Complex training: The effect of exercise selection and training status on post-activation potentiation in rugby league players

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Running head

Post-activation Potentiation and Exercise Selection

ABSTRACT

This study compared the post-activation potentiation (PAP) response of the hex bar deadlift (HBD) and back squat (BS) exercises. The PAP response between different levels of athletes was also compared. Ten professional and ten amateur rugby league players performed two experimental sessions. Participants performed a countermovement jump (CMJ) before and 2, 4, 6, 8, 10, 12, 14 and 16 minutes after a conditioning activity (CA) that contained 1 set of 3 repetitions at 93% 1RM of either HBD or BS. A force platform determined peak power output (PPO), force at PPO, velocity at PPO and jump height of each CMJ. Surface EMG of the vastus lasteralis, rectus femoris, tibialis anterior, and gastrocnemius medialis of each participant's dominant leg was recorded during each CMJ. A further ten participants performed a control trial without a CA. The HBD expressed PAP between 2 and 6 minutes post-CA, whereas the BS did not. The HBD exhibited a significantly ($p \leq 0.05$) greater PAP response than the BS for PPO. There were no significant ($p > 0.05$) differences between stronger and weaker players. There were no significant ($p > 0.05$) changes in the EMG variables. These results suggest that HBD is a suitable CA for eliciting PAP in stronger and weaker athletes. Strength and conditioning coaches should consider the CA and time frame between the CA and the plyometric exercise for optimal PAP responses.

KEYWORDS: potentiating stimulus, rest interval, hex bar deadlift, back squat, training status, peak power

INTRODUCTION

Complex training (CT) is an effective, time efficient training modality for enhancing strength and power which alternates heavy resistance exercise, with an explosive plyometric exercise which is biomechanically similar (9, 38). This enables both extremes of the force-velocity curve to be trained in one session. Consequently, strength and conditioning coaches can address two training variables in one session.

CT is underpinned by post-activation potentiation (PAP) which theoretically enhances force and power output following a near maximal voluntary contraction, or conditioning activity (CA) (15, 17, 35). The CA also induces fatigue which may inhibit the effects of PAP (35). PAP and fatigue can coexist, however fatigue dissipates at a greater rate, therefore performance can be enhanced when the working muscles have partially recovered but are still potentiated (9, 35). Currently, the underlying mechanisms of PAP are unclear, however it is thought that they could include neural and muscular interactions, and muscle architectural changes (9, 25, 33, 35). Suggested mechanisms include, phosphorylation of myosin regulatory light chains, recruitment of higher order motor units, and changes in muscle pennation angle (9, 25, 33, 35). Scientific research which has investigated the acute effects of CT on lower body power has provided equivocal results, as some studies have reported enhancements in performance (5, 7, 12, 21, 22, 28, 30), whilst other studies have reported no changes or decreases in performance (1, 6, 10, 13, 19, 20, 24).

Interpretation of the optimal intra complex recovery interval (ICRI), the recovery period between the CA and the plyometric exercise, is difficult as previous studies have suggested that this rest period may lie between 0.3 and 18.5 minutes (22, 28, 29). The optimal ICRI and magnitude of the PAP response appears to be dependent on factors including the type of CA and the training status of the individual (17, 26, 28, 35). It is thought that well trained individuals express a greater degree of PAP due to greater type II muscle fibre content and a shorter time course of fatigue following the CA (28, 35). Academic research typically utilises heavy load back squats (BS) as the CA when employing CT for the lower body and the PAP response is measured by vertical jumping (7, 15, 20, 22). Other CAs which have been investigated include front squats (39), squats with varying depth (8, 12, 15, 23), dynamic contractions (31), plyometric exercises (1, 37), and Olympic style lifts (1, 24, 30).

It has been suggested that optimal neural adaptations are induced by near maximal concentric only contractions performed as fast as possible (27). In this regard the conventional straight bar deadlift may be a useful alternative CA, with the technique allowing participants to focus on performing concentric work, with minimal eccentric loading if the bar is released at the top of the lift (32, 34). This may reduce neuromuscular fatigue by decreasing the amount of time under tension (36). The hex bar deadlift (HBD) is a variation of the conventional deadlift that has been reported to reduce the amount of stress on the lumbar spine, hip, and ankle, which may allow a greater load to be lifted and increase muscle activation (3, 32). Additionally, HBD has been shown to induce significantly greater peak velocities in comparison to the straight bar deadlift (32).

The purpose of this study was to determine if HBD reduced the optimal ICRI in comparison to BS. It was hypothesised that HBD would enhance the PAP response due to less time spent under tension and consequently lower fatigue. Currently no studies have considered the HBD as a CA. A secondary aim of this study was to determine any differences in the PAP response between stronger and weaker athletes. It was hypothesised that stronger athletes would express a greater degree of PAP.

