International Journal of EXERCISE SCIENCE

Original Research

Effects of Power-Endurance and Controlled Heavy Squat Protocols on Vertical Jump Performance in Females

CAMERON S. MACKEY†[1], RYAN M. THIELE‡[2], JESSICA SCHNAITER-BRASCHE†[1], DOUG B. SMITH‡[1], and ERIC C. CONCHOLA‡[3]

[1]Applied Neuromuscular Physiology Laboratory, Oklahoma State University, Stillwater, OK, USA; [2]Applied Physiology and Sports Medicine Laboratory, Kansas State University, Manhattan, KS, USA; [3]Department of Kinesiology and Health Studies, University of Central Oklahoma, Edmond, OK, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(4): 1072-1085, 2020. The purpose of this investigation was to examine the immediate and acute vertical jump performance responses throughout and following two different free-weight back squat exercise protocols. Fifteen resistance-trained women (mean ± SD: age = 21.8 ± 0.9 years; height = 164.6 ± 8.4 cm; mass = 68.5 ± 9.2 kg) performed vertical jumps before (Pre), immediately after each set (S1-S5), and up to 20 minutes post squat exercise (Post0-Post20) of either a power-endurance (PE; 5×16 at 40% 1-RM) or controlled heavy (CHP; 5×8 at 80%) protocol. Participants' jump height (JH), mean (MP), peak power (PP), mean (MV) and peak velocity (PV) were measured using a linear position transducer. 2-way repeated measures ANOVAs were run for all dependent variables. In the case of the violation of sphericity Greenhouse-Geisser results were reported. No significant intensity × time interactions were observed for any of the variables (p = 0.30-0.87). Main effects for time were observed ($p \leq 0.001$, $\eta p^2 = 0.52$) for MP and MV, which were significantly lower than Pre at S2 through S5-Post0 (p = 0.001-0.02) time points. Additionally, main effects for time were observed ($p \leq 0.001$, $\eta p^2 = 0.43$) for PP and PV, which were significantly lower than Pre at all time points (p = 0.001-0.03) with the exception of Post10 (p = 0.17-0.21). Lastly, JH was significantly lower than Pre for all time points ($p \leq$ 0.001-0.02) except for Post5 (p = 0.13) and Post10 (p = 0.25). This study suggests overall training volume and not training-load could have attributed to the similar fatigue and recovery-related responses that were observed. The present findings suggest that vertical jump performance may be negatively affected following moderate to heavy exercise for up to 20 minutes.

KEY WORDS: Countermovement, fatigue, post-exercise, recovery, resistance-trained

INTRODUCTION

Complex processes associated with brief bouts of muscular contractions (dynamic or otherwise) may lead to differences in subsequent performance responses. This may primarily depend upon the characteristics of muscle action/activation strategy or influences of task familiarity, resulting in enhanced muscular performance (postactivation potentiation), or deficits to any related performance characteristics (fatigue) (29). For example, previous lab-specific techniques (e.g., isokinetic dynamometry) have resulted in maximal and rapid force/strength deficits following dynamic exercise protocols (leg press, squat, leg extension) (4, 5, 10, 16, 31). Although decreases (18-48%) (6, 31) in maximal strength post-exercise (measured upon completion of last set) have been reported, a greater emphasis on immediate (intraset, and within exercise bout) and acute recovery responses is needed for a variety of purposes (injury prevention, exercise program design, determining physiological responses).

Training programs are certainly intended to improve specific variables (strength, speed, agility, lean body mass) over the course of various training blocks (meso, macro, micro cycles), however, understanding the potentially less intuitive (intraset and acute) responses to a multi-set bout of resistance training may help guide deliberate alterations to the program. Interestingly, due to the nature of commonly utilized traditional resistance exercise protocols, many authors have commonly focused on the accumulation effect of exercise (i.e. acute recovery) on performance. For example, Conchola et al. (5) observed decreased maximal and rapid strength (up to 30 minutes) after performing work matched free-weight squat protocols in resistance trained males. Although a dissimilar exercise was utilized, Linnamo, Hakkinen, and Komi (16) reported greater force deficits (23.7%) after a maximal [5 × 10 at 80% One-repetition maximum (1-RM)] leg extension exercise protocol compared to its explosive (5 × 10 at 40% 1-RM) counterpart (11% force deficit). However, recent authors have utilized innovative augmented volume loading schemes, through paired-set training (the use of agonist and antagonist exercises performed in an alternating manner) and reduced rest intervals, to maximize time-efficiency compared to traditional-set training (all sets of the same exercise are performed before the execution of all sets of the next exercise) (22). Since most sport-related activity requires consistent dynamic effort across repetitive bouts of explosive tasks, measuring intraset performance may provide a more comprehensive illustration of the sub-accumulation effect of exercise/activity. Additionally, the utilization of practical assessments may assist with distinguishing task- or training-specific adaptations as alterations to programs (e.g., intensity, volume, rest intervals, etc.) are inevitably implemented.

