Optimal Recovery Time for Postactivation Potentiation in Professional Soccer Players

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Abstract

Mola, JN, Bruce-Low, SS, and Burnet, SJ. Optimal recovery time for postactivation potentiation in professional soccer players. *J Strength Cond Res* 28(6): 1529–1537, 2014—Resistance exercise may acutely enhance muscle contractile activity, which is known as postactivation potentiation (PAP). Postactivation potentiation augments important skills that require power production that are necessary during soccer performance. The aim of this study was to determine the optimal recovery time to elicit PAP after a bout of high-intensity resistance exercise in professional soccer players. Twenty-two senior professional soccer players (mean [SD]; age, 23 [4.5] years; stature, 1.83 [6.6] m; body mass, 80.9 [7.8] kg) were randomized to either an experimental ($n = 11$) or a control group ($n = 11$). Both groups performed a standardized warm-up and baseline countermovement jump (CMJ) followed by a 10-minute recovery. The control group then performed a CMJ at 15 seconds and at 4, 8, 12, 16, and 20 minutes, whereas the experimental group performed a 3 repetition maximum (RM) squat and then an identical CMJ protocol. No significant differences were found between the groups for CMJ peak power ($p > 0.05$) or jump height ($p > 0.05$). No time effect for peak power ($F_{(6,60)} = 2.448$; $p = 0.063$) or jump height ($F_{(6,60)} = 2.399$; $p = 0.089$) was observed throughout the experimental group trials. Responders ($n = 6$) displayed individualized PAP profiles at 4 ($n = 3$), 12 ($n = 1$), and 16 ($n = 2$) minutes after conditioning contraction, whereas nonresponders ($n = 5$) did not. A set of 3RM squats failed to acutely potentiate all participants CMJ performance. Both PAP responders and nonresponders were identified and have individualized PAP time constants. This is not consistent with the previous literature, which used identical protocols. Strength and conditioning practitioners need to individualize recovery "windows" and identify athletes who respond to PAP before undertaking a complex training intervention.

Key Words strength, power, football, explosive

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Introduction

Recent literature has shown increasing interest in soccer performance (8,17). To date, sports organizations and scientists (5,19,34,36,37) have delineated various testing and training recommendations to improve the physical attributes associated with soccer performance. The physiological demands of soccer are multifaceted; players need to possess high levels of speed, endurance, repeated sprint ability, muscular strength, and power (36–38). Indeed, more successful teams' players demonstrate greater physical capacities in comparison to less successful teams (27,38).

The optimization of training programs and player fitness is a fundamental aspect of player and team preparation. Specifically, the ability to optimize muscular power is deemed fundamental for sports performance, especially in professional soccer (36,40). However, limited preseason and inseason training time restricts the implementation of programmes to develop strength and power. As such, programming must use time-efficient methods to optimize muscular development. Complex training has been suggested as an effective time-efficient method to concurrently increase both muscular strength and power (11) using biomechanically similar exercises (23). In complex training, a low-velocity high-intensity load (barbell squats >80–90% repetition maximum [RM]) is used before substantially greater-velocity lower-intensity loads (plyometric/vertical jumping), which increases power expression through postactivation potentiation (PAP).

Postactivation potentiation refers to a "phenomenon whereby muscular performance is enhanced acutely after an activity executed at a relatively higher intensity" (Lowery et al., p.3320 (29)) expressed as enhanced rate of force development and muscular power, augmenting explosive muscle actions such as jumping (25,26). Suggested mechanisms for PAP are the phosphorylation of myosin regulatory light chains, subsequently increasing myofibrillar sensitivity to Ca^{2+} secretion from the sarcoplasmic reticulum, and increased recruitment of higher order motor units (14,15,18,31). This acute enhancement of muscular power has been suggested as the premise upon which complex training is based (11). Through this enhancement of muscular power, complex training is expected to produce superior chronic exercise adaptation in comparison to traditional strength and power training combinations (11,14).

Methods of eliciting PAP are well established in sports other than soccer (4,25,26), however, literature is equivocal reporting detrimental effects of preloading (21) and the corresponding effects on fatigue and thus muscle contractility. Because the balance between fatigue and potentiation dictates muscle contractile function, the optimal recovery time after conditioning contraction (CC) needed to elicit PAP raises interest. Studies investigating recovery periods range from 15 seconds to 24 minutes (3,4,6,22,25,26). From this, it is apparent that optimal recovery after stimulus may be the deciding factor in PAP realization. In addition, training status has been shown to be a major determinant in actualizing PAP, whereas power trained athletes are better able to actualize PAP (4,6) because of greater fatigue resistance (14) and greater higher order motor units that are more sensitive to PAP mechanisms (14,15,18).

