Eliciting postactivation potentiation with hang cleans depends on the recovery duration and the individual's 1 repetition maximum strength

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Abstract

Dinsdale, AJ and Bissas, A. Eliciting Postactivation Potentiation With Hang Cleans depends on the recovery duration and the individual's 1 repetition maximum strength. *J Strength Cond Res* XX(X): 000–000, 2019—Acutely coupling biomechanically similar resistance exercises (e.g., back squats) with subsequent explosive movements (e.g., countermovement jumps [CMJs]) can elicit an enhancement in explosive force and power production, which is known as postactivation potentiation (PAP). However, limited information exists with regard to the coupling of hang cleans with the CMJ. The purpose of this study was to determine the effectiveness of the hang clean at eliciting PAP through the systematic appraisal of the implemented recovery interval. Twelve explosively trained male track and field athletes completed 8 randomized protocols. These consisted of a structured warm-up, 3 baseline CMJs performed on a force platform, 3 reps of hang cleans set at 90% of 1 repetition maximum (1RM), a randomized rest, and 3 post-CMJs. The rest intervals were set at 0 (T0), 1 (T1), 2 (T2), 3 (T3), 4 (T4), 5 (T5), and 6 (T6) minutes after completing the hang cleans. A repeated-measures analysis of variance showed that the hang cleans did not elicit PAP, although there were significant ($p < 0.05$) decreases in jump height (JH) for T0 (24%), T2 (23%), and T3 (23.3%). Interestingly, when splitting the subjects based on absolute 1RM hang clean (above 80 kg = strong and below 80 kg = weak), significant differences ($p < 0.05$) in JH were observed between the groups at T1 (strong 21.2% and weak +3.8%) and T5 (strong +5.1% and weak 21.9%). Our results suggest that to elicit PAP when using hang-clean protocols, it is important to establish first the function between individual strength levels and recovery duration as this may lead to contrasting optimal performance windows for different explosively trained athletes.

Key words

maximal strength capacity, hang clean, vertical countermovement jumps, complex training

Introduction

Combining biomechanically similar resistance exercises (e.g., back squat) with a subsequent explosive movement (EM) (e.g., vertical jump) may elicit an acute enhancement in explosive force and power production, a phenomenon referred to as postactivation potentiation (PAP). There are several underlying mechanisms that induce the PAP effect, and these comprise an increased alpha motor neuron recruitment, increased synchronization of motor unit firing, enhanced reciprocal inhibition of the antagonist muscles, increased sensitization of the phosphorylation in the myosin light chains, and acute alterations in muscle pennation (1,23,36). The aforementioned coupling process also instigates acute neuromuscular fatigue, which is believed to coexist with the PAP mechanisms (29,38). Sale (29) suggested that the induced acute fatigue dissipates at a faster rate than the PAP mechanism, which leads to an optimal time window for acute explosive adaptation.

Currently, PAP has 2 applications: either as a training stimulus (i.e., complex training or contrast training) or as part of a warm-up strategy in preparation for a competition (17,18). The experimental literature exploring the existence of PAP within these applications is currently divided. On one hand, there is a large number of studies failing to elicit PAP (6,8,20,24,27,35), whereas on the other hand, there is an opposing body of literature with multiple studies that have elicited positive PAP effects (2–4,22,26,30,40). Relevant review articles attribute the apparent inconsistencies within the aforementioned literature to variability in the methodologies used by studies (17,18,38). Indeed, 7 methodological factors are key in instigating and regulating processes pertinent to PAP

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performance outcomes. These are (a) the exercise used to elicit PAP (conditioning contraction [CC]), (b) the intensity of the CC, (c) the volume of the CC, (d) the type of the subsequent EM, (e) the similarity between the CC and the subsequent EM, (f) the recovery duration between the CC and the EM, and (g) the physical characteristics of the subjects recruited. However, each factor has received a varying quantity of systematic appraisal, and limited research exists between the coupling of certain CCs (i.e., weightlifting exercises) and EMs (i.e., jumping or sprinting).

Most PAP studies have selected the back squat as their CC and countermovement jump (CMJ) as their EM (2,7–9,11,20,22,24). By contrast, ballistic type CC such as resisted CMJs (4,26), jump squats (6,32), plyometric exercises (e.g., tuck jumps and drop jumps) (26,39), and weightlifting type exercises (2,3,5,24,26,30,34) have in comparison received less attention. Kinematic and kinetic evaluation of weightlifting type exercises, for instance, would suggest that the triple extension of the hip, knee, and ankle joints within the second pull phase possesses a high mechanical correspondence with the CMJ (15,16,19). Hence, weightlifting derivatives that isolate the second pull phase, such as the hang clean, should theoretically provide an ideal mechanical stimulus for expressing PAP through the performance of CMJ.

