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The effect of accommodating resistance on the post-activation potentiation response in rugby league players

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Running head

Post-activation Potentiation and Accommodating Resistance

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Abstract

This study examined the post-activation potentiation (PAP) response of two conditioning activities (CA), the hexbar deadlift (HBD) and back squat (BS), combined with accommodating resistance; this adds a percentage of the total resistance during the exercise. Twenty amateur rugby league players performed two experimental trials and a control trial without a CA. Participants performed a countermovement jump (CMJ) before and 30, 90, and 180 seconds after one set of three repetitions of each CA at 70% 1 repetition maximum (RM), with up to an additional 23% 1RM from accommodating resistance. Peak power output (PPO), force at PPO, velocity at PPO and jump height were calculated for each CMJ. Surface electromyography (EMG) of the vastus lasteralis (VL), rectus femoris (BF), tibialis anterior (TA), and gastrocnemius medialis (GM) were also measured. Repeated-measures analysis of variance revealed no significant ($p > 0.05$) PAP response for either exercise condition when comparing CMJ variables to baseline values, nor were there any significant ($p > 0.05$) differences between exercise conditions. However, individualized recovery intervals (baseline vs. maximum potentiation response) demonstrated significant ($p \leq 0.05$) improvements in PPO (3.99 ± 4.99%), force at PPO (4.87 ± 6.41%), velocity at PPO (4.30 ± 5.86%), jump height (8.45 ± 10.08%), VL EMG (20.37 ± 34.48%), BF EMG (22.67 ± 27.98%), TA EMG (21.96 ± 37.76%) and GM EMG (21.89 ± 19.65%). Results from this study must be interpreted with caution; however, it is conceivable that athletic performance can be acutely enhanced when complex training variables are individualized.

Keywords: potentiating stimulus, band tension, resistance exercise, countermovement jump, individualization

INTRODUCTION

Post-activation potentiation (PAP) is a phenomenon which refers to the acute augmentation of force and power production following a near-maximal voluntary contraction of skeletal muscle (15, 21, 40). This enhancement in force and power production is thought to be due to increased phosphorylation of the myosin light chain heightening the sensitivity of actin and myosin to Ca^{2+} availability, increased excitability of α-motorneurons, and short-term decreases in muscle fibre pennation angle (15, 35, 39). The relative contributions of these mechanisms to PAP remain unclear however, there is a growing body of scientific research to suggest that muscular power is temporarily augmented following heavy load conditioning activities (CA) of >85% 1 repetition maximum (RM) (6, 13, 23, 24, 30, 31). Similarly, there is empirical evidence which has demonstrated little or no potentiation effects (1, 11, 21, 22, 27).

A common issue with PAP is the intra complex recovery interval (ICRI) required between the CA and plyometric activity, which can limit its practical application. Traditional heavy load CAs, such as back squats (BS), typically report optimal ICRIs of 4-12 minutes (6, 13, 23, 24, 30, 31). This is due to heavy load CAs simultaneously inducing fatigue which inhibits the PAP response (35). However, fatigue dissipates at a greater rate and there is an opportunity to augment performance when the working muscles have partially recovered but are still potentiated (15, 35). Although PAP is typically thought to be elicited by heavy load resistance CAs, there is evidence to suggest that PAP may be evoked by more moderate loads of 60-85% 1RM (4, 34, 39). Therefore, it is plausible that a moderate resistance load combined with accommodating resistance, equating to a heavy resistance load, could be a more practical training strategy to elicit PAP. Previous research has utilized moderate loaded BS combined with accommodating resistance and reported a PAP response 90 seconds (3) and 4 minutes (40) post-CA.

Accommodating resistance is theorized to modify the force-velocity curve during resistance exercise by adding a percentage of the total resistance through latex bands or chains (5). This means that as the barbell continues through the range of motion (ROM) during the concentric phase, additional resistance will be applied (5, 40). Consequently, the effects of biomechanically disadvantageous positions, known as "sticking points", are reduced; this results in increased acceleration and velocity during the concentric phase of the lift which enables greater power outputs to be achieved (28, 40).

Schmidtbleicher (29) suggests that near maximal contractions performed at high velocities induce the greatest neural adaptations. Therefore, the use of accommodating resistance may be an optimal method of eliciting PAP as the length-tension relationship of skeletal muscle is accounted for (28, 40). The reduction in sticking points may enhance type IIb muscle fibre recruitment and elicit optimal adaptations (40). Furthermore, the enhanced acceleration and contraction velocities throughout the full ROM may translate more specifically to plyometric or stretch-shorten cycle (SSC) actions (13, 14) since the rapid production of force throughout the full ROM is a necessity in most sports (3, 40).

Anecdotal evidence suggests that accommodating resistance training increases the speed of the eccentric phase of the lift therefore inducing a greater stretch reflex (33). This attempts to override the golgi tendon reflex, consequently contributing to greater force production during the concentric phase and is referred to as "over-speed eccentrics" (33). It has been suggested that the use of accommodating resistance reduces joint stress throughout the ROM (28) and therefore, could be a safer and more suitable resistance training method for all levels of athletes in comparison to traditional heavy load resistance exercises.

The length of time required to achieve a PAP response may make it difficult for strength and conditioning practitioners to implement complex training in real-world training scenarios, where time is often very limited. Previous research has demonstrated a PAP response 4-8 minutes following the use of a weighted plyometric action as a CA, which involves a fast eccentric to concentric action (36). The lifting technique of the hexbar deadlift (HBD) exercise combined with accommodating resistance may evoke an over-speed eccentrics phase and increase contraction velocity during the concentric phase, whilst facilitating a near maximal voluntary contraction. It is plausible that this may enhance the specificity of the CA to the plyometric action (13, 14) and subsequently induce a PAP response in a shorter period of time which would fit more effectively into real-world training scenarios. In contrast, the technique of the BS exercise combined with accommodating resistance may well increase contraction velocity during the concentric phase, however it encourages a slower eccentric phase which may reduce the specificity between the CA and plyometric activity (13, 14).

To date there is very little academic literature which has investigated the effects of accommodating resistance on the PAP response (3, 40). Therefore, the purpose of this study was to determine whether PAP could be elicited at a shorter, more practical ICRI after a single set of either HBD or BS with the addition of accommodating resistance. It was hypothesized that PAP would be induced following both exercises in comparison to a control group. Furthermore, it was hypothesized that the HBD would elicit a greater PAP response due to the technique of the lift inducing a greater velocity during the eccentric phase, thus enhancing the specificity between the CA and plyometric action (5, 13, 14).