Therefore, the aim of this study was to determine the optimal recovery time required to elicit PAP after intense resistance exercise in senior professional soccer players. We hypothesized the effects of PAP will be displayed at 8 or 12 minutes after the CC in accordance with the researchers who observed this phenomenon in different professional sports other than soccer (25,26).

Methods

Experimental Approach to the Problem

Participants attended the laboratory once. Orientation included a study-brief, hydration assessment, and anthropometrics, consisting of stature and body mass using a stadiometer (Harpenden Anthropometer Holtain Ltd., Crymych, United Kingdom) and Seca scales (710 Flat Scales, Birmingham, United Kingdom), respectively. The experimental session was then completed in 2 phases. The first phase was to determine 3RM squat loading for the experimental group and to familiarize all participants with the experimental procedure, thereby reducing a learning effect during subsequent trials. All players had previously participated in and were familiar with vertical jump testing. A 30-minute seated washout period was prescribed between the first and second phase, thereby reducing the impact of residual fatigue and PAP within muscle (15). During the second phase, the experimental and control groups completed the PAP trial. The experimental group ($n = 11$) completed a standardized warm-up and then a baseline countermovement jump (CMJ) followed by a 10-minute recovery. Participants then performed a 3RM squat and CMJ's at 15 seconds and at 4, 8, 12, 16, and 20 minutes after the squat was completed (25,39). In contrast, the control group ($n = 11$) performed the baseline CMJ, 10-minute recovery, and subsequent CMJ protocol to ensure any effect was because of the 3RM squat CC.

Subjects

Based on a priori power analysis (standardized difference = [1.7/1.2 = 1.42]; $\alpha = 0.05$; $p\beta = 0.8$, where 1.7 = difference between mean values; 1.2 = population *SD*) (24,26), 22 professional soccer players, aged between 18–30 y, (Table 1) from the Npower football league 1 were recruited for this study. Players were randomly assigned to either the control ($n = 11$) or experimental ($n = 11$) groups. No difference ($p > 0.05$) between experimental or control groups body masses [76.6 (14) vs. 74.3 (10.7) kg] was observed. Inclusion criterion consisted of a 1-year minimum structured resistance training experience; there were no current injuries and abstinence from intense physical activity 72 hours before testing. Written informed consent and medical questionnaires were completed before participation. Ethical clearance was provided by the Center for Health, Exercise and Sport Science Ethics Committee, Southampton Solent University.

Testing took place during the first preseason training session at 12:00 PM. Before arrival at the laboratory, all participants were requested to consume their normal breakfast and hydrate for testing and to abstain from maximal exercise and alcohol and caffeine ingestion 72 and 48 hours before testing, respectively. Testing was grouped and conducted in a cyclical manner to complete trials as close together to avoid any between-trial circadian variations in strength and power expression (9). To ensure hydration was consistent between trials, participants were advised to consume ~1 L of water the night before and ~0.5 L of water the morning of testing. Hydration was tested by digital refractometry (Osmocheck Pocket, Vitech Scientific Ltd., West Sussex, United Kingdom). Participants with urine specific gravity ≥1.020 (23) were given an electrolyte-enhanced beverage. Participants consumed water ad libitum and wore identical footwear and clothing throughout trials.

Experimental Procedure

A standardized 5-minute cycle at 60 W (Ergomedic 874e Cycle, Monark, Sweden) and 2-minute dynamic stretching warm-up was completed, emphasizing musculature associated with the squat and CMJ to augment exercise performance, while avoiding the negative effects of static stretching on PAP (12). Dynamic stretching tempo was controlled at a moderate pace (1 second:1 second concentric:eccentric) to avoid stretch-induced potentiation (13).

Table 1. Sample characteristics (mean [*SD*]).

Anthropometrics and variables	Mean (*SD*)
Age (y)	23 (4.5)
Stature (m)	1.83 (6.6)
Body mass (kg)	80.9 (7.8)
Squat 3RM (kg)	88 (14)
Professional soccer experience (y)	5 (5.4)
Resistance training experience (y)	8 (1.4)

After the warm-up, 3 sets of squats (repetitions × %3RM) at 3 × 75%, 2 × 90%, and 1 × 100% of a previously recorded 3RM were completed with 4-minute recovery between sets for energy systems repletion (2). After completing the estimated 100% 3RM squat, load was increased by 2.5 kg until failure occurred in accordance with NSCA guidelines (2). A UKSCA certified strength coach supervised squat testing. All 3RM loadings were determined within 2 attempts. Depth was set in accordance with International Powerlifting Federation (20) guidelines. A 4:1:1:0 repetition tempo (eccentric: isometric:concentric:isometric) was used maintaining muscle tension throughout the squat and equate time under tension between squat determination and experimental sessions. All 3RM attempts used Olympic regulation barbells and bumpers (York, York fitness, United Kingdom).