While the findings of the aforementioned authors have provided novel information, lab-specific techniques/assessments are often costly, difficult to replicate and/or are an unfamiliar task, and generally focus on a specific demographic (i.e., trained participants). Thus, functionally relevant assessments may allow for better interpretation of practical performance characteristics as well as an improved application for broader populations (sedentary, active, elderly). Specifically, the vertical jump [counter movement jump (CMJ), squat jump, drop jump] may serve as a simple, yet effective mode of assessing functional performance across a variety of individuals. Distinct baseline vertical jump characteristics [e.g. jump height (JH), peak velocity (PV), peak power (PP), etc.], have been used to differentiate athletic status/playing status, and create descriptive profiles (i.e. force-velocity; F-v) (18), which may be affected following dynamic exercise (3, 13, 27). For example, Smilios et al. (27) reported vertical jump height was decreased following maximal velocity squats and leg press (4 × 10 based upon 10-RM). In contrast, Saez Saez de Villarreal, Gonzalez-Badillo, and Izquierdo (24) observed significant increases in vertical jump height following high intensity-based squats (>80% 1-RM). Interestingly, Gilbert and Lees (8) reported greater counter movement vertical jump height deficits following a maximal strength

(5 × 1-RM load) compared to a maximal power (5 × load at which participants developed maximum power) squat protocol. Taken together, although different exercise loads and intensities were used, diverse findings are present when assessing vertical jump performance following lower-extremity exercise protocols. These differences may be attributed to varying research questions (fatigue versus potentiation), lower-body exercises (leg press, leg extensions, back-squat), training volume, and/or training intensity utilized for example.

Although the aforementioned studies assessed vertical jump performance following the completion of exercise (accumulating effects), interpreting immediate (intraset, and within-exercise bout) responses may be just as important for a variety of populations (sedentary, recreationally active, athletic, etc.). For example, Hester et al. (13) examined the intraset effects of a high-volume power-oriented back squat protocol (5 × 16 at 40% 1-RM, 2-minute rest interval) on PP of the squat movement (measured by a linear transducer secured to the barbell). Interestingly, PP was significantly reduced from the first repetition to the last repetition, however, no differences were observed in the highest PP repetition between sets. While novel, it is important to note that a 2-minute rest period may be sufficient for recovery of PP between sets following a high-repetition squat protocol. The inclusion of another protocol using a different intensity or load may have revealed differential responses for PP (or other performance measures) within- and/or between-sets. A study by Walker, Davis, Avela, and Hakkinen (30) assessed the within-exercise bout effects of a maximal strength (15 sets at 1-RM) versus hypertrophic (5 sets at 10-RM) resistance loadings on concentric load and maximal isometric force pre-, mid-, and up to 30 minutes post-loading. However, to ensure successful lifts, concentric load had to be significantly reduced at set 10 and 15 of the maximal strength protocol, while the load was maintained during the hypertrophic protocol. Both protocols significantly reduced maximal isometric force from pre- to mid-loadings, however, the deficit remained unchanged from mid- to post-loading for the maximal protocol but continued to decrease during the hypertrophic protocol. While exercise design (maximal vs. hypertrophic) can elicit specific performance responses, the addition of a within-exercise bout assessment and across the acute recovery phase (5, 10, 20 minutes post exercise) may help further elucidate within-exercise bout and acute (recovery) responses to exercise mode and design.

Limited research has examined vertical jump performance post-exercise, and to our knowledge, only one study has assessed other variables besides PP and JH after performing a squat protocol (14). While power is a convenient assessment to examine functional performance, and is commonly reported with jump studies (14, 17), examining the within-exercise bout and acute (recovery) responses for PV could be beneficial in providing an additional degree of specificity on the impact squat protocols have on vertical jump performance. A variety of athletic jumps have been used in research (squat jump, drop jump, CMJ), however the CMJ, which utilizes the stretch-shortening cycle by a downward countermovement from a standing position, provides a practical movement pattern used by a variety of populations, and has been utilized to measure dynamic muscle function (3). For instance, Lowery et al. (17) utilized a volume-matched squat protocol, and while only one set was performed (low intensity 1 × 5 at 56%, moderate intensity 1 × 4 at 70%, and high intensity 1 × 3 at 93% 1-RM), this study tracked CMJ performance (height and power) up to 12 minutes post-exercise. Their results revealed that while no changes in CMJ performance occurred in the low intensity bout, the moderate and high intensity bouts showed an increase in CMJ performance (~5% and ~7%, respectively) at 4 minutes post-exercise and returned to baseline by 8 minutes post-exercise. Thus, the ability to identify direct and acute responses post-exercise may be important in further determining the impact different loadings/intensities have on functional performance. Therefore, the purpose of this investigation was to examine the immediate (within exercise bout) and acute (recovery) performance responses after performing two different (controlled heavy vs. power-endurance) free-weight back squat exercise protocols on vertical jump performance in females.