METHODS

Experimental Approach to the Problem

This study used a repeated measures, counterbalanced research design with random treatment order. The participants completed two familiarization sessions, two experimental sessions, and a control trial to examine the impact of the HBD and BS exercises combined with accommodating resistance on CMJ performance. During the experimental sessions, the participants performed maximal CMJs before and 30, 90, and 180 seconds after 1 set of 3 repetitions of either HBD or BS. Both CAs were performed at 70% 1RM, with the addition of elastic band resistance, which varied from 0% to 23% 1RM across the ROM, with maximum band tension achieved at end range. Each participant also completed a control trial with no CA. The following dependent variables were compared between the baseline and the post-CA CMJs: peak power output (PPO), ground reaction force (GRF) at PPO, velocity at PPO, jump height, and mean electromyography (EMG) values of the vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius medialis (GM).

Subjects

Twenty rugby league players (n = 20) were recruited from a University level rugby league team who play in the BUCS Premier North Division (age: 22.35 ± 2.68 years; height: 182.23 ± 6.00 cm; weight: 94.79 ± 12.79 kg). Inclusion criteria required participants to have at least six months prior experience in a structured resistance training program and to be able to perform HBD, BS and CMJ exercises with correct technique under the supervision of a qualified strength and conditioning coach. The study received full institutional approval from the University's Sport, Health and Exercise Science Ethics Committee. Prior to any experimental procedures, the participants gave their voluntary written informed consent and completed a pre-exercise medical questionnaire.

Participants were asked to refrain from engaging in any strenuous or unaccustomed exercise 48 hours prior to testing, to avoid the intake of caffeine 6 hours prior to testing and avoid the intake of alcohol 12 hours prior to testing.

Procedures

Prior to any experimental trials, the participants attended two familiarization sessions which were separated by one week. During these sessions the anthropometric measurements of height (The Leicester Height Measure, Seca, Birmingham, UK) and body mass (Seca digital scales, Birmingham, UK) were recorded. Leg dominance was also determined, for the purpose of electrode placement, using three tests: the step up, balance recovery and ball kick test (19). Leg dominancy was defined as the leg which was dominant in two of the three tests. The additional resistance from the elastic bands for the corresponding CAs were measured using Seca weighing scales (Seca digital scales, Birmingham, UK) which were previously calibrated following the manufacturer guidelines. Similar to previous research (3, 37) the participants stood on the scales with the bar and the mass was recorded. The bands (Pullum Sports, Leighton Buzzard, Bedfordshire) were then attached to the bar and the participants stood at the end of range for each lift and the mass was recorded. Band tension was defined as the difference between these two measures. This process was repeated with bands of various tension until the additional resistance reached up to 23% 1RM at end range for the corresponding CA.

Prior to the completion of the 1RM tests, the participants underwent a standardized warm-up consisting of a three minute cycle on a Wattbike ergometer (Wattbike Ltd, Nottingham, United Kingdom) at a low intensity of 60 Watts, a series of dynamic stretches (see Table 1) which specifically focussed on the musculature associated with HBD, BS and CMJ, and warm-up sets of the corresponding CA. The procedures for measuring muscular strength adhered to the guidelines recommended by the NSCA (8).

Briefly, this involved progressively increasing the load on the bar until the participants could only perform one successful repetition with correct technique (see Table 2).

Insert Table 1 about here.

Following demonstrations and verbal instructions, the participants practised performing CMJs with correct technique and the aim of optimizing jump height. The participants were instructed to jump with their hands on their hips throughout the CMJ to ensure that it was only the lower body contributing to the production of force and power. Instruction was given to perform the eccentric phase of the jump by flexing the knees to a self-selected depth of approximately 90˚knee flexion (20) and exploding upwards as forcefully and as quickly as possible to minimize the amortization phase. The participants were instructed to keep their legs straight during the flight phase of the CMJ and to land in the same position as take-off. To reduce the risk of injury, instruction was given to cushion the landing by bending the knees as soon as the feet made contact with the ground. The use of CMJs to measure the PAP response is well documented in empirical research (11, 13, 21-24, 30).

Insert Table 2 about here.

To control for circadian rhythm, the experimental sessions were separated by one week and were conducted at the same time of day (2). Prior to the warm-up and data collection, the muscles under EMG examination were prepared following Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines (18) to reduce skin resistance. This process involved measuring anatomical landmarks, shaving and minor abrasion of the site, and cleansing with an alcohol wipe. The surface EMG of the VL, BF, TA, and GM of each participant's dominant leg was recorded during each CMJ.

The participants then completed a standardized warm-up comprising of a three minute cycle on a Wattbike ergometer (Wattbike Ltd, Nottingham, United Kingdom) at an intensity of 60 Watts, a series of dynamic stretches (see Table 1) with specific focus placed on the musculature associated with BS, HBD and CMJ, warm-up sets of the corresponding CA, and three to four submaximal repetitions of CMJs. Following a baseline CMJ, the participants completed three repetitions of the corresponding CA at 70 + 0-23% 1RM from elastic band resistance throughout the full ROM. During the BS, the participants were instructed to control the eccentric phase of the lift, to avoid injury, and to lift as explosively as possible during the concentric phase. Similarly, during the HBD, the participants were instructed to lift as explosively as possible during the concentric phase, but were instructed to perform the eccentric phase of the lift as fast as possible. Subsequently, a single CMJ was performed with maximal effort at ICRIs of 30, 90, and 180 seconds. The control trial followed the same procedure however, the CA was replaced with a 5-minute rest period. This was to ensure that any PAP effects were due to the CAs and not the warm up protocol. In addition, the temperature, relative humidity and atmospheric pressure throughout the experimental trials were recorded as 20.9 ± 1.8 °C, 58.8 ± 11.4 % and 1018.89 ± 8.72 hPa, respectively.

Measurements

Force Platform: To collect the GRF data during the CMJ, a strain gauge force platform (AMTI, BP600900; dimensions 900x600mm, Watertown, Massachusetts, USA) was used. The sampling frequency was set at 1500Hz. Prior to any experimental sessions, the force platform was calibrated according to manufacturer guidelines.

EMG: To collect the surface EMG data, a wireless Noraxon EMG system with 16 bit analogue to digital resolution (Telemyo 2400T, Noraxon, Scottsdale, Arizona, USA) was used. This was sampled at 1500Hz and was synchronized to the GRF data via Qualisys Track Manager Software (Qualisys Oqus 400, Gothenburg, Sweden).