Vertical jumping is considered a valid and reliable measure of lower extremity power (1). Arm swing, however, has shown to augment jump height (16), thereby reducing the efficacy of vertical jumping as a measure of lower extremity power. To isolate the lower limbs, participants placed their hands inside their pockets, remaining stationary on the platform for 2 seconds before jumping to a self-selected depth. Participants were familiarized with this jump technique before testing. Countermovement jumps used the optimal loading for power production (body mass only) (7). Verbal encouragement to maximize jump height was given to augment CMJ performance.

A Kistler (9287B, 3 component force platform; Kistler, Hook, United Kingdom; dimensions: 900 × 600 × 100 mm) force platform, analog-digital amplifier, and control unit (Bioware; Kistler, Hook, United Kingdom) was used to record jump height in the Fz axis. Calibration was checked with a known mass before testing (28). Data were sampled at 2,000 Hz for 6 seconds. Jump height was derived from time in air, identified as the duration between take-off and landing contact time using the assumption of uniform acceleration (equation 1 (1)).

$$\text{Jump height} = 1/2\ g\ (t/2)^2, \tag{1}$$

where $g = 9.81\ \text{m}\cdot\text{s}^{-2}$, $t =$ time in air.

A custom Matlab (Mathworks, Natick, MA, USA) software program capable of automatically calculating jump height and peak power was used to analyze trials. The equation of Sayers et al. (33) converted jump height into peak power because of the strong relationship between estimated and actual peak power in soccer players (35). Countermovement jump dependent variables were assessed as a percentage potentiation based on equation 2 (6).

$$\text{Potentiation} = \frac{\text{Potentiated Variable}}{\text{Unpotentiated Variable}} \times 100 \tag{2}$$

Percent potentiation equal to 100% indicates no potentiation, >100% indicates PAP, and <100% indicates postactivation depression (PAD) (6). Percent potentiation was calculated for CMJ's at 15 seconds, 4, 8, 12, 16, and 20 minutes after the 3RM squat in the experimental group. The baseline CMJ jumped served as the 100% mark with the potentiated variable representing the experimental group, and the unpotentiated variable representing the control group.

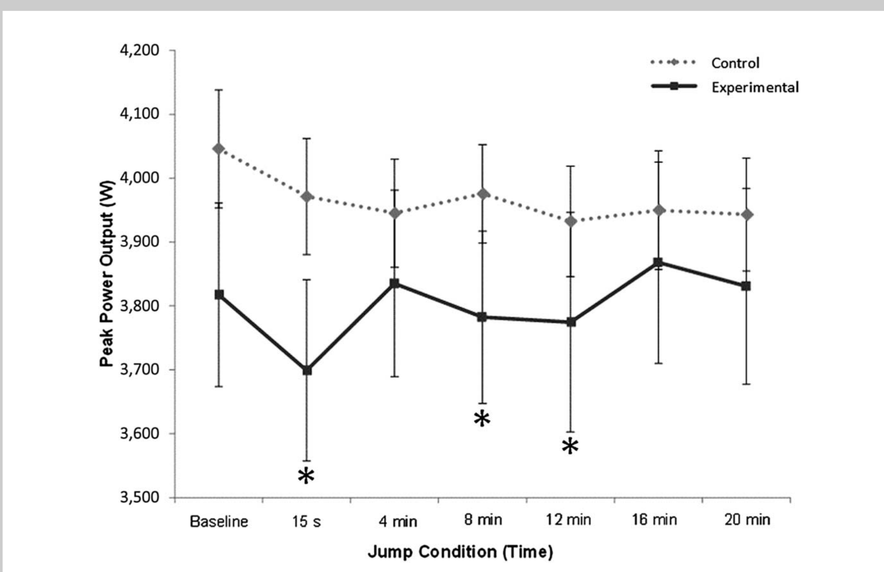

Figure 1. Jump peak power output before and after conditioning contraction (CC) in experimental group and without CC for control group (expressed as mean [*SD*]). *Significant difference from baseline ($p \leq 0.05$).

Statistical Analyses

Descriptive statistics (Mean [*SD*]) were used to summarize the data. A 1-way repeated measures analysis of variance (ANOVA) with a simple contrast was used to examine differences between baseline and experimental jumps within the conditions. Independent samples *t*-tests with a Bonferroni's correction ($\alpha/21$) were used to test between group differences. Significance was set at $\alpha = 0.05$. Analysis was performed using SPSS v20 (SPSS Inc., Chicago, IL, USA).