METHODS

Participants

A power analysis conducted with G*Power 3.1.9.4 (Universitat Kiel, Germany) determined that 7 participants were needed in the present study for a power of 0.80, with an effect size of 0.5 and an alpha level of 0.05. Fifteen resistance-trained women (mean ± SD: age = 21.8 ± 0.9 years; height = 164.6 ± 8.4 cm; mass = 68.5 ± 9.2 kg; 1-RM = 94.2 ± 20.8 kg; 1-RM to mass ratio = 1.4 ± 0.35) volunteered to participate in this investigation. All participants were engaged in a structured weight training program that involved the lower body (including the free-weight back squat exercise) for a minimum of at least 6 months prior to the study. None of the participants reported taking any ergogenic supplements (i.e. caffeine or creatine) prior to the study, nor reported any musculoskeletal injuries of the lower extremities, within 1 year prior to testing. This study was approved by the University Institutional Review Board for human subject's research, and prior to any testing each participant voluntarily completed an informed consent document and health history questionnaire. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (21).

Protocol

This study used a randomized, repeated measures design to investigate the immediate performance responses (within exercise bout) and acute (recovery) effects of two different free-weight back squat exercise protocols on vertical jump performance: PP, mean power (MP), PV, mean velocity (MV), and JH. Participants visited the laboratory on three occasions separated by 4-7 days. The first visit consisted of familiarization to testing procedures, and a 1-RM of the free-weight back squat exercise was determined. On the second and third visit the participants were randomly assigned to either a power-endurance (PE; 5×16 at 40% 1-RM) or controlled heavy squat protocol (CHP; 5×8 at 80% 1-RM). Participants performed vertical jumps before (Pre), immediately after set one (S1), set two (S2), set three (S3), set four (S4), set five (S5/Post0), 5-minutes (Post5), 10-minutes (Post10), 15-minutes (Post15), and 20-minutes (Post20) following either the PE or CHP.

Back Squat 1-RM and Exercise Protocols: The back squat 1-RM and exercise protocols were performed in a multi-purpose adjustable Commercial Power Rack (RockSolid Fitness, Rutland, VT, USA) with a standard Olympic barbell (20.45 kg). With feet positioned shoulder width apart, participants used a high bar placement and squatted starting from an upright position and descending until a ~90° angle at the knees was achieved (23). An elastic band was set for each participant to provide them with kinesthetic feedback of when a 90° knee angle was achieved in order to promote consistent squat depth for each repetition (5). Each back squat 1-RM assessment was performed at a cadence of 60 b·min^{-1} (using a digital metronome), resulting in a tempo of 2 seconds for both the eccentric and concentric contraction phases, ensuring a consistent duration of muscle tension throughout each repetition (12, 28). The following back squat 1-RM procedures were described by Brown (2). All participants achieved a 1-RM in ≤ 5 trials, with 3 minutes rest after each trial. Testing began with a warm-up of 10 repetitions at 50% of the estimated maximal load. The 1-RM was determined by selecting an initial load that the participant estimated would be approximately 90% of their 1-RM and subsequently applying incrementally small (2.27-9.09 kg) loads until the participant could not complete a repetition using proper technique through the full range of motion or could no longer maintain the cadence (60 b·min^{-1}) of the metronome. Additional trials were performed until the 1-RM was determined within 2.27 kg and using these procedures.

The two different squat protocols were work-matched for an equal load volume to allow for potential protocol-specific characteristics to be demonstrated (power-endurance vs. controlled-hypertrophic). The exercise protocols have been previously described (5, 13, 28). In short, participants were randomly assigned to either the PE or CHP squat protocol on separate occasions (4-7 days following 1-RM testing, with 7 days separating the experimental protocols). Each testing session was initiated with a 5-minute warm-up on a cycle ergometer (Monark Exercise 828E, Vansbro, Sweden), at a self-selected low-intensity (~50-60 rpm), followed by a set of 10 repetitions at 50% of participant's 1-RM followed by either the PE or CHP exercise protocols. The protocols were matched for an equal load volume to allow for potential protocol-specific characteristics to be demonstrated. During both protocols, 2 minutes of rest were allotted between each set. For the PE protocol a metronome was used to control tempo, in which a cadence of 60 b·min^{-1} was set for 2 seconds eccentric and an explosive concentric movement. All concentric portions of the repetitions were performed "as rapidly and explosively as possible" with one's feet still on the ground, ending in a neutral and non-plantar flexed position. During the CHP protocol, a cadence of 60 b·min^{-1} was used for a controlled 2 second eccentric and 2 second concentric movement occurred for all repetitions.