METHODS

Experimental Approach to the Problem

The present study employed a repeated measures design. Participants completed two familiarisation sessions and two experimental sessions to investigate the effects of exercise selection and playing level on the temporal profile of PAP (Figure 1). During the experimental sessions, participants performed maximal countermovement jumps (CMJ) before and 2, 4, 6, 8, 10, 12, 14 and 16 minutes after 1 set of 3 repetitions at 93% 1RM of either HBD or BS. 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 EMG values of the vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius medialis (GM).

Insert Figure 1 about here.

Subjects

Ten professional and ten amateur rugby league players were recruited for the present study (Table 1). The professional players were recruited from a First Utility Super League academy, Kingstone Press Championship and League One clubs. Amateur players were recruited from a University level rugby league team who play in BUCS Premier North Division. A further ten participants completed a control trial which did not involve a CA. Participants were required to have a minimum of 6 months previous experience in a structured resistance training programme and were able to complete HBD, BS and CMJ exercises with correct technique under the supervision of a qualified strength and conditioning coach. Each participant provided written informed consent to participate in the present study 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, avoid the intake of caffeine 6 hours prior to testing and avoid the intake of alcohol 12 hours prior to testing. The study received full institutional approval by the Department of Sport, Health and Exercise Science's Ethics Committee.

Insert Table 1 about here.

Familiarisation Sessions

The first familiarisation session involved anthropometric measurements, determination of 1RM BS scores, and familiarisation with the warm-up and experimental protocols. For the purpose of electrode placement, leg dominance was determined using the following three tests: the step up, balance recovery and ball kick test (16). The dominant leg was defined as the leg which was dominant in two out of the three tests. The participants also practised performing CMJs following demonstration and verbal instruction with the aim of optimising jump height. During the second familiarisation session, 1RM HBD scores were determined. The participants were reminded of the experimental protocols and given further CMJ practice.

1RM testing: The participants underwent a standardised warm up which comprised of a 3 minute cycle on a Wattbike ergometer (Wattbike Ltd, Nottingham, United Kingdom) at a low intensity of 60 Watts, followed by a series of dynamic stretches with emphasis placed on the musculature associated with the HBD and BS. 1RM testing for the corresponding exercises was conducted following NSCA guidelines (4). The participants were subsequently split into two equal groups, a stronger and a weaker group, based on their relative 1RM BS scores (Table 2 and Table 3) as this has previously been suggested as a predictor of the PAP response (26, 28).

Insert Table 2 about here.

Insert Table 3 about here.

Experimental Sessions

A randomised, repeated measures, counterbalanced research design was utilised to examine the hypothesis. The participants underwent a standardised warm-up which consisted of a 3 minute cycle on a Wattbike ergometer at an intensity of 60 Watts, a series of dynamic stretches with emphasis placed the musculature associated with the CMJ, HBD and BS, warm-up sets of the corresponding CA, and 3-4 submaximal repetitions of CMJs. A baseline CMJ was then performed before completing 3 repetitions of the CA at 93% 1RM. During the HBD, participants were instructed not resist the eccentric phase of the movement by dropping the bar following a successful lift to, ensure the movement was predominantly concentric. CMJs were performed at recovery intervals of 2, 4, 6, 8, 10, 12, 14 and 16 minutes following the CA. During the second experimental session the CA was changed. The experimental sessions were separated by one week and were conducted at the same time of day to control for circadian variations (2).

Measurements

CMJ: To ensure that only the lower limbs were contributing to the development of power, the CMJ was performed with arms akimbo. A quick countermovement was performed, with instructions to then flex the knees to approximately 90˚, and then explode upwards with maximal effort. Participants were instructed to keep their legs straight throughout the jump and land in the same position as take-off. To minimise the risk of injury, they were instructed to cushion the landing by bending the knees as soon as the feet made contact with the ground.

Force Platform: A strain gauge force platform (AMTI, BP600900; dimensions 900x600mm, Watertown, Massachusetts, USA), which sampled at 1500Hz, was used for the collection of GRF data during the CMJ. The force platform was calibrated and checked before testing according to manufacturer guidelines.

Surface EMG: Surface EMG of the VL, BF, TA and GM of the participants' dominant leg was recorded during each CMJ using a wireless Noraxon EMG system with 16 bit analogue to digital resolution (Telemyo 2400T, Noraxon, Scottsdale, Arizona, USA). The surface EMG was recorded at a sampling frequency of 1500Hz and was synchronised to the GRF data via Qualisys Track Manager Software (Qualisys Oqus 400, Gothenburg, Sweden). The muscles under examination were prepared prior to data collection to reduce skin resistance following SENIAM guidelines (14).

Data Analysis

All data were analysed using MATLAB (MATLAB, version R2014b, MathWorks, Inc., Natick, MA). The vertical component of the GRF was unfiltered because no noise was evident in the signal. This allowed accurate extraction of the dependent variables whilst controlling the effects of different filtering techniques (18).