Results

Within Group Data Analysis: Repeated Jump Peak Power

Repeated measures ANOVA revealed a nonsignificant time effect in the experimental

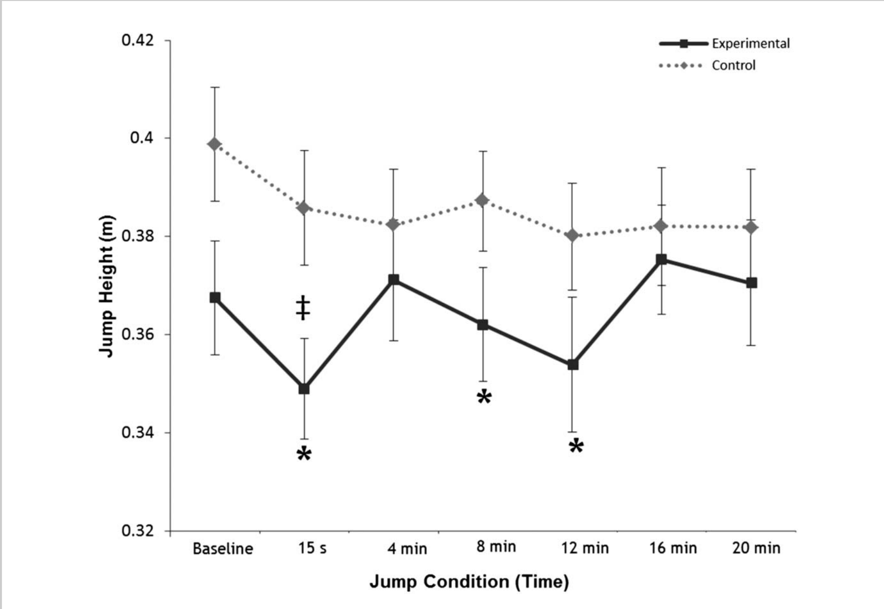

Figure 2. Jump height before and after conditioning contraction (CC) in experimental group and without CC for control group (expressed as mean [*SD*]). *Significant difference from baseline ($p \leq 0.05$); ‡Significant difference between groups ($p < 0.002$).

baseline after a 4-minute recovery. A significant decrease in peak power was detected after 8 and 12 minutes when compared with the baseline ($p \leq 0.05$). No significant differences from baseline were observed for peak power for 16- and 20-minute recovery (Figure 1). No significant differences ($p > 0.05$) between CMJ peak power were observed at any time point in the control group.

Between Group Peak Power

Independent samples *t*-tests with a Bonferroni's correction were used to compare peak power (Figure 1) output between groups, but no significant differences were found between the control group and the experimental group at baseline, 15, 4, 8, 12, 16, or 20 minutes after the CC.

group ($F_{(6,60)} = 2.448$, $p = 0.063$). Nevertheless, the p value prompted further analysis using a simple contrast, which revealed a significant decrease in CMJ peak power (Figure 1), performed immediately after the CC ($p \leq 0.05$). This was followed by a nonsignificant increase in peak power from

Within Group Data Analysis: Repeated Vertical Jump Height

A 1-way repeated measures ANOVA revealed a nonsignificant effect within the experimental group trials ($F_{(6,60)} = 2.399$, $p = 0.089$), but the p value warranted further analysis; therefore a simple contrast suggested a significant decrease in CMJ