Countermovement Vertical Jumps (CMJ): On day one of the study (the familiarization day) countermovement jumps were performed by the participants, and the researcher was there to answer any questions, or critique any incorrect form or attempts. Participants performed two maximal CMJs at each time point with the best jump (based on PP) being used for data analysis. Jump height (cm) was measured based on flight time (ms) of the jump utilizing a jump mat (Just Jump Technologies, Huntsville, AL, USA). Flight time is defined as the amount of time between when the participant's feet left the mat to when the participant's feet returned back on the mat. Additionally, PP, MP, PV, and MV were simultaneously measured during each unloaded jump using a linear position transducer (LPT) (Tendo Sports Machines, Slovak Republic) that was placed directly behind the participant with the nylon string secured to a belt fastened around the participant's waist. Prior to jump testing, each participant's body mass (kg) was measured on a stadium scale (Detecto, Webb City, MO, USA) and entered into the linear transducer microcomputer (Tendo weightlifting analyzer V-207) so that power and velocity output could be measured. Following each jump, MV, PV, MP, and PP were displayed by the microcomputer and were manually recorded. Test-retest reliability determined by intraclass correlation coefficients, SEM, and minimal difference was performed using pretest values from testing days for each dependent variable (Table 1). During each CMJ, participants began in an upright position with feet shoulder width apart and hands positioned on the hips. Previous authors have suggested that attempting to coordinate a rapid arm swing during a VJ may lead to greater within-subject variability and may not be appropriate when measuring the explosive properties of the lower extremity (19). Thus, any rapid/powerful arm swing movements were minimized (hands on hips) in order to limit within-subject variability as well as provide a more uniform assessment. Upon verbal command, participants initiated a downward countermovement followed by a vertical movement as explosively as possibly for all vertical jumps. Each participant was instructed to refrain from tucking their knees while in the air, as this could artificially extend the flight time and ultimately skew the JH data.

Table 1. Reliability statistics for all vertical jump performance measures [peak power (PP), mean power (MP), peak velocity (PV), mean velocity (MV), and jump height (JH)] during the countermovement vertical jump.

	PP	MP	PV	MV	JH
P-value	0.76	0.57	1.00	0.48	0.62
$ICC_{2,1}$	0.98	0.95	0.98	0.95	0.98
SEM	75.33	56.28	0.10	0.08	0.62
SEM%	4.78	6.84	4.53	6.62	4.03

P-value = type I error rate for the one-way repeated measures ANOVA across visits 2 and 3. $ICC_{2,1}$ = intraclass correlation coefficient, model 2,1. SEM = standard error of measurement, expressed as absolute values and percentages of the mean.

Statistical Analysis
All data was analyzed using SPSS version 24.0 (SPSS Inc., Armonk, NY, USA). Separate 2-way repeated measure ANOVAs [Intensity (PE vs. CHP) × Time (Pre vs. S1 vs. S2 vs. S3 vs. S4 vs. S5/Post0] and [Intensity (PE vs. CHP) × Time (Pre vs. S5/Post0 vs. Post5 vs. Post10 vs. Post15 vs. Post20] were run for all dependent variables (PP, MP, PV, MV, and JH). Partial eta squared (ηp^2) values were reported to estimate ANOVA effect sizes (0.01 = small; 0.06 = medium; 0.14 = large). In the case of the violation of sphericity Greenhouse-Geisser results were reported. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

RESULTS

No significant intensity × time interaction was observed for MP ($p = 0.87$, $\eta p^2 = 0.02$), PP ($p = 0.30$, $\eta p^2 = 0.08$), MV ($p = 0.79$, $\eta p^2 = 0.03$), PV ($p = 0.36$, $\eta p^2 = 0.07$), nor JH ($p = 0.73$, $\eta p^2 = 0.05$). However, main effects for time were observed for all variables; MP ($p \leq 0.001$, $\eta p^2 = 0.52$), PP ($p \leq 0.001$, $\eta p^2 = 0.43$), MV ($p \leq 0.001$, $\eta p^2 = 0.54$), PV ($p \leq 0.001$, $\eta p^2 = 0.43$), and JH ($p \leq 0.001$, $\eta p^2 = 0.65$).

Immediate Performance Responses (Figures 1-3): MP and MV were significantly lower following the completions of S2 through S5/Post0 (p = 0.001-0.02) compared to Pre. PP and PV were significantly lower following S1 through S5/Post0 (p = 0.001-0.03) time points compared to Pre. Additionally, JH was significantly lower than Pre following S1 through S5/Post0 ($p \leq 0.001$).