Data Analysis

The GRF and EMG data were analyzed using customized coding scripts in MATLAB (MATLAB, version R2014a, MathWorks, Inc., Natick, MA). The vertical component of the GRF data was left unfiltered as no noise was evident in the signal. Subsequently, the dependent variables could be calculated whilst controlling the effects of different filtering techniques (20).

PPO: The vertical component of the GRF data, firstly, had to be converted to acceleration. This was done by calculating the participant's mass by taking an average of the vertical GRF data 2 seconds prior to the start of the CMJ. Instantaneous acceleration could then be calculated using Newton's second law of motion:

$$A_i = (F_i / m) - g, \text{ where g is the acceleration due to gravity, } 9.81\ m{\cdot}s^{-2}$$

Instantaneous velocity ($m{\cdot}s^{-1}$) could then calculated by integrating instantaneous acceleration using the Simpson's rule. Integration commenced from the start of the CMJ, which was defined as the point where the vertical GRF data was less than 10% of the participant's body mass, and finished at the point of landing. The intervals were equal to the bandwidth. The instantaneous power could then be calculated using the following equation:

$$\text{Power (W)} = \text{vertical GRF (N)} \times \text{Instantaneous Velocity } (m{\cdot}s^{-1})$$

GRF and Velocity at PPO: The GRF at PPO and instantaneous velocity at PPO were determined by identifying the time point at which PPO occurred and finding the corresponding GRF and velocity values.

Jump Height: Flight time was determined by identifying the length of time between take-off and landing. Jump height was then calculated using the following equation:

$$\text{Jump Height} = (g \times \text{flight time}^2) / 8$$

EMG: The raw EMG data were first band-pass filtered (10-450Hz) using a digital 2nd order zero-lag Butterworth filter. The data were then full wave rectified and a linear envelope was created using a digital 2nd order zero-lag Butterworth low pass filter with a cut off frequency of 6Hz. It was then possible to quantify the muscle activity by taking the mean of the EMG data between the start of the jump to the point of take-off, for each muscle.

To assess the relative change in performance between the participants following the CAs, each variable was analysed as a percentage of potentiation which is a frequently used measure in potentiation studies (9):

$$\% \text{ Potentiation} = [(\text{Potentiated Variable} / \text{Non-potentiated Variable}) \times 100] - 100$$

A potentiation percentage of 0% highlights no potentiation, greater than 0% highlights a potentiation effect, and less than 0% highlights fatigue.

Statistical Analyses

Preliminary analysis was conducted to ensure normality and that the data met the assumptions of the statistical test. Statistical analysis was conducted using a 3 x 4 (condition x jump repetition) factorial analysis of variance (ANOVA) with repeated measures on jump repetition to analyse pre-CA and post-CA changes. The peak relative changes in individual performance (baseline vs. maximum potentiation response) during the CAs were analyzed using a 2-way ANOVA (condition x jump repetition) with repeated measures. Any significant interaction effects identified in the analyses were further analyzed using pairwise comparisons with Sidak corrections to correct for type I errors. Significance was set at $p \leq 0.05$. All statistical procedures were conducted using SPSS 23 (SPSS Inc., Chicago, IL).

Intra-class correlation coefficients (ICCs) were calculated to measure the reliability of the experimental data. ICCs were calculated by correlating the absolute values of the variables from the baseline jumps of the experimental sessions.

The average ICCs for PPO, GRF at PPO, velocity at PPO, and jump height were 0.932, 0.807, 0.845, and 0.897, respectively. The average ICC for the mean muscle activity of the VL, BF, TA, and GM were 0.655, 0.715, 0.429, and 0.667, respectively. ICCs were interpreted as poor for values less than 0.5, moderate for values between 0.5 and 0.75, good for values between 0.75 and 0.9, and excellent for values greater than 0.9 (26). See Table 3 for the trial-to-trial ICCs.

Insert Table 3 about here.

RESULTS

Peak Power Output

There was no significant ($p > 0.05$) interaction effect (time x exercise) for PAP during the CMJs at the specified ICRIs. Furthermore, there was no significant ($p > 0.05$) main effect for time for any experimental conditions nor were there any significant ($p > 0.05$) differences between the HBD and BS conditions. See Figure 1.

When the ICRIs were individualized (baseline vs. maximum potentiation response) there was no significant ($p > 0.05$) interaction effect (time x exercise) nor were there any significant ($p > 0.05$) differences between BS and HBD. However, there was a significant ($p < 0.001$) main effect for individualized ICRIs in comparison to baseline CMJs. Follow up pairwise comparisons revealed individualized improvements of 3.99% ($p < 0.001$, CI = 2.39 to 5.60%) in comparison to baseline CMJs for both exercise conditions (See Tables 4 and 5).

Insert Figure 1 about here.

Ground Reaction Force at Peak Power

There was a significant ($p = 0.001$) interaction effect (time x exercise) during the PAP time course. Follow up pairwise comparisons revealed that HBD and BS were significantly different in comparison to the control group at 30 seconds by -6.62% ($p = 0.001$, CI = -11.02 to -2.23%) and -5.51% ($p = 0.009$, CI = -9.91 to -1.12%), respectively. Furthermore, HBD displayed a significant difference in comparison to the baseline CMJ at 30 seconds by -4.33% ($p = 0.007$, CI = -7.77 to -0.89%) but not for BS. In addition, there was no significant ($p > 0.05$) PAP response for either exercise condition nor was there a significant ($p > 0.05$) difference between HBD and BS. See Figure 2.

When the ICRIs were individualized (baseline vs. maximum potentiation response) there was no significant ($p > 0.05$) interaction effect (time x exercise) nor were there any significant ($p > 0.05$) differences between BS and HBD. There was, however, a significant main effect for individualized ICRIs in comparison to baseline CMJs. Follow up pairwise comparisons revealed individualized improvements of 4.87% ($p < 0.001$, CI = 2.82 to 6.91%). See Tables 4 and 5.

Insert Figure 2 about here.

Velocity at Peak Power

There was a significant ($p = 0.008$) interaction effect (time x exercise) for PAP during the CMJs. Follow up pairwise comparisons revealed that both HBD and BS conditions were significantly greater at 30 seconds in comparison to the control group by 6.36% ($p = 0.001$, CI = 2.23 to 10.48%) and by 5.52% ($p = 0.007$, CI = 1.40 to 9.65%), respectively. However, there was no significant ($p > 0.05$) main effect for time for either exercise condition nor was there a significant ($p > 0.05$) difference between HBD and BS. See Figure 3.