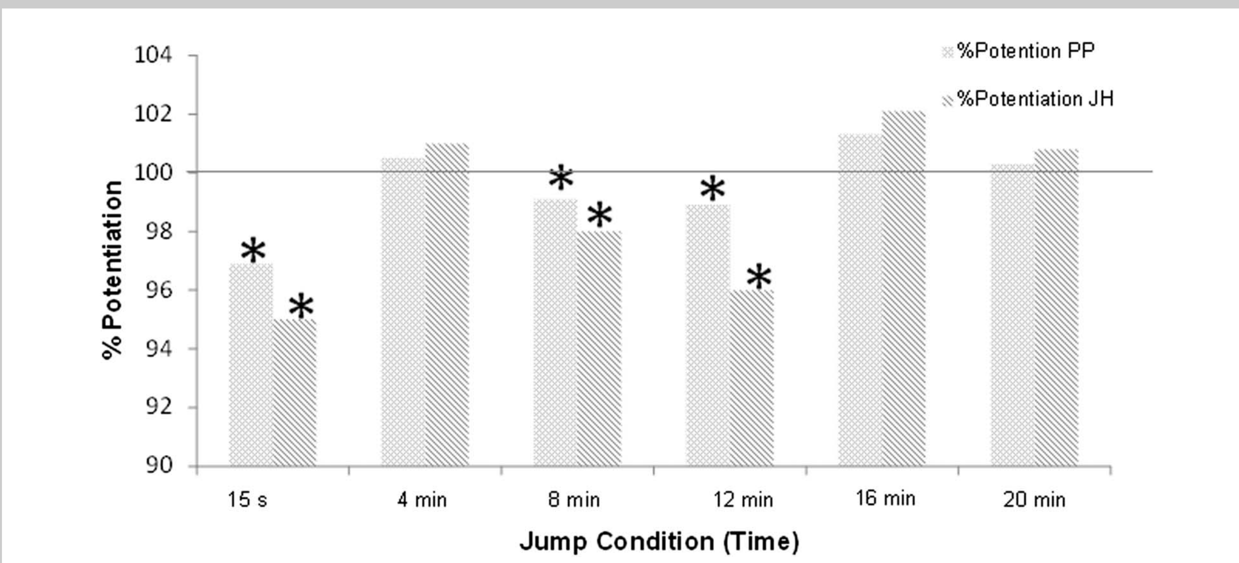

Figure 3. Percentage potentiation for experimental group peak power (PP) and jump height (JH). Percent potentiation equal to 100% (baseline value) indicates no postactivation potentiation (PAP), >100% indicates PAP. *Significant difference from baseline ($p \leq 0.05$).

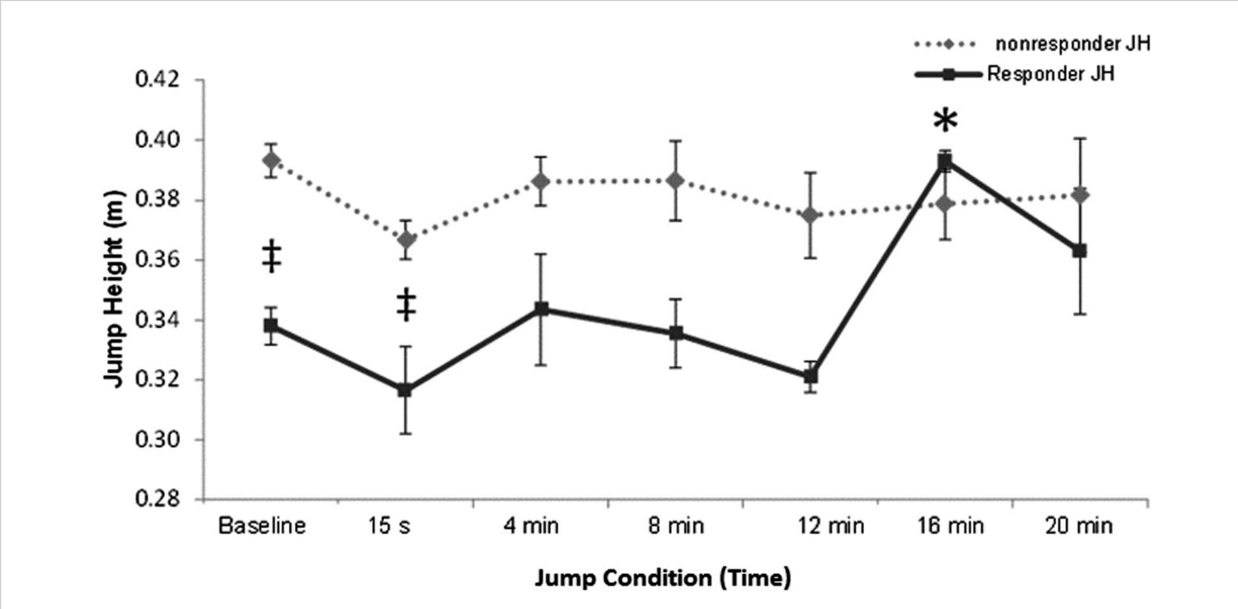

Figure 4. Comparison of jump height (JH) and peak power before and after conditioning contraction in experimental "responder" and "nonresponder" subgroups (expressed as mean [*SD*]). *Significant difference from baseline ($p \le 0.05$); ‡Significant difference between groups ($p < 0.002$).

height performed immediately after the CC ($p \le 0.05$). Jump height at 4-minute recovery was not significantly different from baseline. However, after 8 and 12 minutes recovery, a significant decrease in jump height was observed in comparison with baseline ($p \le 0.05$). No significant differences in jump height were detected when compared with baseline at 16- and 20-minute recovery (Figure 2).

Between Group Vertical Jump Height

Further independent *t*-tests with a Bonferroni's correction were applied to compare jump height between groups. No significant difference in jump height (Figure 2) between groups was observed for baseline, 4, 8, 12, 16, or 20 minutes after the CC. However, jump height in the experimental group was significantly lower than the control group immediately (15 seconds) after the CC ($p < 0.002$).