PPO: The participants' mass was calculated by taking an average of the GRF data 2 seconds prior to the CMJ. The instantaneous acceleration, $m \cdot s^{-2}$, was calculated using Newton's second law of motion:

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

The instantaneous velocity, $m \cdot s^{-1}$, was calculated by integration of the instantaneous acceleration using Simpson's rule. The start of the CMJ was determined as the instant where the GRF data was less than 10% of the participant's body weight. Integration started from the start of the jump and finished at the point of landing, where the intervals were equal to the band width (see Figure 2). It was then possible to calculate instantaneous power using the following equation:

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

GRF and Velocity at PPO: 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.

Insert Figure 2 about here.

Jump Height: Take-off was determined as the instant where the force data was less than 5N and landing was defined as the instant at which the force was greater than 5N. Jump height was then calculated using the flight time method:

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

Muscle Activity: The EMG data were used to derive the mean muscle activity from the start of the jump to take-off for the VL, BF, TA and GM. The raw EMG data were first band-pass filtered (20-450Hz) using a digital 2nd order zero-lag Butterworth filter. The EMG data were then full wave rectified and run through a digital 2nd order zero-lag Butterworth low pass filter with a 6Hz cut off frequency, to create a linear envelope.

Intra-class correlation coefficients (ICC) were calculated by correlating the baseline jumps from the first experimental session to the second experimental session. The ICC for PPO, force at PPO, velocity at PPO, and jump height were 0.964, 0.964, 0.724, and 0.884, respectively. The ICC for the mean muscle activity of the VL, BF, TA, and GM were 0.735, 0.57, 0.775, and 0.914, respectively.

Each variable was examined as a percentage of potentiation to ensure that the comparisons between the different strength levels of the participants were relative (5):

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

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

Statistical Analyses

All statistical procedures were conducted using SPSS 22 (SPSS Inc., Chicago, IL). Following tests of normal distribution, statistical analysis was conducted using a 2 x 2 x 9 (playing level of athlete x exercise x jump repetition) factorial ANOVA with repeated measures on jump repetition to analyse pre-CA and post-CA changes. Any significant interaction effects were further analysed using pairwise comparisons with Sidak corrections to correct for type I errors. Additionally, a repeated measures ANOVA was used to analyse the control data. Significance was set at the $p \leq 0.05$.

RESULTS

Peak Power Output

There was a significant interaction effect (time x exercise) for PAP during the CMJs (p = 0.006). Follow up pairwise comparisons revealed that HBD significantly improved PPO in comparison to baseline by 6.43% at 2 minutes ($p < 0.001$, CI = 2.83 to 10.03%), by 5.01% at 4 minutes ($p = 0.01$, CI = 0.70 to 9.32%), and by 6.14% at 6 minutes ($p = 0.002$, CI = 1.50 to 10.79%), however, there were no significant ($p > 0.05$) improvements for BS. As shown in Figure 3A, HBD expressed greater improvements than BS by 4.97% at 2 minutes ($p = 0.002$, CI = 1.98 to 7.96%), 5.41% at 6 minutes (*p* = 0.007, CI = 1.56 to 9.27%), 4.79% at 10 minutes (*p* = 0.012, CI = 1.10 to 8.48%), 4.02% at 12 minutes (*p* = 0.021, CI = 0.65 to 7.38%), 3.89% at 14 minutes (*p* = 0.019, CI = 0.68 to 7.10%), and 5.71% at 16 minutes (*p* = 0.003, CI = 2.03 to 9.39%). There were no significant (*p* > 0.05) differences between stronger and weaker players. The control group (see Figure 3B) demonstrated a significant decrease in PPO by -5.47% at 16 minutes (*p* = 0.016, CI = -10.09 to -0.85%).

Insert Figures 3A) and B) here.

Ground Reaction Force at Peak Power Output

For GRF at PPO, there were no significant (*p* > 0.05) interaction effects, however there was a significant main effect (*p* = 0.022). Follow up pairwise comparisons revealed a significant improvement in comparison to baseline by 2.49% at 4 minutes (*p* = 0.014, CI = 0.30 to 4.69%) for stronger and weaker athletes following both CAs (see Figure 4).

Insert Figure 4 about here.

Velocity at Peak Power Output

For velocity at peak power, there were no significant (*p* > 0.05) interaction effects, however there was a significant main effect (*p* < 0.001). Follow up pairwise comparisons revealed a significant decrease in comparison to baseline by -3.26% at 16 minutes (*p* = 0.004, CI = -5.86 to -0.65%) for stronger and weaker athletes following both CAs (see Figure 5A). As shown in Figure 5B, the control group also expressed a significant decrease in velocity at PPO by -5.30% at 14 minutes (*p* = 0.05, CI = -10.59 to -0.01%).

Insert Figures 5A) and B) about here

Jump Height

For jump height, there were no significant interaction effects ($p > 0.05$) and there was no significant main effect ($p > 0.05$). See Table 4.

Insert Table 4 about here.

Muscle Activity

For mean muscle activity of the VL, BF, TA and GM, there were no significant interaction effects ($p > 0.05$) and there were no significant main effects ($p > 0.05$). There was a high degree of variability expressed within the data. For all conditions the EMG data ranged from 2.72 ± 20.29% to -0.91 ± 17.46%, 6.58 ± 20.08% to -2.65 ± 22.22%, 3.00 ± 24.77% to -5.20 ± 22.64%, and 9.98 ± 20.95% to 3.72 ± 17.68% for the VL, BF, TA and GM, respectively.