When the ICRIs were individualized (baseline vs. maximum potentiation response) there was no significant ($p > 0.05$) interaction effect (time x exercise) nor were there any significant ($p > 0.05$) differences between BS and HBD. However, there was a significant ($p < 0.001$) main effect for individualized ICRIs in comparison to baseline CMJs. Follow up pairwise comparisons revealed individualized improvements of 4.30% ($p < 0.001$, CI = 2.43 to 6.17%). See Tables 4 and 5.

Insert Figure 3 about here.

Jump Height

There was a significant ($p = 0.035$) interaction effect (time x exercise) for PAP during the CMJs. Follow up pairwise comparisons revealed that both HBD and BS conditions were significantly greater at 30 seconds in comparison to the control group by 9.45% ($p = 0.003$, CI = 2.76 to 16.14%) and 8.98% ($p = 0.005$, CI = 2.30 to 15.67%), respectively. However, there was no significant ($p > 0.05$) main effect for time for either exercise condition nor was there a significant ($p > 0.05$) difference between HBD and BS. See Figure 4.

When the ICRIs were individualized (baseline vs. maximum potentiation response) there was no significant ($p > 0.05$) interaction effect (time x exercise) nor were there any significant ($p > 0.05$) differences between BS and HBD. However, there was a significant ($p < 0.001$) main effect for individualized ICRIs in comparison to baseline CMJs. Follow up pairwise comparisons revealed individualized improvements of 8.45% ($p < 0.001$, CI = 5.18 to 11.71%). See Tables 4 and 5.

Insert Figure 4 about here.

Muscle Activity

For mean muscle activity of the VL, BF, TA and GM, there were no significant ($p > 0.05$) interaction effects (time x condition). Furthermore, there were no significant ($p > 0.05$) main effects for either exercise condition nor were there any significant ($p > 0.05$) differences between any of the experimental conditions.

When the ICRIs were individualized (baseline vs. maximum potentiation response) there was no significant ($p > 0.05$) interaction effect (time x exercise) nor were there any significant ($p > 0.05$) differences between BS and HBD. However, there were significant main effects for individualized ICRIs for VL ($p = 0.001$), BF ($p < 0.001$), TA ($p = 0.001$) and GM ($p < 0.001$) in comparison to baseline CMJs. Follow up pairwise comparisons revealed individualized improvements of 20.37% ($p = 0.001$, CI = 9.25 to 31.48%), 22.67% ($p < 0.001$, CI = 13.53 to 31.80%), 21.96% ($p = 0.001$, CI = 9.92 to 33.99%) and 21.89% ($p < 0.001$, CI = 9.25 to 31.48%) for VL, BF, TA and GM, respectively (Tables 4 and 5). However, it should be noted that there was a high degree of variability expressed within the data as the ICCs ranged from poor to moderate.

Insert Table 4 about here.

Insert Table 5 about here.

DISCUSSION

This is the first study to have examined the effects of the PAP response on CMJ performance in rugby league players using HBD and BS exercises combined with accommodating resistance. This study observed no PAP responses when comparing the variables under investigation at the chosen ICRIs to baseline measures. However, when the ICRIs were individualized (baseline vs. maximum potentiation response) there is evidence to suggest that a single set of HBD and BS combined with accommodating resistance can acutely enhance CMJ performance.

Previous research (3) has examined the effects of four sets of two repetitions of paused box squats combined with accommodating resistance (68 + 6-19.6% 1RM) where loaded (80kg) jump squats were used as a performance measure 75-90 seconds after each box squat (3 minutes recovery between complex sets). The results demonstrated a PAP response in sets two, three and four in comparison to set one (baseline). However, the author recognized that the limitations of this study were low subject numbers and the lack of a control group. Furthermore, Wyland et al. (40) investigated the effects of a single set of BS combined with accommodating resistance (55 + 0-30% 1RM) on sprint performance and reported significant improvements after 4 minutes. This evidence suggests that the optimal ICRI lies between 1.5 and 4 minutes when inducing PAP using accommodating resistance, which is shorter than the conventional methods used for eliciting PAP (24, 31).

Although the present study demonstrated no significant improvements in any of the CMJ variables due to PAP at any of the ICRIs in comparison to baseline, there was a significant fatigue response observed for GRF at PPO immediately (30 seconds) following the HBD condition. Furthermore, both CAs were significantly less than the control group at 30 seconds. This is in agreement with previous research which has reported fatigue immediately (10-30 seconds) following CAs (13, 21, 23, 24, 31). This supports the notion that immediately after the CA, PAP is inhibited by fatigue.

There are a number of factors which must be considered when implementing complex training, including the ICRI and load (35, 39). There are currently no guidelines as to the optimal accommodating resistance load required to induce PAP. Based on the available scientific evidence, an accommodating resistance load of 15-30% has been recommended (3, 5, 40). Anecdotal evidence has recommended a constant barbell load of 60% 1RM when utilising accommodating resistance (33). Although PAP is typically thought to be elicited by heavy resistance loads of >85% 1RM (13, 22, 24) there is also a strong evidence base to support the notion that PAP can be induced by lighter loads of 60-85% 1RM (4, 34, 39). According to Schmidtbleicher (29) maximal concentric only contractions performed as quickly as possible induce optimal neural adaptations. Perhaps a lighter barbell load combined with a greater accommodating load would have induced a PAP response.

The results, unexpectedly, revealed that velocity at PPO and jump height for HBD and BS were significantly greater than the control group at 30 seconds, however there were no significant differences in comparison to baseline. Scientific evidence suggests that stronger individuals are more responsive to PAP stimuli due to greater type II muscle fiber content and quicker recovery from fatigue (9, 31, 35). Stronger individuals are also reported to possess a greater cross sectional area, muscle fiber pennation angle and fascicle length (12). Muscle fiber pennation angle directly influences power output, as larger pennation angles are associated with greater force generating capabilities, whereas smaller pennation angles are synonymous with greater shortening velocities and an increased rate of force transmission in the muscles (16). Therefore, it is conceivable that an individual's muscle fiber pennation angle may also be a contributing factor to PAP. Although the present study did not assess muscle architecture, the authors believe that muscle fiber pennation angle warrants future investigation in PAP studies.

The present study did, however, assess neural activation using surface EMG. The results revealed no significant changes at any of the ICRIs in comparison to baseline for either CA. However, when the ICRIs were individualized (baseline vs. maximum potentiation response) the muscles under examination expressed significantly increased neural activity.