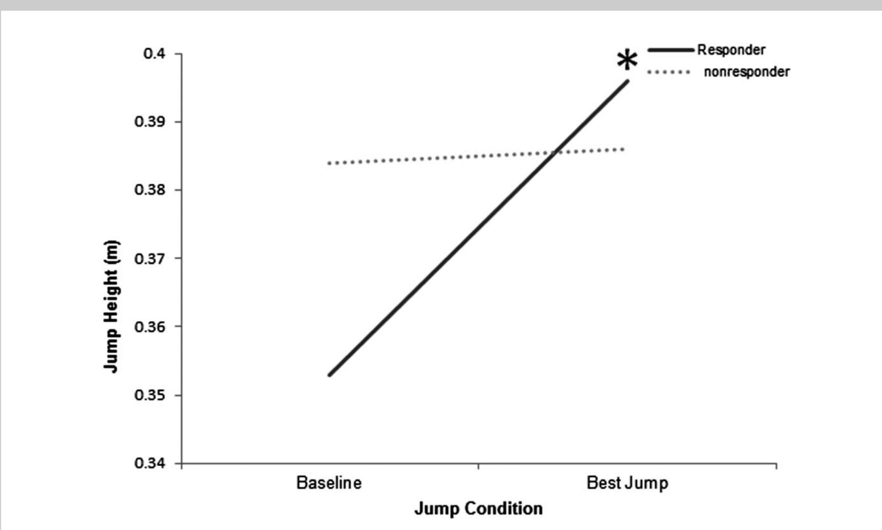

Figure 5. Comparison of responders ($n = 6$) and nonresponders ($n = 5$) baseline and best jumps after potentiation. *Significant difference from baseline ($p < 0.002$).

Percent Potentiation

Jump height and jump peak power expressed as a percent potentiation (Figure 3) was significantly decreased ($p \le 0.05$) immediately after the CC, recovering marginally above baseline at 4 minutes after the CC. At 8 and 12 minutes after the CC, jump height and power were significantly decreased ($p \le 0.05$), yet returned to baseline levels at baseline, at 16, and 20 minutes.

Individual Data Analysis

A differentiation criteria based on the previous findings (26) was used to identify PAP responders ($n = 6$) and nonresponders ($n = 5$) from the

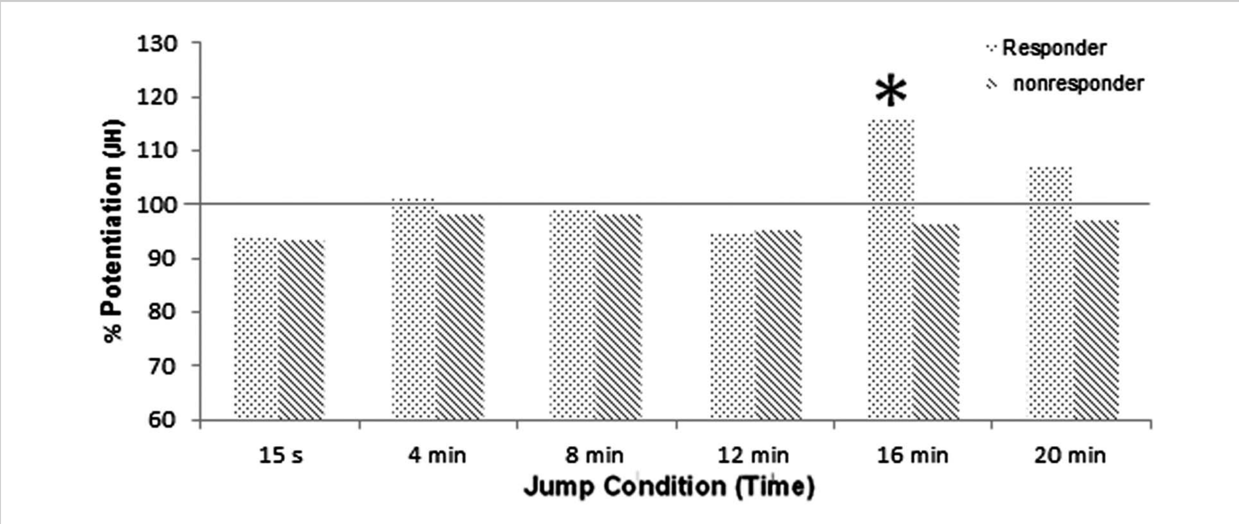

Figure 6. Percentage potentiation for responder and nonresponder jump height (JH). Percent potentiation equal to 100% (baseline value) indicates no postactivation potentiation (PAP), >100% indicates PAP. *Significant difference ($p < 0.002$).

experimental group ($n = 11$). Specifically, any participant displaying an increase in CMJ height ≥1.6 cm at any time point from baseline was deemed a "PAP responder."