Acute Recovery Responses (Figures 1-3): While MP and MV were significantly reduced ($p \leq$ 0.01-0.02) immediately following (S5/Post0) the squat protocols, no other recovery time points (Post5-Post20) were significantly different compared to Pre. However, PP and PV were significantly lower at S5/Post0, Post5, Post15, and Post20 ($p \leq$ 0.001-0.04), but not at Post10 (p = 0.17-0.21), compared to Pre. In addition, while JH was significantly lower than Pre at S5/Post0, Post15, and Post20 ($p \leq$ 0.001-0.02), no differences were observed at the Post5 and Post10 (p = 0.13-0.25) time points.

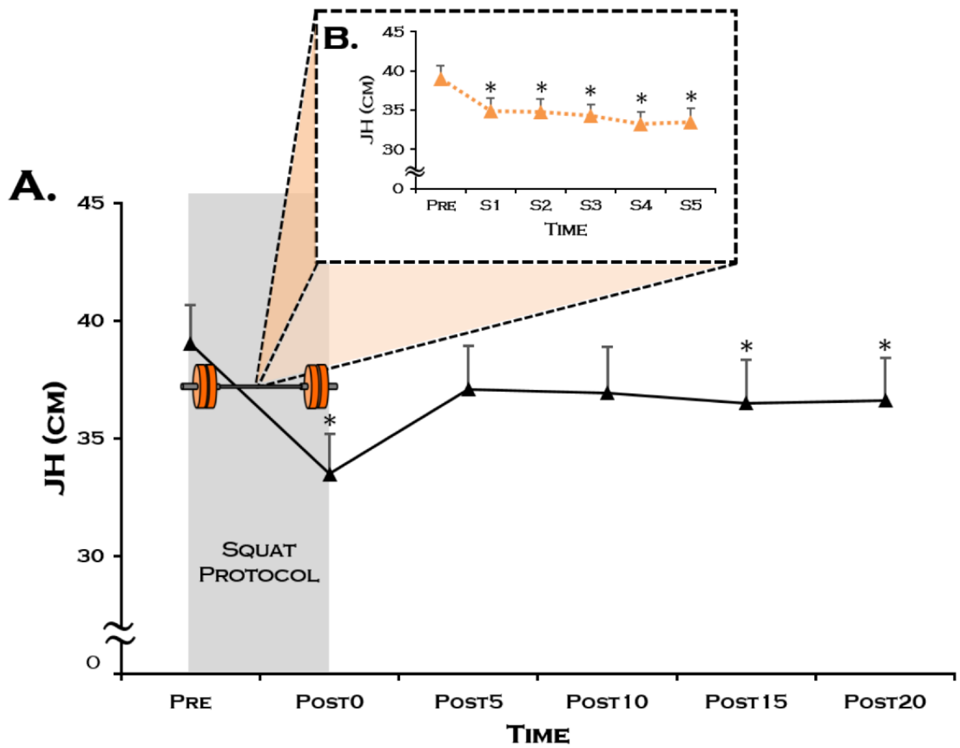

Figure 1. Vertical Jump Height (JH) values (A) before (Pre) and following (Post 0-Post 20) the squat protocols. Vertical JH performance was significantly reduced at Post 0, Post 15, and Post 20 (p = 0.001-0.02). Vertical JH values (B) before (Pre) and following each set (S1-S5) of the experimental protocol. JH performance was significantly lower following all protocol sets (S1-S5) compared to Pre (p = 0.001). * Indicates significantly lower compared to Pre.