Therefore, there is evidence to suggest that PAP is induced by the recruitment of higher order motor neurons due to increased motor-neuron pool excitability (15, 23, 35). However, these results must be interpreted with caution as there was a high degree of variability present within the EMG data. As such, it is difficult to draw any conclusions regarding the underpinning mechanism of PAP from the EMG analysis. This is consistent with findings in previous research (17, 22, 30).

The present study aimed to kinetically alter the HBD and BS exercises by combining a moderate load CA with accommodating resistance to modify the force-velocity curve. Previous research has utilized Olympic style lifts to alter the force-velocity profile of the CA (1, 27, 32). Andrews et al. (1) and Seitz et al. (32) reported significantly greater PAP responses in Olympic style lifts in comparison to heavy load CAs, therefore the ability to produce high forces at high velocities may induce optimal PAP responses due to the specificity of the CA to the plyometric action (14). However, McCann and Flanagan (27) reported no significant difference between hang cleans and heavy load BS as a CA in eliciting PAP and state that the ICRIs were "highly individualized".

Although there was no significant PAP response at any of the ICRIs in comparison to baseline, the results of the present study highlighted significant improvements in CMJ performance when the ICRIs were individualized (baseline vs. maximum potentiation response) which is in agreement with previous research (6, 9, 11, 13, 27). A possible explanation for this individualized response is the elevation of the phosphorylation of myosin regulatory light chains (15, 23, 35). The near maximal contraction induced by both CAs may have increased the release of Ca^{2+} ions from the sarcoplasmic reticulum, therefore activating a greater volume of myosin light chain kinase. This heightens the sensitivity of the actin-myosin complex to Ca^{2+} ions and increases the ATP availability at the complex. As a result, the rate of actin-myosin cross-bridging is increased.

Furthermore, there were no significant differences between HBD and BS when the ICRIs were individualized. Accommodating resistance is theorized to induce an over-speed eccentric phase which enhances the SSC as a greater stretch reflex is elicited and the Golgi tendon organ is overridden resulting in greater force production during the concentric phase (33). The accommodating resistance may also induce a preparatory muscle stiffness during both exercises where there is an increase in motor unit activation at the top of the lift however, at the bottom of the lift, when the load is decreased, the motor units are still activated therefore resulting in a surplus of neural activation thus evoking a PAP response (5). In addition, due to the bands actively pulling the loads downwards with greater force than the effect of gravity during the eccentric phase of both exercises, the muscles may have been better able to utilize the stored elastic strain energy during the concentric phase as result of the reduced effects of "sticking points" (40). Collectively, this may explain why there were no differences between the HBD and BS.

A limitation of the present study is the absence of any thermoregulatory data. Scientific evidence suggests that an increase in muscle temperature enhances muscular force and power (10). Furthermore, an increase in muscular temperature may have evoked greater muscular activation, elevated the phosphorylation of myosin light chains and enhanced the storage and release of elastic strain energy (7). In addition, research suggests that an increase in core temperature, due to the natural change in body temperature from morning to evening, can mediate enhanced power outputs (25, 38). However, given that the warm up was standardized and of a low intensity, it can be assumed that any individualized PAP response was not a result of increased muscular temperature but due to the selected CAs within the study.

In conclusion, the results of this study did not express a PAP response at any of the chosen ICRIs. However, there is evidence to suggest a PAP response following HBD and BS combined with accommodating resistance when the ICRIs are individualized.

Although there is evidence to suggest possible underpinning mechanisms of PAP, the results from this study must be interpreted with caution. Further research is required to ascertain the optimal barbell and accommodating resistance loads required to evoke a PAP response as well as identifying the optimal ICRI. Moreover, future research should consider individualizing the loads as this may result in further performance enhancements for athletes. In addition, more research is required to determine the underpinning mechanisms of PAP. Lastly, research should investigate the longitudinal effect of this training modality by utilizing individualized ICRIs.

PRACTICAL APPLICATIONS

Based on the results of the present study, strength and conditioning coaches should individualize the ICRI between the CA and subsequent plyometric action when implementing PAP within their training programs. Both moderately loaded HBD and BS exercises combined with accommodating resistance are appropriate methods of eliciting PAP if the ICRIs are individualized. Based on current literature, it may be possible to evoke a PAP response between 1.5 and 4 minutes when utilizing this training modality. Strength and conditioning specialists should ensure that they identify the optimal IRCIs, loads and exercises for their athletes to maximize results.

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FIGURE LEGENDS

Figure 1. Mean ± SD and individual PAP responses for PPO for both exercise conditions. All results are expressed as a percentage of baseline.

Figure 2. Mean ± SD and individual PAP responses for GRF at PPO for both exercise conditions. *significantly different from the control group ($p \leq 0.05$). All results are expressed as a percentage of baseline.

Figure 3. Mean ± SD and individual PAP responses for velocity at PPO for both exercise conditions. *significantly different from the control group ($p \leq 0.05$). All results are expressed as a percentage of baseline.

Figure 4. Mean ± SD and individual PAP responses for jump height for both exercise conditions. *significantly different from the control group ($p \leq 0.05$). All results are expressed as a percentage of baseline.

TABLES

Table 1. Standardized dynamic warm up for strength testing, experimental trials and control trials.

Exercise	Sets	Reps
Body weight squats	1	6
Mountain climbers (E/S)*	1	6
Thoracic rotations (E/S)*	1	6
Glute Bridge	1	6
Band pull aparts	1	6

*E/S = Each Side

Table 2. Comparison of the absolute and relative 1RM loads lifted.

Strength Measure	Hex Bar Deadlift (Mean ± SD)	Back Squat (Mean ± SD)	p value
1RM Absolute Load (kg)	167.00 ± 33.98	133.75 ± 28.19	< 0.001
1RM Relative Load (kg/kg)	1.78 ± 0.41	1.42 ± 0.30	< 0.001

Table 3. Average ICCs and ICCs between each condition for each variable.

Variables	HBD - BS	HBD - CON	BS – CON	Average	Interpretation
PPO	0.908	0.936	0.953	0.932	Excellent
GRF at PPO	0.817	0.825	0.779	0.807	Good
Velocity at PPO	0.844	0.785	0.907	0.845	Good
Jump Height	0.883	0.875	0.934	0.897	Good
Muscle activity of the VL	0.633	0.674	0.658	0.655	Moderate
Muscle activity of the BF	0.758	0.787	0.601	0.715	Moderate
Muscle activity of the TA	0.554	0.284	0.450	0.429	Poor
Muscle activity of the GM	0.799	0.519	0.684	0.667	Moderate

Table 4. Mean ± SD of the percentage change in comparison to baseline for all variables across the different ICRIs. Mean ± SD of the percentage change in comparison to baseline for all variables when the ICRIs were individualized (baseline vs. maximum potentiation response).

