The Acute Potentiating Effects of Back Squats on Athlete Performance

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Abstract

Crewther, BT, Kilduff, LP, Cook, CJ, Middleton, MK, Bunce, PJ, and Yang, G-Z. The acute potentiating effects of back squats on athlete performance. *J Strength Cond Res* 25(12): 3319–3325, 2011—This study examined the acute potentiating effects of back squats on athlete performance with a specific focus on movement specificity and the individual timing of potentiation. Nine subelite male rugby players performed 3 protocols on separate occasions using a randomized, cross-over, and counterbalanced design. Each protocol consisted of performance testing before a single set of 3 repetition maximum (3RM) back squats, followed by retesting at ~15 seconds, 4, 8, 12, and 16 minutes. The 3 tests were countermovement jumps (CMJs), sprint performance (5 and 10 m), and 3-m horizontal sled pushes with a 100-kg load. Relationships between the individual changes in salivary testosterone and cortisol concentrations and performance were also examined. The 3RM squats significantly ($p < 0.001$) improved CMJ height at 4 (3.9 ± 1.9%), 8 (3.5 ± 1.5%), and 12 (3.0 ± 1.4%) minutes compared with baseline values, but no temporal changes in sprinting and sled times were identified. On an individual level, the peak relative changes in CMJ height (6.4 ± 2.1%, $p < 0.001$) were greater than the 3-m sled (1.4 ± 0.6%), 5-m (2.6 ± 1.0%), and 10-m sprint tests (1.8 ± 1.0%). In conclusion, a single set of 3RM squats was found effective in acutely enhancing CMJ height in the study population, especially when the recovery period was individualized for each athlete. The study results also suggest that the potentiating effects of squats may exhibit some degree of movement specificity, being greater for those exercises with similar movement patterns. The current findings have practical implications for prescribing warm-up exercises, individualizing training programs, and for interpreting post-activation potentiation research.

Key Words postactivation potentiation, muscle, training, warm-up

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Introduction

Postactivation potentiation (PAP) is a well recognized phenomenon that involves the preconditioning of muscle through heavy exercise to induce acute improvements in human performance during sprinting, running, throwing, and weightlifting activities (20,39). The mechanism for PAP has been primarily attributed to the phosphorylation of myosin regulatory light chains, which make the protein filaments actin and myosin more sensitive to the release of calcium (Ca^{2+}), and this triggers a cascade of events to enhance the muscle response (21). The recruitment and subsequent expression of the high order motor units offer a secondary mechanism to explain PAP response of muscles (39).

Back squats are one of the most commonly performed training exercises in sport and most, if not all, training facilities have the basic equipment needed for squatting. Squats have been widely used across research to elicit a PAP response in either highly trained, recreationally trained, or untrained populations (see reviews on this topic [20,33,39]). Despite the fact that many studies investigating PAP have reported improvements in functional performance after different squatting exercises and protocols (5–7,18,23,24), a similar number have also reported no changes in the performance outcomes (2,27,29,32,37,40).

A lack of movement specificity between the PAP stimulus and testing exercises offers one potential explanation for this variability. Dynamic contractions have been shown to display potentiation patterns related to joint angle (30), muscle fiber activation (30), and stretching velocity (17). Thus, it may be reasoned that back squats are more likely to potentiate exercises with similar biomechanical patterns (e.g., countermovement jumps [CMJs]) than other lower-body exercises with dissimilar movement patterns (e.g., sprints). In support

Table 1. Physical characteristics of participants.*

Variables	Mean ± *SD*
Age (y)	20.1 ± 0.9
Body mass (kg)	99.9 ± 9.1
Height (cm)	184.4 ± 5.5
Squat 3RM (kg)	156.7 ± 18.0

*3RM = 3 repetition maximum.

of this concept, differential PAP effects on sprint performance were noted in response to either front squats or back squats (41). However, little research has directly addressed the movement-specific effects of back squats (as a PAP stimulus) on functional whole-body exercises and in an athletic population.