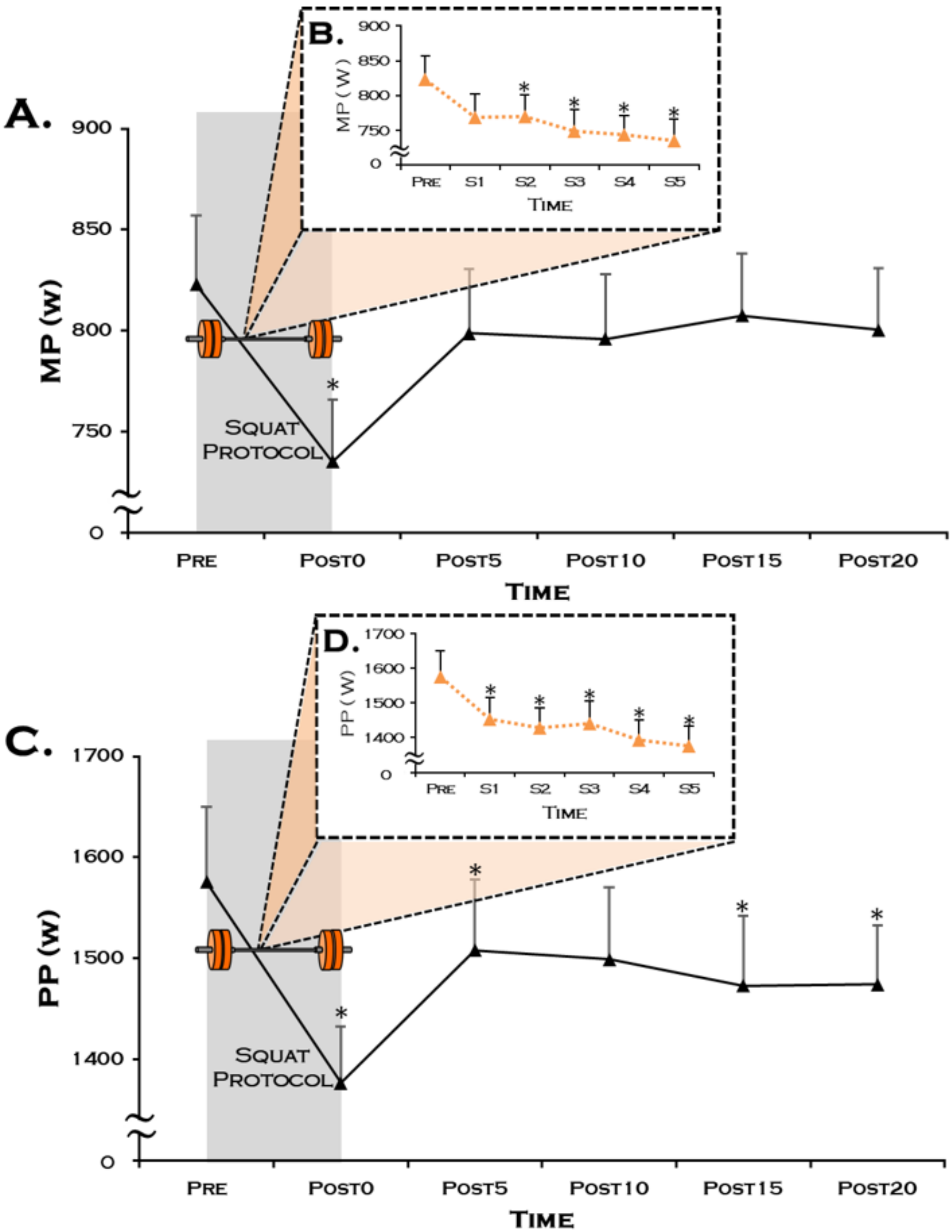

Figure 2. Vertical Jump MP (A) and PP (C) before (Pre) and following (Post 0-Post 20) the squat protocols as well as following individual sets of the experimental protocol (B; D). MP was significantly lower at Post 0 ($p = 0.02$) (A) and following S2-S5 ($p = 0.002$-0.01) (B) compared to Pre. Additionally, PP was significantly lower at Post 0, Post 5, Post 15, and Post 20 ($p = 0.04$) (C) and following all protocol sets S1- S5 compared to Pre ($p = 0.001$-0.03) (D). * Indicates significantly lower compared to Pre.