Variables	30 seconds	90 seconds	180 seconds	Individualized ICRIs
PPO	-1.13 ± 4.70%	3.16 ± 11.00%	1.10 ± 9.23%	3.99 ± 4.99% *
GRF at PPO	-3.77 ± 4.91% ┼	1.64 ± 6.36%	1.68 ± 5.24%	4.87 ± 6.41% *
Velocity at PPO	2.88 ± 5.10% ┼	0.90 ± 7.09%	2.62 ± 6.59%	4.30 ± 5.86% *
Jump Height	4.09 ± 9.10% ┼	1.03 ± 7.34%	-0.64 ± 6.46%	8.45 ± 10.08% *
EMG VL	8.81 ± 32.93%	9.33 ± 34.51%	9.29 ± 37.80%	20.37 ± 34.48% *
EMG BF	8.40 ± 28.03%	9.37 ± 28.65%	4.47 ± 27.31%	22.67 ± 27.98% *
EMG TA	11.69 ± 38.85%	7.68 ± 29.30%	2.60 ± 29.81%	21.96 ± 37.76% *
EMG GM	7.11 ± 20.19%	12.32 ± 18.56%	8.16 ± 21.74%	21.89 ± 19.65% *

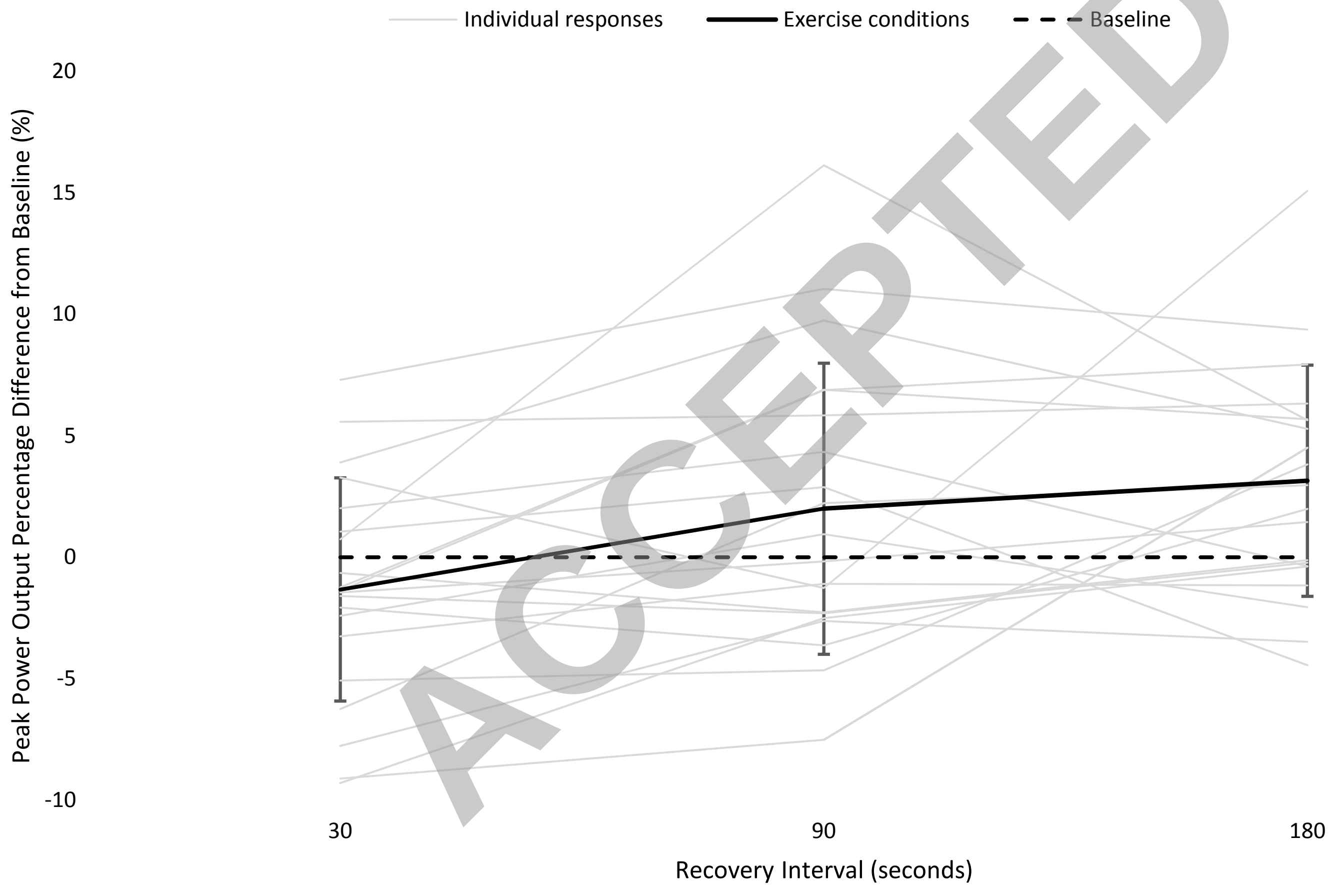
*Denotes a significant ($p \leq 0.05$) difference in comparison to baseline; ┼denotes a significant difference in comparison to the control group.

Table 5. Number of participants that peaked at each ICRI and the number of participants that expressed no PAP response for the measured variables. Percentage differences for basline vs. maximum potentiation response for the corresponding number of participants presented as mean ± SD.

Variables	**30 seconds**	**90 seconds**	**180 seconds**	**Non- Responders**
PPO	0	7 (7.58 ± 2.66%)	9 (2.94 ± 2.48%)^	4 (-1.58 ± 0.51%)
GRF at PPO	0	8 (4.32 ± 1.93%)	9 (6.65 ± 3.35%)^	3 (-2.75 ± 2.04%)
Velocity at PPO	10 (4.05 ± 3.41%)^	4 (5.33 ± 4.51%)	4 (2.35 ± 2.45%)	2 (-1.67 ± 0.56%)
Jump Height	7 (6.91 ± 5.03%)^	6 (11.17 ± 9.08%)	3 (8.00 ± 2.15%)	4 (-1.89 ± 1.79%)
EMG VL	3 (12.40 ± 10.32%)	6 (13.66 ± 12.39%)	8 (30.08 ± 32.96%)^	3 (-6.82 ± 0.57%)
EMG BF	5 (25.58 ± 24.10%)	6 (37.01 ± 23.48%)^	4 (17.48 ± 9.68%)	5 (-8.04 ± 7.07%)
EMG TA	7 (34.56 ± 23.38%)^	4 (30.91 ± 24.44%)	2 (43.99 ± 27.21%)	7 (-7.58 ± 6.26%)
EMG GM	5 (22.02 ± 13.93%)	6 (20.07 ± 14.21%)	7 (23.79 ± 13.12%)^	2 (-4.46 ± 3.11%)