DISCUSSION

When investigating the optimal ICRI of the PAP response, previous studies have used recovery intervals ranging from 0.3 to 24 minutes for the BS exercise (7, 19, 20, 22, 28). It is thought that the optimal ICRI for the BS is 4-12minutes for well-trained individuals (7, 21, 22, 29). The PAP response following the HBD significantly improved PPO at 2, 4, and 6 minutes post-CA for both stronger and weaker rugby league players. This finding suggests that HBD is a suitable CA for inducing PAP.

Optimal adaptations to the nervous system are induced by near maximal concentric only contractions performed as fast as possible (27). The HBD was performed as a concentric only contraction as participants were instructed not to resist the eccentric phase of the movement. This lifting technique may have reduced the effects of neuromuscular fatigue due to a reduction in time under tension and a reduced eccentric load (36), therefore enabling a greater magnitude of PAP to be elicited at a greater rate.

Although no study has ever used HBD as a CA, other studies have attempted to reduce the volume of eccentric work by examining the effects of partial BS on jump performance. Crum et al. (8) and Mangus et al. (23) reported no significant improvements in comparison to baseline when utilising quarter and half squats. Although the eccentric phase of the lift is reduced, potentially reducing fatigue, the concentric phase is also reduced which may reduce the potentiating effect. In contrast, Esformes and Bampouras (12) investigated the effect of 3RM parallel squats and 3RM quarter squats on jump performance. Although both conditions significantly improved performance, the parallel squat condition showed the greater improvement. This may have been due to the fact that professional athletes with greater strength levels were recruited. Collectively, these results suggest that the full ROM throughout the concentric phase of the lift is paramount in eliciting PAP. HBD may be advantageous as the lifting technique allows the eccentric phase to be reduced and the concentric phase to be maximised. This may explain why HBD appears to elicit a greater magnitude of PAP in weaker athletes as well as stronger athletes.

Velocity at PPO for both exercises decreased over time however, HBD appeared to express greater velocities than BS during the PAP time course. HBD may have enhanced the contraction velocity, making the CA more specific to the plyometric action (8, 26). Swinton et al. (33) found that HBD reduced peak moments at the lumbar spine, hip, and ankle therefore more evenly distributing the load across the joints of the body. Interestingly, there was an increased peak moment at the knee despite the magnitude of the moment arm being reduced, therefore indicating that muscular effort was enhanced due to the distribution of the load. It is possible that the mechanics of HBD alters the force-velocity curve of the movement, subsequently enhancing the contraction velocity. This may allow greater forces to be generated at greater velocities during key phases of the lift, which may explain the enhanced PAP response.

Previous research has investigated the effects of differing contraction velocities during the CA, by utilising Olympic style lifts. Andrews et al. (1) and Seitz et al. (30) found that Olympic style lifts were superior in evoking PAP in comparison to conventional methods, highlighting that the ability to produce high forces at high velocities may influence the PAP response. Conversely, McCann and Flanagan (24) reported no differences between the PAP response of BS and hang clean on CMJ performance. Perhaps, the technical demands of the Olympic style lifts are also a contributing factor to the ambiguous findings. Additionally, the optimal ICRI for Olympic style lifts is reported at 7-10 minutes post-CA (29, 30), further emphasising the advantages of HBD demonstrated in this study.

The present study found no significant improvements in CMJ performance following BS, which is in agreement with previous research (6, 19, 24). However, it is important to note that the ICRIs were relatively short in these studies (10 seconds – 6 minutes) and may not have been adequate for PAP to occur. These results are substantiated by Jones and Lees (20) who reported no improvement in CMJ performance at 3, 10 or 20 minutes post-CA. However, the authors recognise that there was a small sample size (n = 8) and that the trends in the data were not significant as a result. Contrastingly, Kilduff et al. (22) reported significant increases in CMJ performance 8 minutes following heavy load BS with professional rugby union players. Crewther et al. (7) also found significant improvements in CMJ performance after a single set of 3RM BS at ICRIs of 4, 8, and 12 minutes in professional rugby union players. Collectively, research indicates that BS decreases performance with shorter ICRIs but may be an appropriate CA for well-trained athletes (7, 19, 21, 22, 28).

In the present study, there were no significant differences between stronger and weaker players in any of the dependent variables. This finding conflicts with previous research which has suggested that training status is a modulating factor in eliciting PAP (17, 26, 28). Kilduff et al. (21) found a significant correlation between strength levels and the magnitude of the

PAP effect. Seitz et al. (28) reported that individuals able to squat ≥2 x body mass expressed a significantly greater PAP response than individuals who squatted <2 x body mass. In the present study, the relative 1RM BS scores for stronger and weaker players were 1.75 ± 0.32 and 1.24 ± 0.14, respectively. Whereas, the relative 1RM HBD scores were 2.11 ± 0.24 and 1.76 ± 0.28 for stronger and weaker players, respectively. This may further explain why HBD induced a greater PAP response.