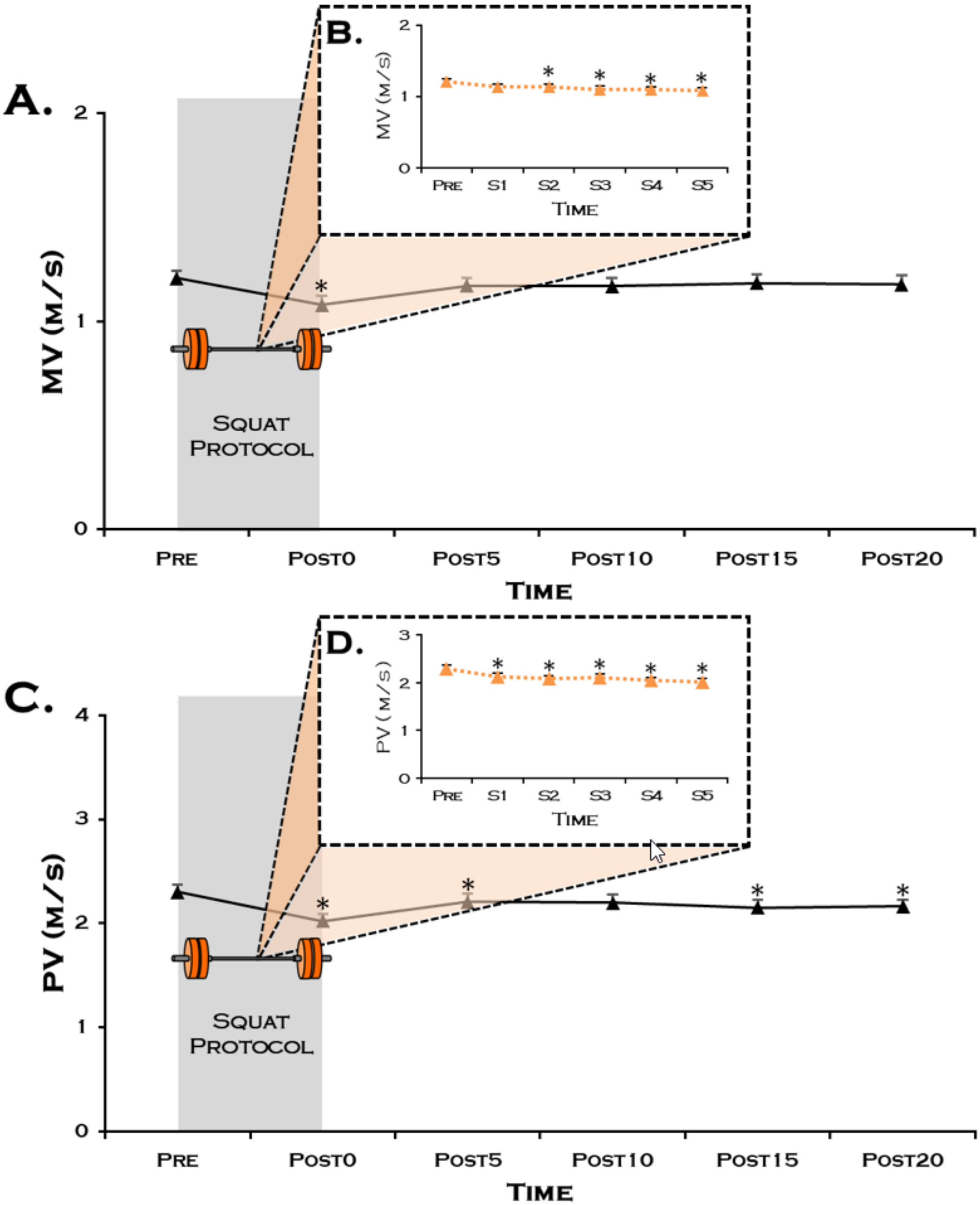

Figure 3. Vertical Jump MV (A) and PV (C) before (Pre) and following (Post 0-Post 20) the squat protocols as well as following individual sets of the experimental protocol (B; D). MV was significantly lower at Post 0 ($p = 0.004$) (A) and following S2-S5 ($p = 0.001$-0.02) (B) compared to Pre. Additionally, PV was significantly lower at Post 0, Post 5, Post 15, and Post 20 ($p = 0.001$-0.02) (C) and following all protocol sets S1- S5 compared to Pre ($p \leq 0.001$-0.03) (D). * Indicates significantly lower compared to Pre.

DISCUSSION

The purpose of this investigation was to examine the immediate (within exercise bout) and acute (recovery) vertical jump performance responses following two different volume-matched free-weight back squat exercise protocols. Interestingly, the present study observed no differences between squat conditions (PE; 5×16 at 40% 1-RM vs. CHP; 5×8 at 80% 1-RM). A key finding from the present study was the immediate performance deficits (PP, PV, and JH) after performing only a single set of exercise, regardless of the intensity. However, when assessing acute recovery post-exercise bout, dissimilar recovery responses (partial recovery Post5-Post10) were observed between the performance variables (MP, MV, PP, PV, & JH). Nonetheless, the overall findings revealed decreased performance for 20 minutes post-exercise (Figures 1-3). These results demonstrate how explosive and rapid performance may be negatively impacted after completing one set of a designated exercise, and performance may be decreased up to 20 minutes following the exercise bout.