The limited number of studies exploring the effectiveness of weightlifting type CCs in eliciting PAP have mainly used the snatch (26), hang clean (2,24), variations of second pull exercises (3,5,34), and isometric midthigh pulls (30). However, the studies exploring the effectiveness of the snatch and the hang clean have all failed to elicit a consistent PAP response within their entire selected sample. In particular, Radcliffe and Radcliffe (26) coupled the snatch with the standing long jump and supported that PAP was elicited in only male subjects, whereas McCann and Flanagan (24), who coupled a 5RM hang clean with the CMJ at both 4 and 5 minutes after CC, found some interesting individual changes without though an overall group response. Studies exploring second pull variations have all elicited significant improvements in either jump height (JH) or high pull power output (3,5,34), but they only explored a small variety of recovery durations (i.e., 3–5 and 8 minutes), exercise intensities (i.e., 40–60%, 70%, 85% of 1 repetition maximum [1RM], and wave loading patterns), and volumes (i.e., 1 × 5, 3 × 3, 4 × 4, and 2 × 5). This is not the case though with studies using back squats as CC and CMJ as EM to elicit PAP because they have used a wider range of intensities (40–95% of 1RM), recovery durations (1–16 minutes), and set configurations (1 × 3–10 × 1) (2,7,9,11,22,24). Therefore, further evaluation of these factors is required to establish the effectiveness of weightlifting type CC at eliciting PAP.

It is evident from the above review that the current experimental evidence whether weightlifting type CCs (including the hang clean) can effectively elicit PAP in jumping movements is unclear and inconclusive. Therefore, to provide clarity on the suitability of the hang-clean exercise to serve as a positive stimulus in a PAP protocol, there is a real need for further scientific exploration. The experimental procedures which apart from the necessary PAP coupling will also need to factor in the effects of recovery duration and existing strength levels. Consequently, the purpose of this study was to determine the effectiveness of the hang clean at eliciting PAP in jumping performance (dependent variable) through the systematic appraisal of the implemented recovery duration (independent variable). A second purpose of this study was to explore the effects of subjects' strength levels (independent variable) on their ability to elicit PAP in jumping performance (dependent variable).

TABLE 1. Postexercise-baseline change scores in the CMJ's mechanical variables across all tested protocols (M ± *SD*).*

	Jump height (Δ m)	Peak power (Δ W)	Peak force (Δ N)	Peak velocity (Δ $m \cdot s^{-1}$)	Peak rate of force development (Δ $N \cdot s^{-1}$)
C	-0.007 ± 0.014	-103 ± 232	-8 ± 63	-0.017 ± 0.122	-63 ± 947
T0	-0.017 ± 0.023†	-40 ± 358	7 ± 75	-0.045 ± 0.117	284 ± 1,193
T1	0.004 ± 0.018	-16 ± 219	12 ± 89	-0.006 ± 0.116	526 ± 1,563
T2	-0.013 ± 0.016†	26 ± 192	-18 ± 131	0.023 ± 0.078	-236 ± 1,377
T3	-0.014 ± 0.016†	44 ± 161	10 ± 91	0.027 ± 0.101	432 ± 1,074
T4	-0.005 ± 0.019	-28 ± 158	19 ± 71	-0.002 ± 0.080	255 ± 1,368
T5	0.008 ± 0.021	-23 ± 217	-44 ± 78	0.014 ± 0.113	-326 ± 1,213
T6	-0.011 ± 0.018	-9 ± 144	15 ± 66	0.007 ± 0.083	-132 ± 1,178

*C = control condition; CMJ = countermovement jump; T0 = no recovery; T1 = 1-min recovery; T2 = 2-min recovery; T3 = 3-min recovery; T4 = 4-min recovery; T5 = 5-min recovery; T6 = 6-min recovery.

†$p < 0.05$.