The inconsistencies observed could also be explained by individual variation in the timing of potentiation. This is highlighted by studies that have reported no changes in group performance (i.e., main effects) after squats or other loading exercises (2,22,29,38), but further examination of the peak responses of individuals (irrespective of their timing) did reveal significant performance improvements. Potentially, when group changes in performance do occur, the magnitude of potentiation occurring on an individual level could actually exceed that reported. These findings emphasize the need to address both the group and individual PAP responses, especially for athletic populations where the observed results may strongly influence training practice.

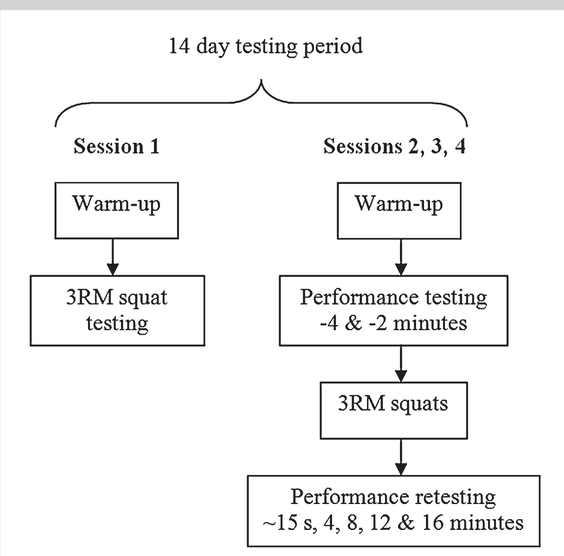

Figure 1. Experimental design. 3RM = 3 repetition maximum.

This study sought to examine the acute potentiating effects of back squats on athlete performance with a specific focus on movement specificity (i.e., by testing jumps, sprints and sled movements) and the individual timing of potentiation (i.e., by comparing the peak individual responses over time). It was hypothesized that the potentiation of performance (if it occurred) would be greater for those tests with similar movement patterns. A further hypothesis was that the timing of potentiation would differ between each athlete so that the peak individual responses would be greater than any group response occurring over time.

Methods

Experimental Approach to the Problem

A randomized, crossover, and counterbalanced design was used to examine the effects of back squats on athlete performance. Backs squats were chosen because they are easy to implement and have proven ability to potentiate performance (23,24). The chosen tests (i.e., sprints, sled pushes, CMJs) were instrumented to provide performance outputs relevant to the study population (i.e., rugby union players), such as speed and power (15), and they allowed direct comparisons between lower-body exercises with different movement patterns. Rugby union is a popular contact sport involving 2 teams of 15 players and each team is made up of 2 distinct playing units, with forwards primarily considered the 'ball winners' and backs the 'ball carriers' (15). Based on correlational studies in athletes (10–12), the possibility that the performance changes might be related to individual testosterone and cortisol concentrations was also addressed. To improve the validity of our findings, the study protocols were implemented within normal training procedures.

Subjects

Nine subelite male rugby players who could squat 1.5 times their body mass (based on their 3 repetition maximum [3RM] lifts in Table 1) were recruited. They were part of a high-performance training squad for a professional rugby union team and were actively involved in weight training at the time of this study (i.e., rugby off-season). During the experimental period, subjects were performing specific training that included strength, sports speed, skill, and game conditioning. Each subject had the risks and benefits of the investigation explained to them, and they filled out a health questionnaire and provided written informed consent before the study commencement. The Human Subject Ethics Committee of Swansea University provided ethical approval.

