0.06	0.52; 0.17	**1.03**; 0.34	**1.20**; 0.40	0.94; 0.31	0.27; 0.09
		CON		298454	-3026; -0.03	9954; 0.11	5410; 0.06	6825; 0.08	3803; 0.04	6879; 0.08	-0.14; -0.05	0.46; 0.15	0.25; 0.08	0.32; 0.11	0.18; 0.06	0.32; 0.11

Ave = Average; CA = Conditioning activity; CON = Control; ER = Elastic resistance; ES = Effect size; ISO = Isometric; N = Newtons; $N.s^{-1}$ = Newtons per second; PF = Punch force; RFD = Rate of force development; SWC = Smallest worthwhile change; S:N = Signal to noise ratio; Δ = change in mean. Bold and underlined values highlight a S:N of ≥ 1.

Table 2 Mean differences, ES, and S:N ratio of punch force variables between pre-CA, and at several time points post-CA.

			SWC (0.2; 0.6)	Pre	Δ pre-3; ES	Δ pre-5; ES	Δ pre-7; ES	Δ pre-9; ES	Δ pre-11; ES	Δ pre-13; ES	S:N pre-3 (0.2; 0.6)	S:N pre-5	S:N pre-7	S:N pre-9	S:N pre-11	S:N pre-13
	JH Peak	ISO	0.8;	35.3	0.2; 0.04	-0.1; -0.01	0.3; 0.08	0.1; 0.02	-0.3; -0.08	0.2; 0.04	0.20; 0.07	-0.06; -0.02	0.42; 0.14	0.09; 0.03	-0.34; -0.11	0.22; 0.07
	(cm)	ER	2.4	35.0	0.2; 0.06	0.2; 0.05	0.5; 0.16	0.5; 0.15	-0.3; -0.08	0.4; 0.13	0.24; 0.08	0.20; 0.07	0.68; 0.23	0.68; 0.23	-0.33; -0.11	0.53; 0.18
		CON		35.7	-0.1; -0.03	-0.1; -0.03	0.4; 0.13	0.1; 0.02	-0.5; -0.18	-0.08; -0.08	-0.11; -0.04	-0.11; -0.04	0.48; 0.16	0.09; 0.03	-0.65; -0.22	-0.27; -0.09
	JH Ave	ISO		35.0	-0.04; -0.1	-0.44; -0.10	-0.08; -0.02	-0.12; -0.03	-0.44; -0.12	0.13; 0.04	-0.05; -0.02	-0.55; -0.18	-0.10; -0.03	-0.15; -0.05	-0.55; -0.18	0.17; 0.06
	(cm)	ER		34.6	-0.11; -0.03	-0.17; -0.05	0.40; 0.13	0.25; 0.08	-0.18; -0.06	0.35; 0.11	-0.14; -0.05	-0.21; -0.07	0.50; 0.17	0.32; 0.11	-0.23; -0.08	0.43; 0.14
C		CON		35.4	-0.21; -0.07	-0.13; -0.04	0.16; 0.06	-0.01; 0.00	-0.52; -0.17	-0.36; -0.12	-0.27; -0.09	-0.16; 0.05	0.20; 0.07	-0.01; 0.00	-0.65; -0.22	-0.45; - 0.15
M J	FT Peak	ISO	0.006;	0.536	0.001; 0.04	0.000; -0.01	0.002; 0.07	-0.001; -0.03	-0.002; -0.07	0.002; 0.06	0.22; 0.07	-0.03; -0.01	0.40; 0.13	-0.18; -0.06	-0.33; -0.11	0.30; 0.09
	(ms)	ER	0.019	0.534	0.002; 0.06	0.001; 0.05	0.004; 0.17	0.004; 0.16	-0.002; -0.07	0.006; 0.25	0.27; 0.08	0.23; 0.07	0.72; 0.23	0.70; 0.22	-0.30; -0.09	0.90; 0.34
		CON		0.539	-0.001; -0.03	-0.001; -0.03	0.003; 0.13	0.000; 0.02	-0.004; -0.17	-0.001; -0.03	-0.12; -0.04	-0.10; -0.03	0.48; 0.15	0.07; 0.02	-0.63; -0.20	-0.12; -0.04
	FT Ave	ISO		0.534	0.000; 0.00	-0.023; -0.43	-0.001; -0.03	-0.001; -0.03	-0.003; -0.11	0.001; 0.04	0.06; 0.02	-3.75; -1.18	-0.18; -0.06	-0.17; -0.05	-0.52; -0.16	0.18; 0.06
	(ms)	ER		0.531	0.000; 0.00	-0.002; -0.06	0.003; 0.12	0.002; 0.07	-0.001; -0.06	0.003; 0.11	0.00; 0.00	-0.28; -0.09	0.50; 0.16	0.32; 0.10	-0.23; -0.07	0.45; 0.14
		CON		0.537	-0.002; -0.07	-0.001; -0.03	0.001; 0.06	0.000; 0.02	-0.004; -0.17	-0.002; -0.11	-0.25; -0.08	-0.13; -0.04	0.23; 0.07	0.07; 0.02	-0.63; -0.20	-0.40; -0.13