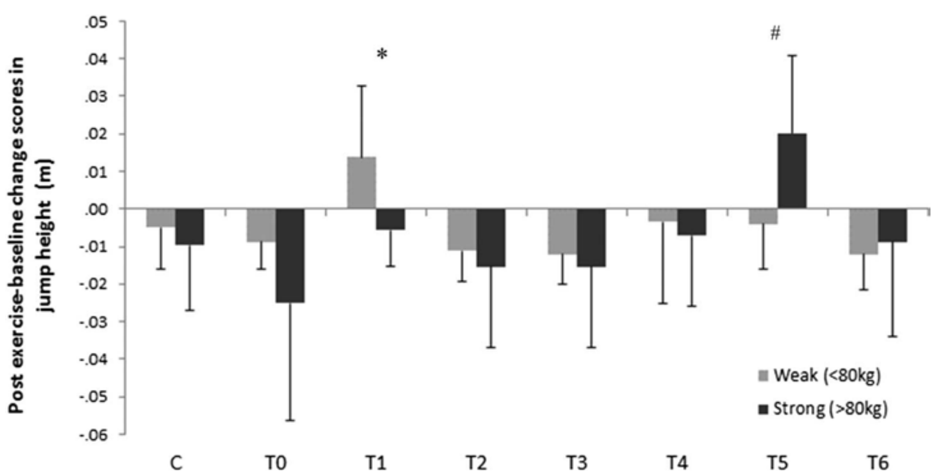

Figure 1. Postexercise-baseline change scores in the vertical jumps split based on 1RM hang-clean strength. *$p < 0.05$; #$p < 0.01$; C = control condition; T0 = no recovery; T1 = 1-minute recovery; T2 = 2-minute recovery; T3 = 3-minute recovery; T4 = 4-minute recovery; T5 = 5-minute recovery; T6 = 6-minute recovery; 1RM = 1 repetition maximum.

Methods

Experimental Approach to the Problem

The study followed randomized repeated-measures design, whereby all the subjects participated in the following 11 sessions: 2 familiarization sessions, a single strength testing session, and 8 randomized experimental sessions (7 PAP conditions and 1 control condition). The 7 PAP conditions systematically manipulated the recovery duration (0–6 minutes) between the CC (hang clean) and the subsequent EM (vertical countermovement jump [CMJ]). The study was performed within a 3-week period; the first week consisted of the familiarization and strength testing sessions. The subsequent 2 weeks were dedicated to the completion of the 8 experimental conditions. To ensure sufficient recovery, a 72-hour interval was observed between the strength testing session and the first experimental testing day (30). Similarly, a 48-hour recovery window was selected between each of the experimental testing days (25). Each of the experimental testing days consisted of 2 randomly selected conditions, which were separated by 1 hour of seated rest. This time interval between conditions was selected because of the previously observed dissipation of both PAP and fatigue after 20 minutes of rest (7,22).

Subjects

Once ethical approval was obtained from Carnegie Faculty Research Ethics committee, 12 strength trained male university track and field athletes (age = 22.5 ± 5.7 years, stature = 1.80 ± 0.07 m, mass = 80.3 ± 8.7 kg, hang-clean 1RM = 81.9 ± 16.7 kg, hang-clean 1RM normalized to body mass = 1.02, parallel back-squat 1RM = 123.5 ± 27.2 kg, and back-squat 1RM normalized to body mass = 1.54) were recruited. The subjects were informed of the benefits and risks of the study by receiving a subject information sheet. All subjects were aged older than 18 years and gave written informed consent to indicate their voluntary participation. The subjects were recruited based on selection criteria, which set a minimum strength training experience standard of 1 year. The selection criteria also set 2 minimum strength competency standards. First, subjects were required to parallel back squat at least their own body mass for 4 repetitions. Second, subjects were required to hang clean at least half of their own body mass for 4 repetitions.

Procedures

The familiarization sessions were used to gain informed consent, medically screen the subjects, gain basic anthropometric measurements, and enable the subjects to experience all key aspects of the intended protocols. Within the second familiarization session, the subjects performed 6 consecutive CMJs, which were used to establish the within-subject variation in CMJ performance. Furthermore, each of the subject's weightlifting technique was evaluated by a qualified strength and conditioning coach, and the subjects who did not possess the required level of competency were removed from the study. The strength testing session comprised 1RM strength tests for both the hang clean initiated from midthigh and the parallel back squat. To standardize the 1RM protocol, the subjects performed 3 warm-up sets as follows: 1 set of 8 reps at 50%, 1 set of 4 reps at 75%, and 1 set of 1 rep at 90%. The subjects approximated their own 1RM strength to select the desired load. The implemented recovery duration between warm-up sets was 2 minutes. Once the warm-up sets were complete, the first 1RM attempt was administered. The subjects chose their own recovery duration between 1RM attempts, although this choice was limited to between 3-5 minutes. The 1RM test was terminated by either a voluntary withdraw or failure to complete the selected load.