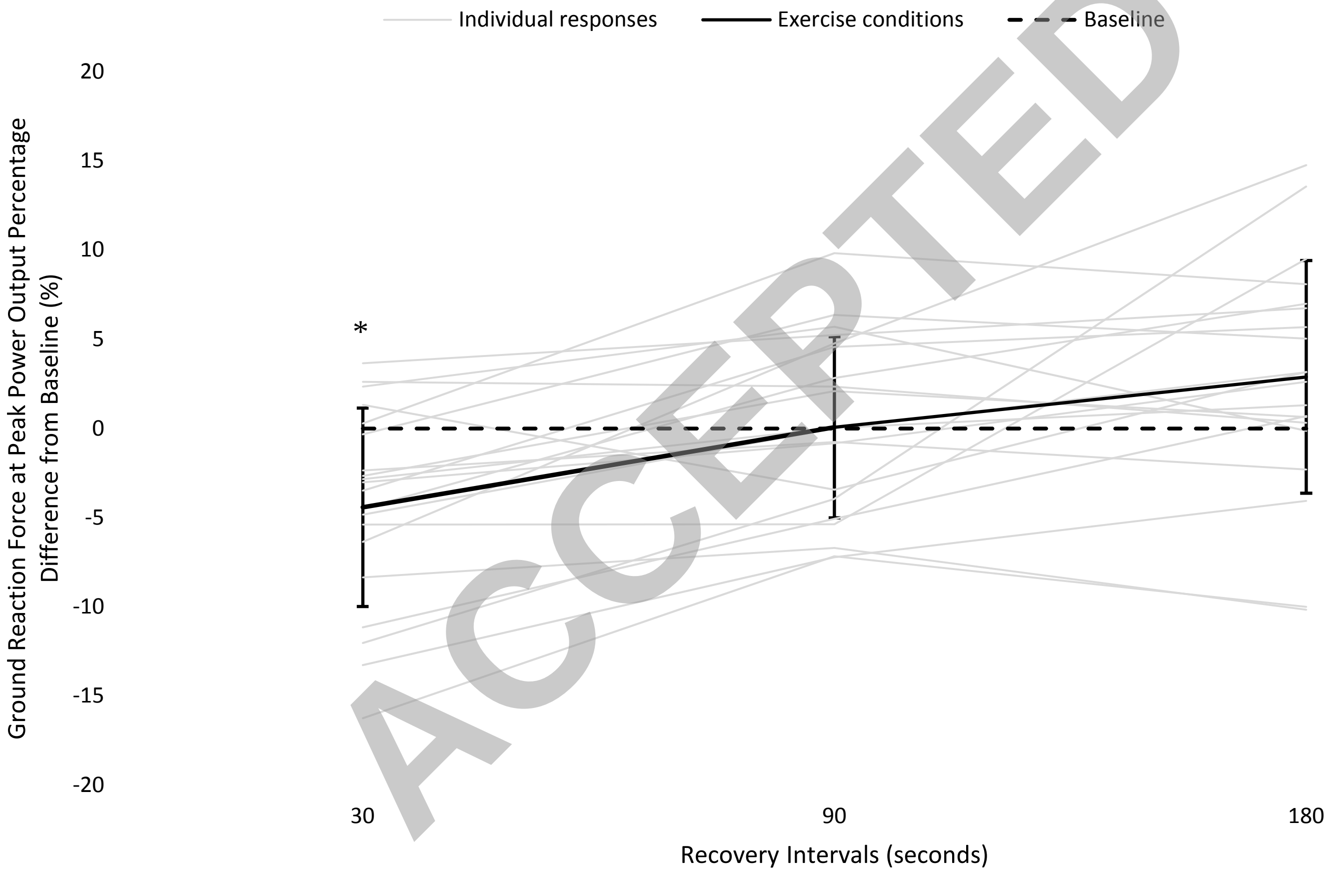
^Denotes the ICRI at which the greatest number of participants expressed a peak PAP response.

Figure 1



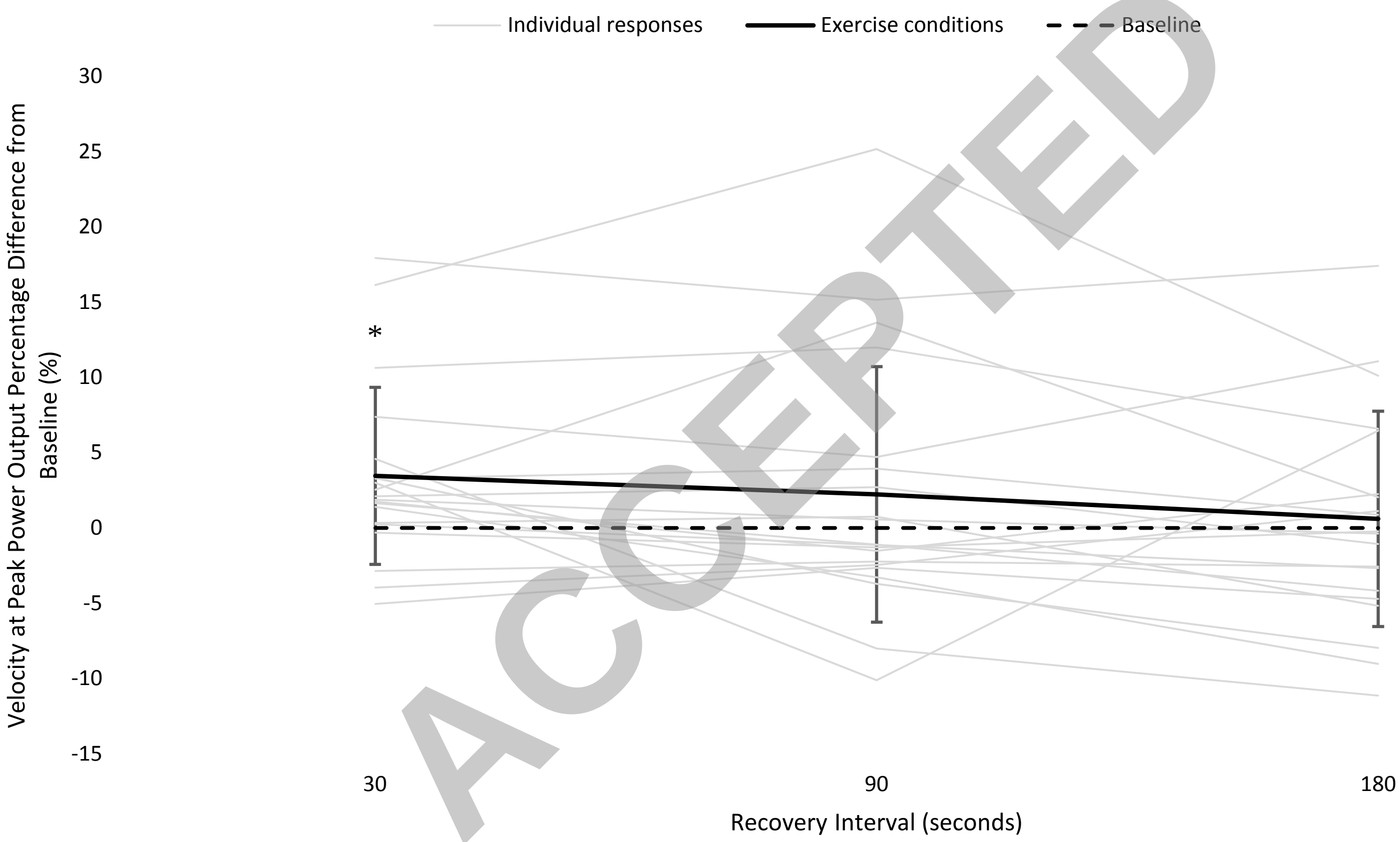
Individual responses
Exercise conditions
Baseline
Peak Power Output Percentage Difference from Baseline (%)
20
15
10
5
0
-5
-10
30
90
180
Recovery Interval (seconds)