Due to HBD being a less technically demanding exercise, it was possible for a greater absolute load to be lifted, which is likely to have heightened the PAP response. A possible explanation for this enhanced response is that it may have elevated the phosphorylation of myosin regulatory light chains (33, 35). The increased load may have caused a greater increase in sarcoplasmic Ca^{2+}, therefore activating more myosin light chain kinase. Consequently, the amount of ATP available at the actin-myosin complex may have increased therefore, increasing the rate of actin-myosin cross-bridging.

Another underpinning mechanism of PAP is enhanced neural excitability within type II muscle fibres (17, 28). In the present study muscle fibre type was not assessed however, neural activation was assessed using surface EMG. Few studies have examined the effects of PAP with EMG analysis. This study highlighted a large amount of variability within the EMG data, with no significant changes in muscle activation and no clear trends when interpreting the mean differences of the data. Therefore, no conclusions can be drawn from the EMG data of this study about the underlying mechanisms of PAP. This is in agreement with Jones and Lees (20) who reported no significant differences in EMG data and high variability within the data. Ebben et al. (11) also reported no significant improvements in EMG variables during upper body CT. Both of these studies reported no significant changes, which is in agreement with the present study. This evidence conflicts with the suggestion that the underlying mechanism of PAP is due to the recruitment of higher order motor units (40).

Some studies of similar design have failed to include a control group (24, 28). The control group in the present study highlighted no potentiating effects due to the warm up protocol or due to earlier CMJs in the time course inducing a PAP response on later CMJs. It is likely that the PAP response was due to the CAs as previous studies have demonstrated this using a control group (19, 22, 30). However, there appeared to be fatiguing effects due to the CMJs. Andrews et al. (1) and Weber et al. (38) reported significant decreases in jump performance during the control conditions of their experimental protocols. Additionally, Jones and Lees (20) reported no significant decrease during their control trials however, when interpreting the data it is clear that there was a mean decrease in jump performance over time. Therefore, future research should carefully consider the post-CA recovery intervals to ensure there is no fatiguing effects due to the CMJs.

In conclusion, the results of this study suggest that the optimal ICRI for HBD lies between 2 and 6 minutes, which is earlier than the 4-12 minutes proposed by previous research for the BS. It is likely that the concentric only contraction induced by the HBD enhances the PAP response and reduces neuromuscular fatigue as less time is spent under tension. CT appears to be a suitable training modality for both stronger and weaker rugby league players when HBD is used as a CA. Future research should investigate the effects of CAs with different force-velocity profiles and the impact this has on subsequent plyometric performance as contraction velocity could be an influential factor in eliciting PAP. Further research is required to understand the underpinning neuromuscular mechanisms of PAP. Lastly, future studies should carefully consider the post-CA ICRIs, or only choose one post-CA ICRI, as too many post-CA measures may induce additional fatigue.

PRACTICAL APPLICATIONS

Based on the findings of the current study, strength and conditioning coaches should carefully consider exercise selection when implementing CT to enhance lower body power. Although training status has been highlighted as an important factor in eliciting PAP response, it appears that the absolute load which is lifted may also influence PAP. HBD is an effective potentiating stimulus as it is a safer, less technically demanding exercise which enables a greater load to be lifted. The results of this study suggest that an ICRI of 2-6 minutes is optimal for HBD and it appears to be a suitable CA for stronger and weaker athletes. When designing CT programmes strength and conditioning specialists should consider the training status of the individuals, the most appropriate CA, and the recovery interval between the CA and subsequent plyometric exercise to optimise performance.

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TABLES

Table 1. Anthropometric and physical characteristics of the participants (n = 20)*

Variable	Stronger (n=10) Mean ± SD	Weaker (n=10) Mean ± SD	p value
Age (years)	22.30 ± 2.91	19.10 ± 1.10	0.004
Height (cm)	178.99 ± 6.52	183.75 ± 5.67	0.98
Weight (kg)	85.89 ± 11.47	88.35 ± 11.93	0.644
1RM Back Squat (kg)	149.50 ± 27.30	109.00 ± 15.69	0.001
1RM Hex Bar Deadlift (kg)	180.50 ± 22.42	154.00 ± 17.57	0.009
Relative 1RM Back Squat (kg/kg)	1.75 ± 0.32	1.24 ± 0.14	< 0.001
Relative 1RM Hex Bar Deadlift (kg/kg)	2.11 ± 0.24	1.76 ± 0.28	0.008

Table 2. Absolute 1RM loads lifted by the participants*

Participants	Hex Bar Deadlift (kg) Mean ± SD	Back Squat (kg) Mean ± SD	p value
All (n =20)	167.25 ± 23.85	129.25 ± 30.02	< 0.001
Stronger (n =10)	180.50 ± 22.42	149.5 ± 27.30	< 0.001
Weaker (n = 10)	154.00 ± 17.57	109. 00 ± 15.69	0.146