Postactivation potentiation Responder vs. Nonresponders

Jump height

Independent samples t-tests with a Bonferroni's correction were used to compare responder and nonresponder jump height (Figure 4). A marginally significant difference ($p \leq 0.05$) in jump height between groups for baseline and 15 seconds after the CC was detected, although this is questionable once the Bonferroni's correction is applied. No difference in jump height was observed between groups at 4, 8, 12, 16, or 20 minutes after the CC (Figure 4).

Jump Height Within Responders and Nonresponders

A 1-way repeated measures ANOVA revealed a significant time effect ($F_{(6,60)} = 40.12$, $p = 0.0001$). Further analysis using a simple contrast found no difference in CMJ height (Figure 4) performed immediately after the CC or at 4, 8, or 12 minutes after the CC. However, CMJ height was significantly potentiated 16 minutes after the CC ($p \leq 0.05$) in comparison to baseline (Figure 4; Figure 5), followed by a return towards baseline at 20 minutes (Figure 4). No differences were observed for the nonresponder group.

Percent Potentiation in Responders and Nonresponders

Postactivation potentiation responder percent potentiation jump height did not significantly differ from baseline immediately, 4, 8, or 12 minutes after the CC. However, a significant increase in responder jump height occurred at 16 minutes after the CC ($p < 0.002$) followed by a return to baseline at 20 minutes (Figure 6). Nonresponder jump height did not significantly differ from baseline at any time point after the CC (Figure 6).

Discussion

The aim of this study was to determine the optimal recovery time required to elicit PAP after intense resistance exercise in senior professional soccer players. It was hypothesized CMJ PAP would be realized at approximately 8 and 12 minutes after the CC similar to previous research (25,26). This study had 2 main findings. Firstly, a set of 3RM squats failed to acutely enhance all experimental participants CMJ performance through PAP, although both PAP responders and nonresponders exist. Secondly, the time constant of PAP elicited by the responders differed between these individuals.

Previous investigations used recovery intervals ranging from 0 to 24 minutes (3,4,6,21,22,25,26) with no agreement as to the optimal PAP "window." This is the first study to the authors' knowledge to use senior professional soccer players with a methodology designed to identify an optimal recovery window after intense resistance activity, demonstrating that a 3RM squat did not uniformly augment jump height. This is not consistent with the previous literature, which used identical (25,26) CMJ protocols. This could have been attributed to central nervous system fatigue (2) because of the determination of participant 3 RM and testing within the same day. Although this is a limitation of the study, it was unavoidable because of the availability of the sample group. Nevertheless, transient changes in CMJ performance were consistent with these studies (25,26) namely, that intense resistance exercise acutely decreased (at 15 seconds) CMJ performance ($n = 11$). Nonresponders ($n = 5$) remained in a depressed or constant state of activation, whereas responders ($n = 6$) actualized PAP at 4 ($n = 3$), 12 ($n = 1$), and 16 ($n = 2$) minutes after the CC. Data from these studies support the theory that fatigue and potentiation coexist (31) with the magnitude of PAP determined by the interaction between potentiation and fatigue resulting in either net potentiation, attenuation, or constant state of activation. Although the individualized nature of PAP is well established, to the authors' knowledge no data has reported such a heterogeneous response to individual optimal recovery after intense resistance exercise.

Genotype and phenotypic expression influence individual responsiveness to PAP. For example, a significant relationship ($r = 0.631$; $p < 0.009$) between 3RM squat strength and PAP exists (25). As such, stronger individuals are more responsive to PAP stimulus (3,6,22,25). All previous studies reporting potentiated jump height using this protocol employed professional rugby players (25,26) who are typically stronger than soccer players because of the physical nature of the sport and greater emphasis placed on muscular strength and power and resistance training for sports preparation (10).

This may explain no significant CMJ potentiation and diverse optimal recovery times to those hypothesized (8–12 minutes) in this sample. Soccer players in this study were recruited from the Npower football league 1 and had an estimated 100-kg 1RM squat and 8 years of formal resistance training experience suggesting a trained status (2). However, Wisloff et al. (40) recorded a mean 1RM squat of 171 kg in Norwegian professional soccer players. Similarly, Hoff and Helgerud (19) reported 1RM squat values ranging from 176 to 215 kg for professional soccer players. In contrast, studies using recreationally trained individuals have reported mean 1RM squat loads of 83.6 kg (22). Data from these studies suggest that the soccer athletes recruited were akin to a "recreational status," despite long-term strength training. This may highlight differences in physical preparation and the importance placed on strength and power development among different soccer teams and professional leagues. Because more successful teams' players demonstrate greater physical capacities in comparison to less successful teams, optimizing strength and power training may improve sports performance and subsequent match outcomes (38).