The experimental protocol consisted of 6 components completed in the following order: (a) An initial 10-minute warm-up (consisting of 5 minutes of light aerobic running and 5 minutes of prescribed dynamic stretching), (b) 3 baseline maximum CMJs, (c) 3 minutes of rest, (d) 1 set of 3 reps of hang cleans set at 90% of 1RM, (e) a randomly selected seated recovery duration (0–6 minutes), and (f) 3 postexercise maximum CMJs. The combined volume and intensity of a single set of 3 repetitions set at 90% of 1RM have previously elicited PAP in back-squat protocols (9,11,28), whereas previous studies (2,24) that implemented lower intensities (i.e., 60 and 85% of 1RM) combined with higher volumes (i.e., 1 × 5 and 3 × 3) for midthigh hang-clean exercises failed to elicit PAP-positive effects. Therefore, the selected loading characteristics of the current study for the hang clean were deemed as the most appropriate.

Seven randomly assigned recovery durations were implemented, which were as follows: 0 (T0), 1 (T1), 2 (T2), 3 (T3), 4 (T4), 5 (T5), and 6 (T6) minutes. Unlike heavy-loaded back-squat protocols whereby PAP has been observed between 4 and 12 minutes (9,11,22,28), the aforementioned recovery was selected because of the volume of studies that have elicited PAP between 2 and 5 minutes after implementing ballistic-type CCs (3,5,26,32,34,39).

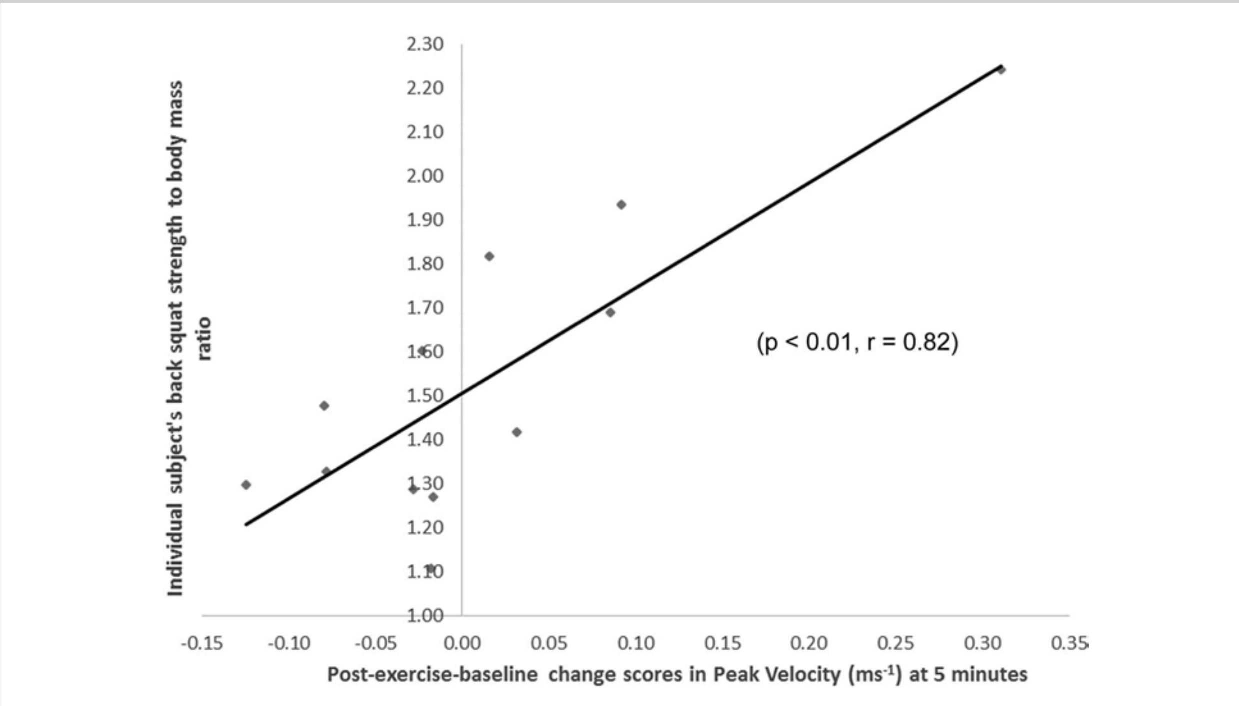

Figure 2. The relationship between the postexercise-baseline change scores in peak velocity at 5 minutes and the individual subject's 1RM back-squat strength to body mass ratio. 1RM = 1 repetition maximum.