*1RM = 1 repetition maximum

Table 3. Relative 1RM loads lifted by the participants*

Participants	Relative 1RM Hex Bar Deadlift (kg/kg)	Relative 1RM Back Squat Deadlift (kg/kg)	p value
All (n =20)	1.94 ± 0.31	1.49 ± 0.35	< 0.001
Stronger (n =10)	2.11 ± 0.24	1.75 ± 0.32	< 0.001
Weaker (n = 10)	1.77 ± 0.28	1.24 ± 0.14	0.042

*1RM = 1 repetition maximum

Table 4. Mean ± SD jump height for all post-CA jump. Values expressed as a percentage difference from the baseline jump

	Jump Height					
	Overall	**Hex Bar**	**Back Squat**	**Stronger**	**Weaker**	**Control**
2 minutes	0.84 ± 6.67	2.57 ± 7.2	-0.88 ± 5.77	1.17 ± 4.92	0.52 ± 8.18	-2.63 ± 5.56
4 minutes	-1.67 ± 8.26	-1.71 ± 10.34	-1.62 ± 5.76	-0.74 ± 6.69	-2.60 ± 9.68	-2.85 ± 5.01
6 minutes	0.80 ± 9.08	2.46 ± 9.65	-0.85 ± 8.38	1.60 ± 8.77	0.01 ± 9.53	-2.37 ± 5.69
8 minutes	-1.34 ± 8.55	0.04 ± 9.95	-2.73 ± 6.85	-0.86 ± 7.44	-0.86 ± 7.44	-8.42 ± 6.4
10 minutes	-2.48 ± 8.55	-1.34 ± 10.14	-3.63 ± 6.66	-1.32 ± 7.39	-3.65 ± 9.62	-8.39 ± 5.07
12 minutes	-2.65 ± 8.99	-1.46 ± 10.8	-3.84 ± 6.8	-3.00 ± 8.76	-2.3 ± 9.42	-8.33 ± 7.75
14 minutes	-4.45 ± 8.53	-3.80 ± 9.06	-5.09 ± 8.14	-4.26 ± 7.08	-4.64 ± 9.95	-10.96 ± 7.71
16 minutes	-4.69 ± 9.07	-1.98 ± 10.89	-7.4 ± 5.89	-4.28 ± 8.04	-5.10 ± 10.19	-8.77 ± 6.42

*CA = conditioning activity

FIGURES

Figure 1. A schematic representation of the study design. 1RM = 1 repetition maximum; CA = conditioning activity

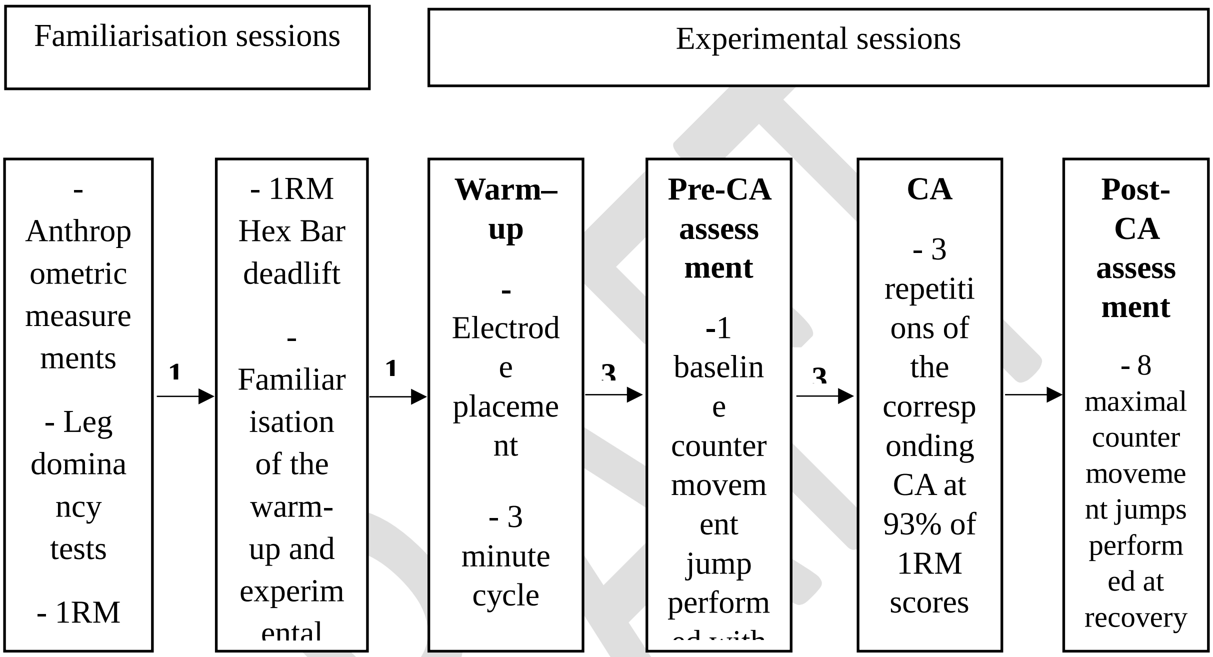

Figure 2. The vertical force trace from a participant performing a countermovement jump. *Note:* point ‘a’ represents the start of the jump; point ‘b’ represents take-off; point ‘c’ represents landing.