Study Protocols

This study was conducted over a 14-day period at the start of the rugby off-season (Figure 1). Testing occurred across 4 sessions each separated by 2–5 days of rest and supplementary training. In the first session, subjects were assessed for their 3RM back squats using an Olympic barbell and free weights (8). Briefly, a loaded bar was placed across the shoulders and upper back, with feet slightly wider than

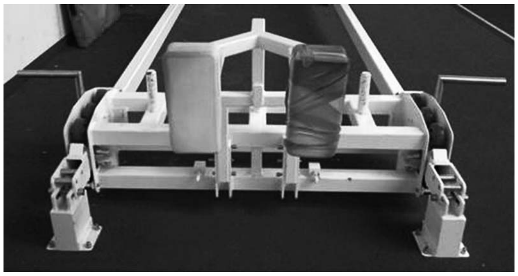

Figure 2. Frontal view of the Assassin machine.

shoulder width apart. Subjects then squatted down until the midthigh was parallel to the ground, before returning to the start position without assistance. The loads started at 40–60% of perceived subject 3RM (using a 4–8 repetition range) and then increased until a 3RM lift was achieved within 3–4 sets. Recovery periods of 2–3 minutes were provided between trials to reduce any fatigue effects. The 3RM testing of squats is very reliable (coefficients of variation [CV] = 1.5%) in trained men (8). Five days after the 3RM assessments, subjects performed the 3 remaining sessions in a randomized order.

The testing protocols were based on previous research (23,24). Before testing, a standard warm-up was performed comprising of dynamic exercises (e.g., squats, jumps, stride outs) and stretching of the lower-body muscle groups. Countermovement jumps, 5-m and 10-m sprints, and 3-m horizontal sled pushes were each assessed in a separate session. Each session involved single repetition performance testing at 4 and 2 minutes before a single set of 3RM back squats, followed by retesting at ~15 seconds, 4, 8, 12, and 16 minutes. Two baseline tests were performed before the squats to determine whether a learning or warm-up effect occurred, and these were averaged for analysis. Subjects were seated between each trial to reduce any fatigue effects. Testing

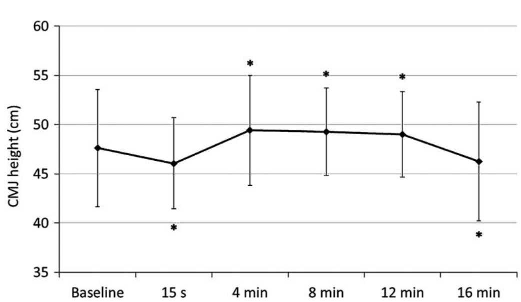

Figure 3. Countermovement jump height before and after the 3 repetition maximum squats (mean ± *SD*). *Significantly different from baseline $p < 0.01$.

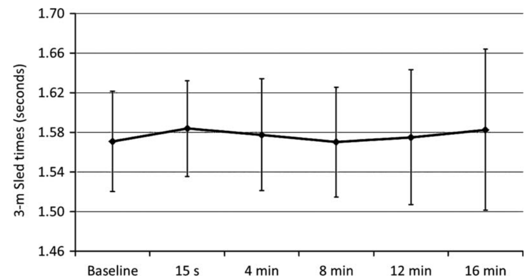

Figure 4. Horizontal sled times before and after the 3 repetition maximum squats (mean ± *SD*).

was performed at a similar time of day (8.30 AM ± 1 hour) to account for diurnal variation in sporting performance (14) and hormones (9). Subjects were instructed to replicate their dietary intake 24 hours before each session. Water was allowed during testing but was stopped 5 minutes before sample collection to prevent dilution of the saliva samples.

Performance Testing

The CMJs were performed with a light bar (<1 kg) placed across the shoulders and upper back, with feet slightly wider than shoulder width apart. The bar was used to eliminate arm mechanics during the vertical jump. Subjects squatted down to a self-selected depth before explosively jumping to achieve maximal height. The CMJs were performed on a jump mat (Probotics Inc., Huntsville, AL, USA), which calculated height based on flight times. This technology provides valid measures of vertical jump height compared to a criterion system ($r = 0.967$) (25). Pilot testing indicated that the jump mat system also provides reliable (CVs < 2.0%) measures of jump height. The sprints were assessed using an electronic timing system (Brower Timing System, Draper, UT, USA) that recorded times to an accuracy of 0.01 seconds. Timing started when the first beam was broken. Subjects started in a crouched position 0.5 m behind a set of timing lights before sprinting through lights placed at 5 and 10 m from the first set. The assessment of sprint times is highly reliable (CVs = 1.9–2.0%) in trained men (8).