A control condition was also implemented, which was randomly assigned along with the other 7 conditions. The control condition followed the same protocol steps as the other experimental conditions with 2 exceptions. First, hang cleans were not performed, and second, a set recovery duration of 6 minutes was administered between the baseline maximum (i.e., pre) CMJs and postexercise maximum CMJs. In terms of the initial warm-up, this consisted of 5 minutes of light aerobic running, followed by these dynamic stretches performed over a distance of 10 m: body mass (BM) lunges, BW squats, inchworms, heel-to-toe walks, high knees, butt flicks, and 2 preparatory CMJs. Initiating a warm-up with a light aerobic element followed by a structured set of dynamic stretches and practice trials has been identified as an optimal preparation strategy above alternative strategies (e.g., static stretching) (10,37).

All CMJs were recorded by a Kistler 9287BA force plate (Kistler Instruments Ltd., Winterthur, Switzerland) set at a sampling frequency of 1000 Hz, and they were analyzed through the functions offered by the software package BioWare 3.2.6 (Kistler Instruments Ltd). The CMJs were performed with the subjects placing their hands on their hips.

To remove unwanted random noise, a second-order Butterworth (low-pass) digital filter set at 50 Hz was applied to raw force plate data. Once all the jump data had been filtered, the following mechanical variables were calculated from the force-time curves: JH using the flight time method ($d = 1/2\ at^2$), peak power (PP), peak velocity (PV), peak force (PF), and peak rate of force development (PRFD). An average value of the 3 trials was used for the subsequent statistical analysis. The average was selected because of this study's intention to explore the responses from this coupling and not to favor PAP, whereby best scores potentially mask reduced responses caused by fatigue.

Statistical Analyses

Initially, descriptive statistics were calculated for all the mechanical variables, and then, subsequently, each variable underwent normality and sphericity analysis. However, when the data did not possess sphericity, then the Huynh-Feldt correction factor was applied to the analyses of variance (ANOVAs) output. Once the initial analysis was complete, a 2-factor (2×8) repeated-measures ANOVA (pre-post [2 levels = 1 baseline and 1 post] recovery interval [8 levels = 7 recovery times + 1 control]) was implemented on each depended variable. If a significant interaction was identified, then simple contrasts were used between the baseline and postexercise scores. In addition, 95% confidence intervals (CIs, 95%) and Cohen's *d* effect size (ES) were calculated between the baseline and postexercise conditions. To establish the within-subject variation in performance for all examined mechanical variables, the intraclass correlation coefficient (ICC, [3,1]), CI of the ICC, and coefficient of variation (CV, 68%) were calculated from the CMJs undertaken within the familiarization session. The reproducibility was considered high for all of the variables: JH (CV 1.76%, ICC 0.987, and CI 0.955–0.996), PP (CV 3.00%, ICC 0.979, and CI 0.928–0.994), PF (CV 2.03%, ICC 0.975, and CI 0.916–0.993), PV (CV 1.99%, ICC 0.902, and CI 0.692–0.971), and PRFD (CV 8.09%, ICC 0.915, and CI 0.732–0.975).

Finally, to identify whether the subjects' strength levels affected the outcome of the protocol, the whole group was split in to 2 subgroups based on these 4 strength categories: absolute back-squat 1RM strength (strong >125 kg and weak <125 kg), back-squat 1RM strength normalized to body mass (strong >1.6 and weak <1.6), absolute hang-clean 1RM strength (strong >80 kg and weak <80 kg), and hang-clean 1RM strength normalized to body mass (strong >1.1 and weak <1.1). The aforementioned strength levels were selected because of the findings of similar studies within this area (22,27,31). Subsequently, 4 separate two-factor (recovery interval and subgroup) mixed-design ANOVAs were performed on the difference data. If a significant interaction was identified by the ANOVA, then contrasts were implemented between the subgroup responses at each recovery interval. In addition to the mixed-design ANOVAs, Pearson R correlation coefficients were calculated between the individual–subject strength scores and the postexercise baseline change scores. Statistical significance was set at $p \leq 0.05$, and all the statistical tests were performed using the IBM SPSS statistical software for Windows (version 22; SPSS, Inc., Chicago, IL, USA) package.