Figure 2



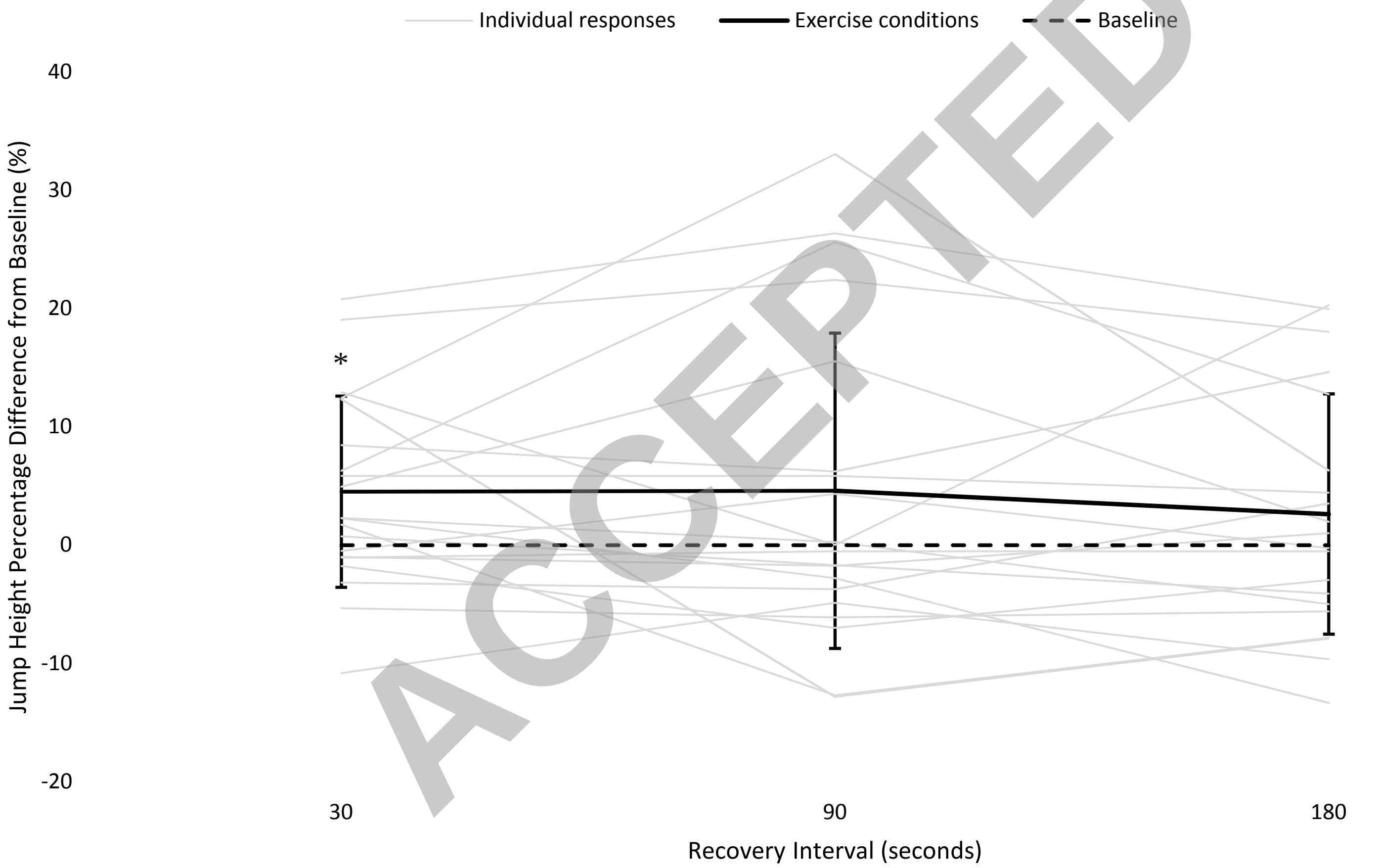
Individual responses
Exercise conditions
Baseline
20
15
10
5
0
-5
-10
-15
-20
*
Ground Reaction Force at Peak Power Output Percentage Difference from Baseline (%)
30
90
180
Recovery Intervals (seconds)

Figure 3



Individual responses
Exercise conditions
Baseline
Velocity at Peak Power Output Percentage Difference from Baseline (%)
30
25
20
15
10
5
0
-5
-10
-15
*
30
90
180
Recovery Interval (seconds)
ACCEPTED

Figure 4



Individual responses
Exercise conditions
Baseline
40
30
20
10
0
-10
-20
Jump Height Percentage Difference from Baseline (%)
*
30
90
180
Recovery Interval (seconds)