The horizontal sled pushes were performed on the 'Assassin,' a custom-built machine resembling a rugby scrum machine (Figure 2). The Assassin consists of a wheel-based sled that moves along 2 runners on either side of a steel frame (1.8 m × 7.2 m × 1.1 m) secured to the ground with steel bolts. Two pads were attached to the front of the sled, and this allowed subjects to push maximally against the sled with only minimal discomfort. Subjects started in a semicrouched position with their shoulders lightly touching the pads, before explosively pushing the sled a distance of ~3.5 m. Hydraulic arms protruding from the end of each runner slowed the sled down. Timing lights were used to assess sled movement times with the first set placed 10 cm in front of the

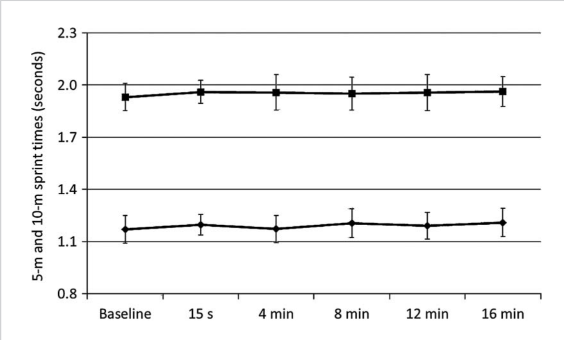

Figure 5. Sprint times before and after the 3 repetition maximum squats (mean ± *SD*).

sled itself and then 3 m from the first set. Based on pilot testing the frame runners were set on level 4 for this study, equivalent to an incline of ~3°, and additional resistance was provided by placing a 100-kg load into 2 receptacles (50 kg each) within the sled itself.

Hormone Testing

The hormone collection and testing procedures are based on previous research (10–12). Whole saliva samples were collected by passive drool before and after each session. Subjects were given sugar-free gum (Wrigley's, Plymouth, United Kingdom) to stimulate saliva flow and the samples were frozen at −20°C before assay. The samples were analyzed in duplicate for testosterone and cortisol using commercial kits (Salimetrics, State College, PA, USA) and the manufacturer's guidelines. The minimum detection limit for the testosterone assay was 6.1 pg·mL with interassay CV of 8.3–10.6%. The cortisol assay had a detection limit of 0.012 μg·dL with intra and interassay CVs of 5.0–9.8%. The samples for each subject were analyzed within the same assay run to eliminate the effects of interassay variance.

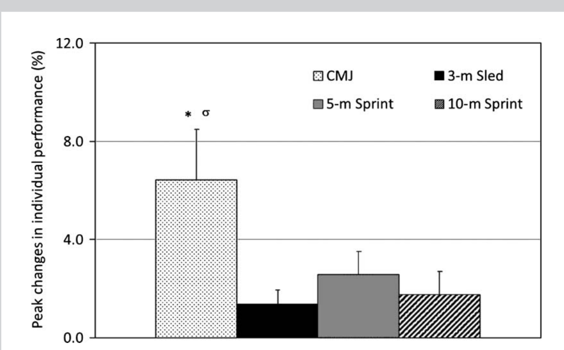

Figure 6. Peak relative improvements in individual performance (mean ± *SE*). *Significantly different from baseline, $p < 0.001$; σSignificantly different from the other tests, $p < 0.05$.

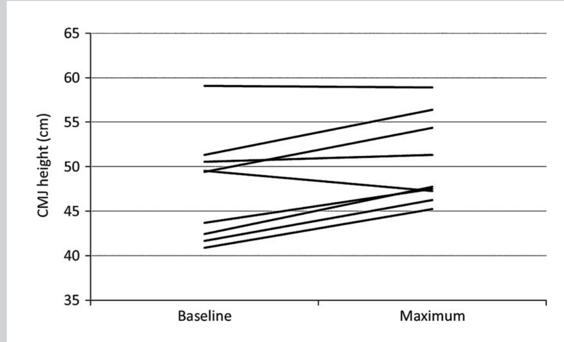

Figure 7. Peak individual responses for the countermovement jump test.