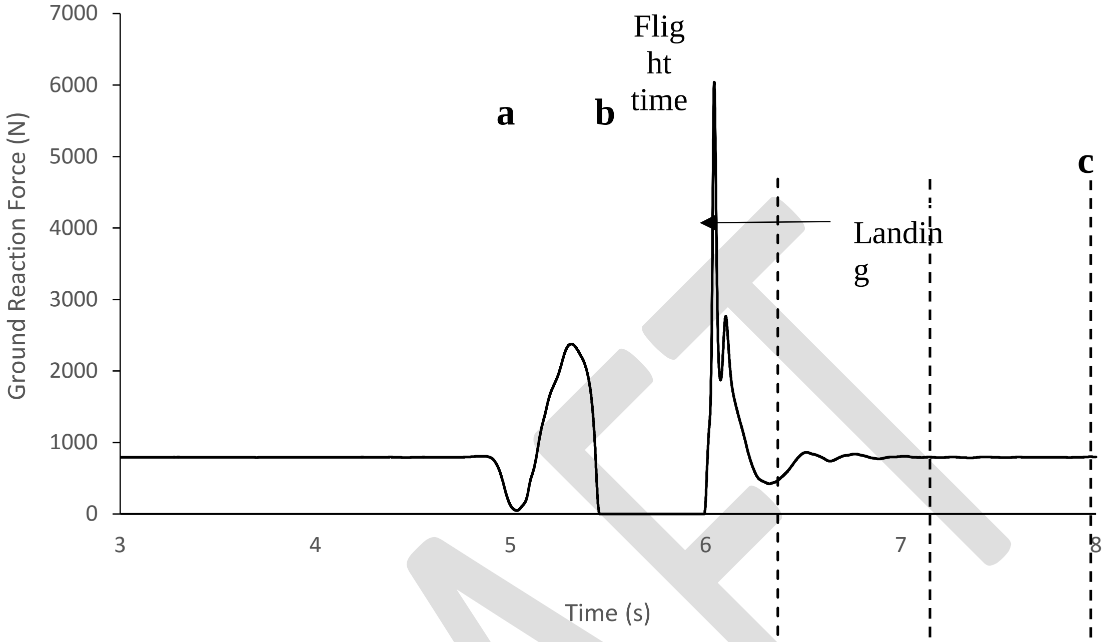

Figure 3. A) PPO PAP response during the series of CMJs for the hexbar deadlift and back squat exercises. B) Time course for the control trial. All results are expressed as a percentage of baseline. *significantly different from baseline ($p \leq 0.05$). ┼hexbar condition significantly different to back squat condition. PPO = peak power output; CA = conditioning activity; PAP = post-activation potentiation; CMJ = countermovement jump