Ave = Average; CA = Conditioning activity; cm = centimetres; CON = Control; ER = Elastic resistance; ES = Effect size; FT = Flight time; ISO = Isometric; JH = Jump height; ms = milliseconds; SWC = Smallest worthwhile change; S:N = Signal to noise ratio; Δ = change in mean.

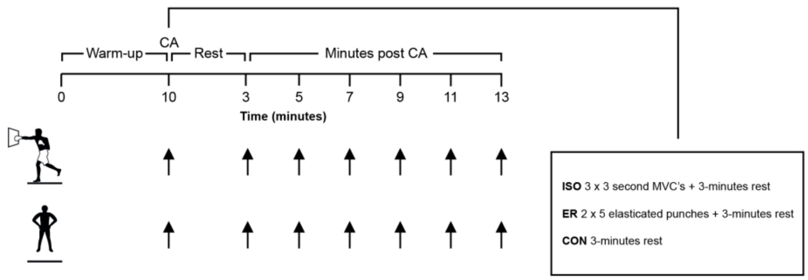

Figure 1 Schematic representation of the experimental measures across 3 trials. CA = Conditioning activity; ISO = Isometric; ER = Elastic resistance; CON = Control; MVC = Maximal voluntary contraction.

210x90mm (300 x 300 DPI)

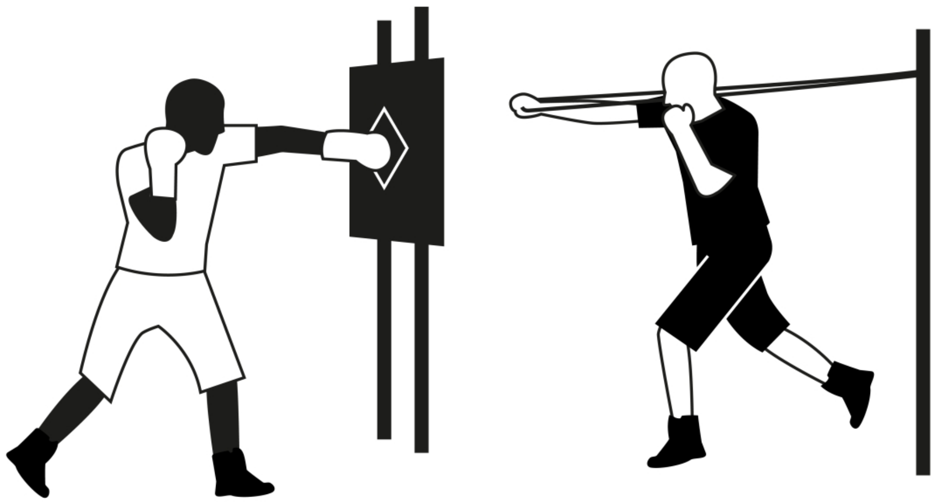

Figure 2 Example techniques of the ISO (left) and ER CA's (right). CA = Conditioning activity; ISO = Isometric; ER = Elastic resistance.