Results

The two-factor repeated-measures ANOVA identified significant differences in JH for the pre-post factor ($p = 0.007$) and pre-post $\times$ time interaction ($p = 0.036$). The simple contrasts identified significant ($p < 0.05$) decreases in JH with respect to the baseline scores at T0 (-4.0%, CI 95%: -0.032 to -0.002, ES = -0.53 [medium]), T2 (-3.1%, CI 95%: -0.024 to -0.003, ES = -0.28 [small]), and T3 (-3.3%, CI 95%: -0.024 to -0.003, ES = -0.32 [small]), (Table 1). The repeated-measures ANOVA identified no significant changes in any of the mechanical variables (PP, PV, PF, and PRFD) in terms of either factor (pre-post, time) or pre-post $\times$ time interaction (Table 1).

The 2-factor mixed-design ANOVAs exploring the JH variable identified a significant ($p < 0.05$) interaction between the recovery interval and the absolute hang-clean 1RM strength subgroup. Contrasts identified significant differences ($p < 0.05$) between stronger (>80 kg) and weaker (<80 kg) subjects at both T1 and T5 (Figure 1). The responses of the stronger subjects at T1 were significantly reduced (-1.2%) in comparison with the enhanced (3.8%) performance of the weaker subjects (strong CI 95%: -0.019 to 0.008, ES = -0.07 [trivial], weak CI 95%: 0.001 to 0.027, ES = 0.23 [small]). By contrast, at T5, the reverse was observed as the stronger subjects' performance was enhanced (5.1%), whereas the weaker subjects' performance was reduced (-1.9%) (strong CI 95% 0.009 to 0.038, ES = 0.30 [small], weak CI 95%: -0.022 to 0.008, ES = -0.12 [trivial]) (Figure 1). The same trends in JH were observed within the other 3 strength subgrouping factors, although no significant interactions were identified.

The Pearson's R correlations coefficients exploring the relationship between changes in JH and the individual strength scores showed only one significant relationship, which was observed between the hang-clean 1RM normalized to body mass and changes in JH at 1 minute after hang clean ($p < 0.05$, $r = -0.68$). By contrast, several significant correlations were observed between changes in certain mechanical variables (i.e., PP and PV) and certain strength measures (i.e., back-squat 1RM normalized to body mass and hang-clean 1RM normalized to body mass). Significant relationships were observed between PV at 5 minutes after hang clean with the back-squat 1RM normalized to body mass ($p < 0.01$, $r = 0.82$), as well as the hang-clean 1RM normalized to body mass ($p < 0.05$, $r = 0.58$). Furthermore, a significant correlation ($p < 0.05$, $r = -0.63$) was observed between the back-squat 1RM normalized to body mass and changes in PP at 1 minute after hang clean.

Discussion

To date and our knowledge, this is the first study to systematically explore the combination of these PAP protocol factors: hang clean, recovery duration, and strength levels. Overall, a significant ($p < 0.05$) decline in jumping performance was observed after the execution of hang cleans with shorter recovery durations (0, 2, and 3 minutes). There was no a single condition that induced PAP within the entire sample. However, splitting the subjects by maximal hang-clean strength capacity showed that the weaker subjects (<80 kg) experienced a positive PAP effect at 1-minute recovery, whereas stronger subjects (>80 kg) experienced a similar PAP at 5 minutes. Correlations were observed between strength capacity and changes in both PV ($p < 0.01$, $r = 0.82$) at T5 and PP ($p < 0.05$, $r = 0.63$) at T1 (Figure 2).

First, the current findings are in agreement with those of McCann and Flanagan (24) and Andrews et al. (2) who also used hang cleans to elicit PAP effects on vertical jump performance. Andrews et al. (2) identified similar reductions in JH after coupling multiple sets (3 sets of 3 reps) of hang cleans at 60% of 1RM with the CMJ. McCann and Flanagan (24) identified that coupling hang cleans with the CMJ at 5-minute recovery yielded a significantly higher JH than at 4 minutes. However, the CMJ height at 5 minutes was not significantly larger than the baseline test. Therefore, based on the findings from their whole sample, selecting short recovery durations (≤3 minutes) after coupling hang cleans with the CMJ, will induce acute fatigue, which will reduce performance and outweigh any elicited PAP effects. Short recovery (15 seconds–3 minutes) durations have induced similar short-term reductions within performance after coupling back squats with the CMJ (7,11,22). Such short-term reductions in performance have been previously explained by the time it takes to fully replenish the creatine phosphate levels within the muscle fibers (40). However, experimental analysis of the changes in biochemical indices (muscle PCr, ATP, and blood lactate) within an isometric PAP protocol has not corresponded with the changes in force output (12). Therefore, further research should explore the coexistence between the underlying mechanisms that induce acute fatigue and the underlying PAP mechanisms.