Statistical Analyses

Normality testing was conducted on the independent variables before analyses. For each test, the changes in performance (vs. baseline values) were examined using analysis of variance (ANOVA) with repeated measures. The maximum percent changes in individual performance (vs. baseline values) were examined and compared using ANOVA with repeated measures. Fisher's protected test for least significant differences was used as the post hoc procedure where appropriate. Cohen's effect sizes are presented for all of the significant findings. Relationships between the individual changes in the hormonal and performance variables were assessed using Pearson product–moment correlation coefficients. The significance level was set at $p \leq 0.05$.

Results

There were no significant baseline differences for any performance measure ($p = 0.208$–0.861). A significant main effect was identified when examining the temporal changes in CMJ height ($p < 0.001$, Figure 3). Post hoc analyses revealed a significant ($p < 0.01$–0.001) reduction in CMJ height at 15 seconds (−3.3 ± 1.5%, effect size = −0.29) from baseline values, followed by improvements at 4 (3.8 ± 1.9%, effect size = 0.31), 8 (3.5 ± 1.5%, effect size = 0.32), and 12 (3.0 ± 1.4%, effect size = 0.27) minutes, and then a further decrease in CMJ performance at 16 minutes (−2.9 ± 2.0%, effect size = −0.23). No significant main effects were identified for the 3-m sled test ($p = 0.913$, Figure 4) and the 5-m ($p = 0.347$) and 10-m ($p = 0.807$) sprints over time (both Figure 5).

On an individual level, a significant main effect was identified for the peak relative changes in test performance ($p = 0.03$, Figure 6). Post hoc analyses indicated a significant improvement in CMJ height (6.4 ± 2.1%, $p < 0.001$, effect size = 0.53) from baseline, but there were no such changes in the 3-m sled test (1.4 ± 0.6%) and the 5-m (2.6 ± 1.0%) and 10-m (1.8 ± 1.0%) sprints. The relative change in CMJ height was also significantly ($p = 0.033$–0.006) greater than the other tests. Figure 7 shows the individual response patterns for the CMJ test.

No significant main effects were identified for either the testosterone or cortisol variables across the 3 days of testing ($p = 0.150–0.823$). When the testosterone to cortisol ratio data were examined no significant main effects were found pretesting ($p = 0.406$), but the posttesting values approached significance ($p = 0.07$). No significant relationships were identified between the individual relative changes in hormones and peak performance across any test.

Discussion

This study had 2 major findings: first, a single set of back squats acutely enhanced CMJ performance, especially when the recovery period was individualized for each athlete, and second, the group and individual results indicate that movement-pattern specificity is another important consideration when attempting to potentiate athlete performance using back squats. No relationships were identified between the individual changes in hormones and performance after the back squats.

In the current format, a single set of 3RM squats was effective in acutely enhancing CMJ performance in the study population. This result is consistent with previous PAP research using different squatting protocols (5,7,18,23,24,31,34–36,42). The transient improvements in CMJ height at 4, 8, and 12 minutes were preceded by an initial performance reduction at 15 seconds, as others have found (18,23,24). These data confirm the fatigue may dominate during the early recovery stages so that performance of subsequent voluntary activity may be diminished or unchanged (39). The data presented also support the hypothesis that fatigue and potentiation can coexist in skeletal muscle (33). That is, a preloading stimulus can provide both performance enhancing and inhibiting effects with each expressed on different timescales. The realization of PAP will only occur after sufficient recovery is provided after the initial stimulus to allow the performance enhancing mechanisms to outweigh the inhibitory mechanisms (33).