363x209mm (300 x 300 DPI)

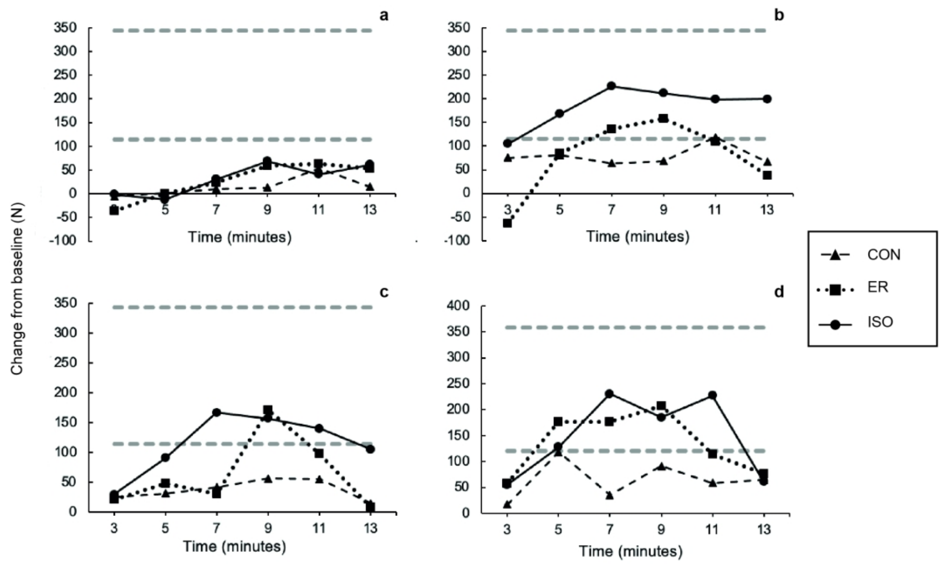

Figure 3 Changes from baseline in peak punch impact force for all punches (a = jab, b = cross, c = lead hook, d = rear hook) under all 3 conditions, across 6 time-points. Grey dash lines represent SWC = Smallest worthwhile change thresholds (0.2) and (0.6); N = Newtons.

210x148mm (300 x 300 DPI)

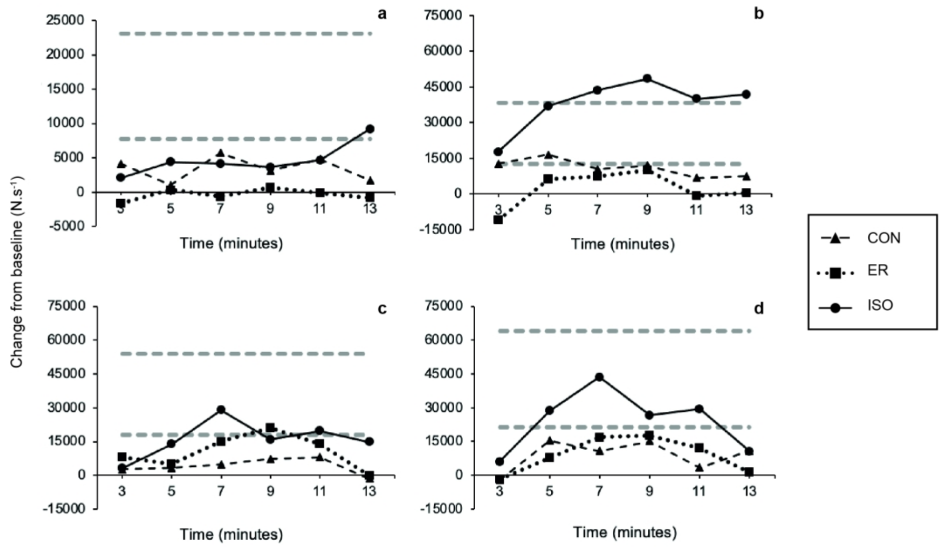

Figure 4 Changes from baseline in peak RFD for all punches (a = jab, b = cross, c = lead hook, d = rear hook) under all 3 conditions, across 6 time-points. Grey dash lines represent SWC = Smallest worthwhile change thresholds (0.2) and (0.6); N.s-1 = Newtons per second.

210x148mm (300 x 300 DPI)