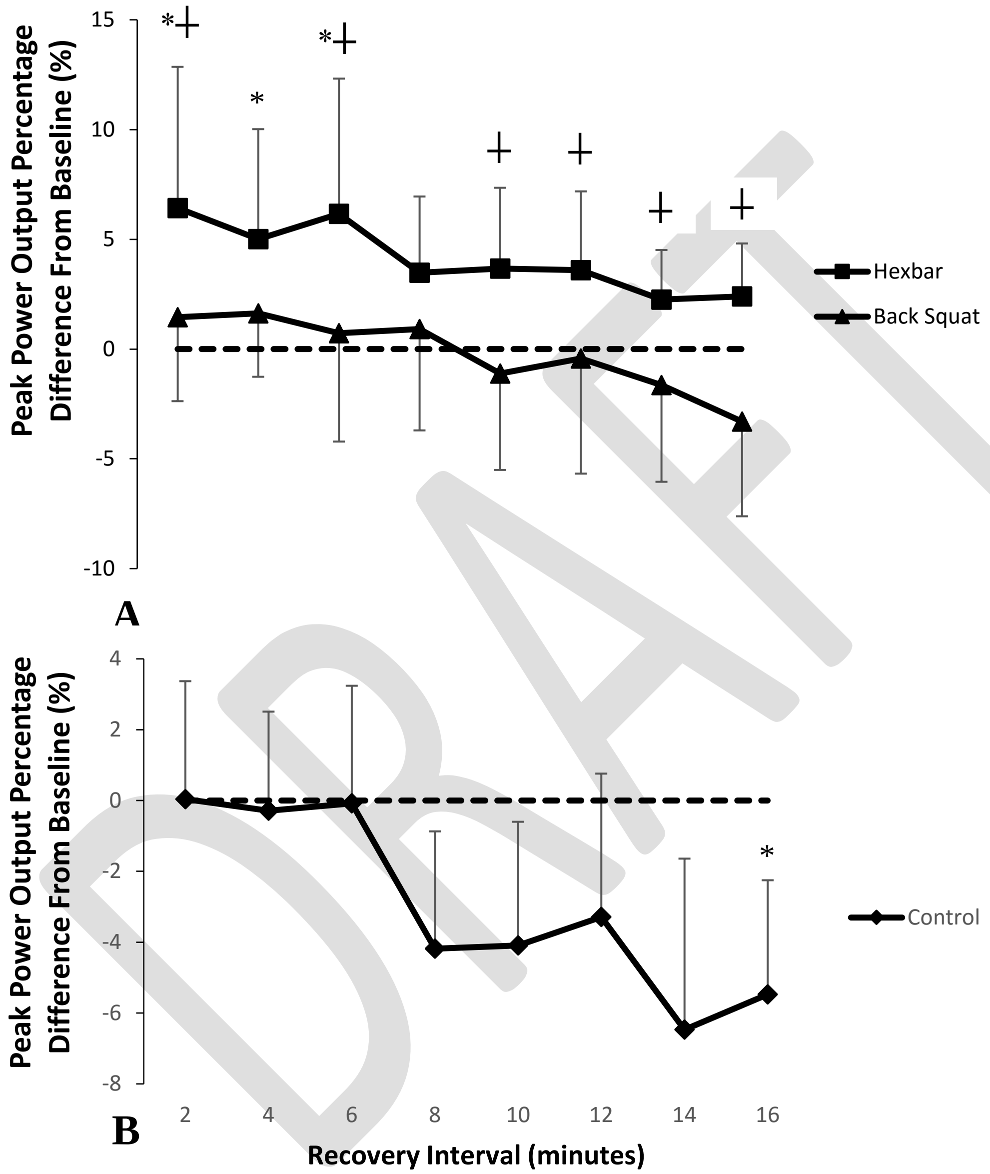

Figure 4. Force at PPO PAP response during the series of CMJs for both exercises and both playing levels. All results are expressed as a percentage of baseline. *significantly different from baseline ($p \leq 0.05$). PPO = peak power output; CA = conditioning activity; PAP = post-activation potentiation; CMJ = countermovement jump.

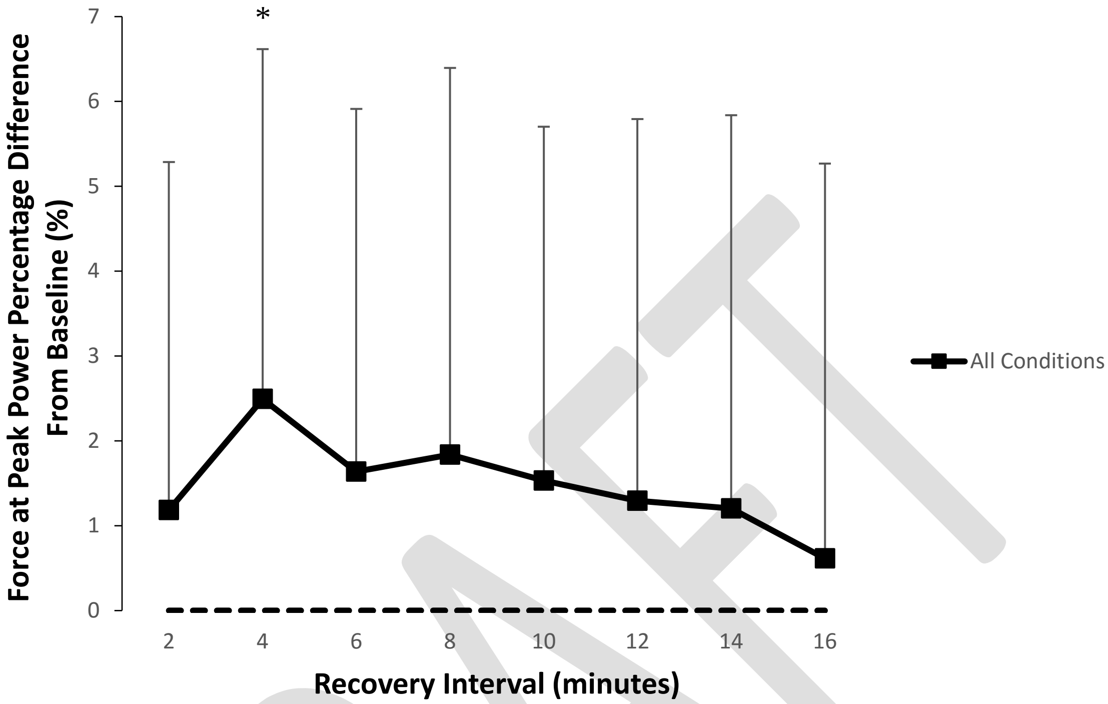

Figure 5. A) Velocity at PPO PAP response during the series of CMJs for both exercises and both playing levels. B) Time course for the control trial. All results are expressed as a percentage of baseline. *significantly different from baseline ($p \leq 0.05$). PPO = peak power output; CA = conditioning activity; PAP = post-activation potentiation; CMJ = countermovement jump