Subject characteristics such as muscular strength, fiber type distribution, training type and level, and the strength-power ratio can influence the potentiation response (39). For instance, greater changes in CMJ height have been observed in stronger, more experienced athletes or individuals compared to less trained athletes or weaker individuals (7,19,34). The importance of strength is confirmed by correlations between individual strength and the magnitude of the performance changes occurring (24,35,40,42). However, we found no correlations between 3RM squat strength and the relative performance changes in each test (data not shown). Strength training may also increase the probability of PAP occurring by developing the type II fibers and allowing more of the high-threshold motor units to be recruited (34). Indeed, some athletes may possess a greater percentage of type II fibers to actualize these effects (7). Some of these factors are applicable to the current population and could help to explain the positive changes in CMJ performance after the squatting protocol.

The inability of the 3RM squats to potentiate sprinting and sled performance could be attributed to the dissimilar movement patterns of the squats and the assessed exercises. Similarly, differential effects on sprinting performance were noted in response to either front squats or back squats (41). Dynamic contractions have also been shown to display potentiation patterns specific to joint angle, muscle fiber activation (30), and stretching velocity (17). Nevertheless, the effects of preloading stimuli on sprinting outcomes are equivocal with reports of improvements (6,26,41), no changes in performance (2,38), or variable results depending on the distance examined (28) and the time of assessment (6). This variability could also be explained by the actual protocols used to induce PAP and subject-related factors, as described previously. The assessment of a loaded, horizontal sled test is unique to this study, but the biomechanics of this test would seem relevant for many sports (e.g., rugby, judo, wrestling) and should therefore be employed in future studies.

In support of our initial hypothesis, the peak individual changes in CMJ performance (6.4%) were superior to the group results over time (3.0–3.8%). This finding is supported by studies that have reported no changes in group performance (2,22,29,38), but when further testing was carried out on the individual response patterns (irrespective of their timing) significant improvements were noted. Our results can be attributed to differences in the timing of PAP with 2 subjects peaking at 4 minutes, 3 at 8 minutes, and 2 at 12 minutes. Two subjects exhibited a reduced performance across all time points. The greater relative changes in individual CMJ height (vs. sled and sprint tests) also suggest that the potentiating effects of the back squats may exhibit some degree of movement specificity. Given the magnitude of the individual PAP responses occurring across research (6–9%), it would be prudent to determine whether the use of PAP and individual recovery periods can benefit training workouts and long-term performance gains.

Previous studies on athletes (e.g., rugby, soccer) have indicated that the expression of power and strength may be related to individual hormonal profiles (3,4,10–12), but we found no relationships between the hormonal and performance variables. It is noteworthy that the cited studies tested elite athletic groups with more advanced training backgrounds. Furthermore, the rugby players tested in previous studies were shown to exhibit greater absolute squat strength (estimated 1RM = 180–211 kg) than the current population (estimated 1RM = 167 kg) (10–12). Therefore, in this athletic population, one's ability to use the hormonal milieu may also be determined by additional training and strength-related factors. Indeed, the training and development of the type II fibers may help to realize the testosterone and cortisol effects because these structures are more sensitive to the steroid actions (1,16). Resistance training may also help to regulate androgen receptor content in type II muscle fibers (13). The possibility of differential hormonal effects between stronger and weaker athletes should be addressed using acute and longitudinal research designs.

In conclusion, a single set of 3RM squats was found effective in acutely enhancing CMJ height in an athletic population but more so when the recovery period was individualized for each athlete. The study results also suggest that the potentiating effects of squats may exhibit some degree of movement specificity, being greater for those exercises with similar movement patterns.

Practical Applications

The current findings have practical implications for strength-trained athletes. For example, the use of back squats as a warm-up or training stimulus for improving vertical jump performance, especially when the recovery period is individualized for each athlete. The sport-specific outcomes should determine the selection of the PAP stimuli to ensure similar movement patterns with the test exercises. Some possible examples include the use of vertical back squats to potentiate high jump performance and the use of horizontal squats for enhancing sprint starts. One must still consider other practicalities when applying PAP such as equipment availability, the influence of other exercises, training variation, and adaptations to a preloading stimulus. Our results further confirm the need for researchers and practitioners to interpret PAP studies from both a group and individual perspective.

Acknowledgments

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