Chiu and Salem (5) and Barnes et al. (3) identified that a wave-loading snatch pull protocol elicits significant ($p < 0.05$) PAP effects after 3 minutes of recovery. In comparison, hang-clean CC studies (with this study included) (2,24) have all identified acute fatigue at the corresponding recovery duration, which interestingly involved the performance of fewer total repetitions. A possible explanation for the difference between these very similar CCs is the execution of the catch phase. Limited mechanical knowledge is available regarding the energetics of either the clean or snatch catch phases. By contrast, pull derivatives of the Olympic lifts have been shown to require high levels of mechanical energy expenditure (21). Inferences from this study would suggest that the combination of the pull and catch phases require a much greater energetic requirement than pulls on their own and therefore a different PAP-acute fatigue interaction exists between the derivatives of these similar exercises.

The findings of this study identified small nonsignificant increases in JH at T1 (1.2%) and T5 (1.8%) (Table 1). The subsequent mixed-design ANOVA revealed significant differences in the responses from stronger versus weaker subjects when split by absolute hang-clean 1RM strength (Figure 1). Interestingly, weaker subjects (<80 kg) improved their jump performance at 1-minute recovery, whereas stronger subjects (>80 kg) after 5 minutes of recovery. The findings that an individual's strength level can alter the response to a PAP protocol have been previously identified with regard to other CCs (22,27,31). However, this finding contradicts previous literature indicating that stronger subjects experienced PAP at earlier intervals, as well as with a greater magnitude than weaker individuals (22,27,31). The aforementioned studies have all implemented variations of the back squats with CMJs or squat jumps. However, these studies provide a variety of definitions with regard to the term strong (i.e., 1RM > 125 kg, 1RM > 160 kg, 1RM to body mass > 1.6, and 1RM to body mass > 2) and as such offer several different strength thresholds that can be used to elicit PAP. Hence, this is the first study that has identified that the maximal strength capacity of the hang clean alters the optimal point that PAP can be elicited. The application to the observed findings does raise an interesting quandary when considering athletes who lift loads that are near to this strength threshold. For example, athlete A has a comparatively heavy mass (i.e., 105 kg) but lifts less than their mass (i.e., 85 kg), whereas athlete B has a smaller mass (i.e., 70 kg) and lifts heavier than their mass (i.e., 75 kg). Therefore, based on this study's findings, athlete A would potentiate at 5 minutes, although athlete B would potentiate at 1 minute although athlete B possess a higher strength ratio normalized to body mass and as such would be considered as stronger. Further analysis showed a significant relationship ($p < 0.05$, $r = -0.68$) between normalized hang-clean strength to body mass and changes in JH after 1 minute. The negative correlation supports the concept that hang-clean strength is an important factor in determining the outcome for this type of PAP protocol. The application of these findings would seem to be limited when considering athletes who hang clean loads near to 80 kg and possess either very high or low strength to mass ratios. However, it is important to note that this is the first study that has identified that the maximal strength capacity of the hang clean alters the optimal point that PAP can be elicited in explosively trained athletes.