Training status affects CC-induced fatigue (3) and is an important variable because PAP is the net balance between potentiation and fatigue (31). Resistance trained athletes are also better able to perform complex motor skills such as the squat. Strength expression is not only dependent on the force-generating capacity of the neuromuscular apparatus but also movement pattern competence (32). This sample's comparatively lower 1RM squat may be because of low strength confounded by poor physical competency resulting in the inability to sequentially recruit type 2 motor units and achieve MVC of hip and knee flexor and extensors type 2 motor units that are responsive to PAP (15). Batista et al. (3) used leg presses over squats to increase the ability to achieve knee flexor and extensor MVC in recreationally trained individuals. Thus, leg pressing may improve the ability to realize PAP by ensuring a maximal volitional CC of the musculature used in the subsequent activity, despite not being kinematically similar to jumping. Had this study used leg pressing, the nonresponder participants may have realized PAP.

The disparity between responders and nonresponders may also be because of strength differences or participant compliance. Figure 4 depicts the time constant of PAP responders and nonresponders. Nonresponders baseline jump height was greater than responders, although not quite significant. This suggests nonresponders may have greater strength and type 2 fibers facilitating jump performance. Indeed, a strong correlation ($r = 0.78$; $p < 0.02$) exists between squat strength and jump height in professional soccer players (40). Conversely, nonresponders may have greater relative strength augmenting jump height, but less higher order motor units and therefore responsiveness to PAP. However, responders ($n = 6$) had greater ($p \leq 0.05$) 3RM squat strength than nonresponders (96.7 [14] vs. 80 [9.4] kg), despite no difference ($p > 0.05$) between their body masses (76.6 [14] vs. 74.3 [10.7] kg). Although body composition was not measured, it is unlikely nonresponders had greater relative strength. These findings also agree with the previous research delineating a relationship ($r = 0.63$; $p < 0.009$) between 3RM squat strength and PAP (25). All 3RM squats time under tension were equated and taken to momentary muscular failure. Based on each individual's physical competency, recruitment of higher order motor units was maximized, thereby augmenting the likelihood of PAP realization.

Systematic (CC type, intensity, volume) and biological (genotype and phenotype) variation influences this elusive individual optimal recovery window. This dilemma may be resolved by using multiple recovery windows such as in this study and others (3,4,6,22,25,26). However, contractile activity modulates potentiation and fatigue, performing maximal CMJ's at each recovery window will induce cumulative fatigue and PAP (31). For example, CMJ's 15 seconds after the CC were depressed then returned to basal values (4 minutes). This PAD was realized at 8 and 12 minutes, whereas CMJ height was potentiated at 16 minutes. This "rebound-PAD" and "rebound-PAP" may have been induced by previous fatiguing (15 seconds, 4, and 8 minutes) and potentiating (12 minutes) CMJs rather than the CC. It is also possible that the selected recovery windows may not have been suitable to identify the time constant of nonresponder PAP.

Strength training increases type 2 myosin heavy chain isoform expression (29). This will alter muscle force–velocity relationships (30), possibly initiating a concomitant shift in PAPs time constant. As such, long-term PAP complex training will produce unpredictable shifts in the individual optimal recovery window. Should strength and conditioning specialists design long-term complex training interventions, it may be prudent to perform acute PAP studies such as this every fourth microcycle to determine the new status of the “PAP-time curve”.

Therefore, PAP is an individualized and complex phenomenon. Some ($n = 5$) participants responded to the CC whereas some ($n = 6$) did not. Postactivation potentiation is the premise on which complex training is based and is responsible for inducing the purported supernormal chronic training adaptation. By extension, this suggests athletes who train in a depressed state of activation will realize subnormal adaptations to complex training, contrary to previous suggestions (11).

Practical Applications

These findings have significance for practitioners who wish to incorporate evidenced PAP-based complex training into strength and conditioning programs. Acute PAP studies such as this may be incorporated into a preseason testing battery (37). It is important that strength and conditioning professionals identify individual athletes who may benefit from this type of training before undertaking a complex training intervention. Once responders have been identified, fixed complex recovery times may be logistically favorable, although strength and conditioning practitioners need to individualize recovery windows because all athletes will not respond positively to a uniform recovery window. It may be necessary to perform acute PAP studies, such as this study, every fourth microcycle to determine the new status of the “PAP-time curve.” The results of this study also confirm the need for researchers and strength and conditioning practitioners to interpret PAP studies from an individual perspective even when employing a homogeneous sample.

Acknowledgments

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