Several possible mechanisms and theories could be attributed to the PAP observed for the 2 subgroups within this study. The most likely mechanisms responsible for these changes are an increased sensitization of the phosphorylation process in the myosin light chains or an increased alpha motor neuron recruitment. A possible explanation for why stronger subjects potentiated at a later recovery interval could be attributed to the structure and function of their neuromuscular system, which could be assumed consisting of larger fast-twitch fibers and a more efficient neural recruitment strategy (13,33). Interestingly, Hamada et al. (14) presented data showing that subjects with a higher number of fast-twitch fibers endured more initial acute fatigue in comparison to subjects with a higher number of slow-twitch fibers. Furthermore, their data also showed that subjects with a higher number of fast-twitch fibers experienced a larger PAP response, which occurred later in comparison to subjects with a higher number of slow-twitch fibers. The findings of this study imply that stronger subjects in the hang clean (> 80 kg) endured a greater quantity of initial acute fatigue than weaker subjects, and as such, they experienced a delayed point of optimized performance. By contrast, weaker subjects potentiated earlier with a smaller increase in CMJ height. Inferences made with regard to this evidence would suggest that athletes with high hang-clean strength levels optimize PAP at a later recovery interval due to possessing a better developed network of fast-twitch fibers, whereas athletes with low hang-clean strength levels optimize their performance at an earlier recovery interval due to a reduced capacity in terms of their fast-twitch fibers. Obviously, these inferences need to be interrogated through clinical experiments. In summary, 3 repetitions of hang cleans set at 90% of 1RM could provide a neuromuscular stimulus that can effectively elicit PAP in the CMJ, although this is dependent on the interaction between the intensity, volume, recovery duration, and individual–subject strength characteristics.

The ANOVAs identified an absence of significant changes with regard to all the mechanical variables. However, a significant correlation ($p < 0.01$, $r = 0.82$) was observed between the back-squat 1RM normalized to body mass and changes in PV at 5 minutes after hang clean (Figure 2). Similarly, a significant correlation ($p < 0.05$, $r = 0.63$) was also observed between the back-squat normalized 1RM to body mass and changes in PP at 1 minute after hang clean. The relationships observed between back-squat 1RM to body mass and the changes in both PV and PP matched the trends observed in JH. Furthermore, this trend matched the previous literature that PAP enhances the generation of PV and PP (9,28). In contrast to the findings of this study, previous literature has identified that PAP also boosts the PF and PRFD (8,9). However, the aforementioned studies used back squats as their CCs, which, in contrast to hang cleans, rely on different movement patterns. A more applicable research to hang cleans would be that of Chiu and Salem (5) who identified that snatch high pulls increased ankle joint work within subsequent CMJs. Therefore, the present findings could infer that the hang cleans stimulated an increased contribution of the ankle plantar flexors within the extension sequencing of the CMJ (5,15,16,19). Moreover, an enhanced contribution of the ankle plantar flexors would correspond with the timing of the improved PV and PP, whereas the force variables occur earlier within the segmental sequence and thus would not be improved.

The results of the current study would suggest that there are several areas relating to both acute and chronic applications that require further research. Moreover, limited evidence exists with regard to the other protocol factors (e.g., volume and intensity) when coupled with hang cleans. Further research should explore the acute effects of coupling hang cleans with the CMJ while recruiting subjects who possess much greater strength levels. A key finding of this study was that stronger subjects elicited PAP at a later recovery duration than weaker subjects. Therefore, further research should focus on the acute effects of repeatedly alternating the hang cleans with CMJ to replicate a complex training format. Furthermore, there has not been a study to date exploring the chronic usage of hang cleans in complex training. Hence, establishing the chronic cost-benefit relationship for this type of training strategy would enable coaches to make an informed choice with regard to the suitability of this strategy to their own practice.

In conclusion, coupling hang cleans with CMJs has the potential to elicit PAP, although this is dependent on the strength capacity of the individual and the selected recovery duration. The increased CMJ height is most likely to be attributed to an increased velocity and power output produced from the associated PAP mechanisms. Further research should explore the chronic effects of this coupling within a complex scheme of training. In addition, more highly trained subjects with a greater strength capacity should be recruited to establish whether other strength thresholds interact with the selected recovery durations.

Practical Applications

Careful consideration is recommended for coaches when selecting the coupling of the hang clean with the CMJ. First, large reductions in JH were observed after implementing the hang cleans in the shorter recovery durations (≤3 minutes). Second, coaches should consider the 1RM hang-clean strength capacity of their athletes when constructing a com- plex training strategy. Therefore, when designing a complex training strategy, stronger explosively trained athletes (>80 kg) should use a recovery window of 5 minutes between the performance of the hang cleans (3 reps at 90% of 1RM) and the subsequent CMJs. However, if your explosively trained athlete's 1RM hang clean is less than 80 kg, then you may consider selecting a very short recovery period (1 minute) between the performance of the hang cleans (3 reps at 90% of 1RM) and the subsequent CMJs. Further research should focus on the acute effects of the repeated coupling of this strategy, to establish the optimal volume of complex sets. In addition, further chronic exploration of this type of coupling using equated volumes of weightlifting and plyometric components is required. Therefore, undertaking such a study would establish the cost-benefit relationship for undertaking this type of complex training

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