A novel finding of the present study was the immediate (after one set of squats) decrease in PP (~8), PV (~7%), and JH (~10%). These variables were further decreased following S5/Post0 by ~13%, ~12%, and ~14%, respectively (Figure 2). In addition, the present study observed a ~7% decrease in both MP and MV following the second set of squats, where both MP and MV were reduced up to ~11% following S5/Post0 (Figure 2 & Figure 3). While several studies have investigated the acute effects (i.e. a single set or bout) of loaded squats (half, back, or jump squats) on vertical jump performance (11, 14, 15, 17, 20, 25, 26, 31), the intended purpose of these studies were to elicit post-activation potentiation responses. Furthermore, while the previous studies included squat based movements within their workout, to the authors knowledge, only two studies assessed vertical jumps directly following loaded back squats (15, 17). Nevertheless, in agreement with our findings, Jensen and Ebben (15) reported a significant decrease in JH for males and females (~11% and ~4%) immediately (10s) after performing a single set of 5-RM back squats. Additionally, Lowery et al. (17) observed significant decreases in JH and power output directly following volume-matched back squats using moderate (1 × 4 at 70% 1-RM) and high-intensity (1 × 3 at 93% 1-RM) conditions. While the two previous studies only examined vertical jump performance after a single set of squats, Smilios et al. (26) investigated vertical jump performance across multiple sets with two different loading protocols (moderate loaded jump squats, 3 × 5 with 30-60% of 1-RM, and half squats 3 × 5 with 60% 1-RM). In contrast to the present study, Smilios et al. (26) observed a significant increase (~4%) in JH after the first and second sets. Differences between the present study's findings and Smilios et al (26) could be attributed to squat protocols (regular squat vs. jump squats), overall volume (controlled for overall volume vs. non-controlled), intensity (40 and 80% 1-RM, vs. 30-60% 1-RM), rest periods between sets (2 min vs. 3 min), and purpose (assess responses post-sets, vs. potentiation responses). Interestingly, while dissimilar responses were observed post-exercise between these studies, future research may expand on these findings by examining within-set responses and varying intensities as well as exercises within a variety of populations.

An interesting finding from the present study was the similar fatigue- and recovery-related responses between the two squat protocols after controlling for overall training volume.

Specifically, the present study observed a significant decrease (~7-14%) in all performance measures following the completion (S5/Post0) of both squat protocols (Figures 1-3). These findings are similar to those of Hester et al. (14) who reported no difference between a jump squat (10 × 20% 1-RM) or heavy (5 × 80% 1-RM) protocol on vertical jump performance (PP, PV, and JH). In addition, although Hanson et al. (11) was attempting to elicit potentiation, the authors found no significant differences in kinetic measures (net impulse, time of ground contact, and vertical ground reaction force) for vertical jumping following a low-intensity, fast velocity (1 × 8 at 40% of 1-RM) or high-intensity, slow velocity (1 × 4 at 80% of 1-RM) set of squats. Contrary to our findings, Lowery et al. (17) observed a significant increase in JH and PP 4-8 minutes following their volume-matched moderate- and high-intensity back squat protocol. Differences between Lowery et al. (17) and the present study may be related to squat protocols (single set vs. multiple sets) purpose (induce potentiation vs. assess exercise responses) and sex (male vs. female). Interestingly, while the performance measures appeared to start recovering by Post10, PP, PV, and JH were significantly lower at Post15 (~6-7%) and Post20 (~6%) when compared with Pre (Figures 1-3). Similarly, Hester et al. (14) observed decreases in PP (~5%), PV (~5%), and JH (~4%) measured at 10 minutes following their heavy squat protocol. Thus, taken together, these findings suggest that vertical jump performance can be significantly reduced immediately following a bout of either power-endurance or controlled heavy squat protocols for resistance-trained females.

The immediate and acute decreases in performance for the aforementioned as well as present study may be related to the effects of fatigue. While fatigue is a complex process that may involve both metabolic and neural physiological changes, it is plausible that repetitive repetitions of low- to high-intensity muscular contractions can induce peripheral fatigue. Mechanisms of neuromuscular fatigue have largely been characterized as being peripheral, likely occurring from an inability to restore Na+ (sodium) and K+ (potassium) gradients across the sarcolemma resulting in large amounts of K+ being depleted, thereby leading to impaired action potential conduction efficiency (9). The decreased Ca2+ (calcium) reuptake combined with an inhibition of the t-tubules which reduces sarcoplasmic reticulum calcium release may lead to decreased sensitivity at the cross-bridge binding sites (7). In addition to peripheral mechanisms, it is plausible that stimulation of group III and IV chemoreceptor afferent neurons may have occurred, which have inhibitory effects on the α-motoneurons innervating the fatigued muscle (1). Although performance deficits (PP, PV, JH) were observed after just a single set of back squats, we acknowledge that acute mechanical or viscoelastic tissue changes (e.g., stiffness, creep, elasticity) may have contributed to immediate alterations to the stretch-shortening cycle (6). Due to the nature of the experimental protocols (controlled tempo during the eccentric phase), it is plausible that even acute bouts of mechanical loading may influence tissue compliance, thus affecting muscle force transmission and decreasing ballistic performance during the countermovement jump. However, while the present study did not directly assess these various physiological characteristics, future research is warranted for assessing the contributions of peripheral mechanisms and viscoelastic alterations on direct performance responses following functional mechanical loading.

The findings of this study revealed that both the power-endurance and controlled heavy squat protocol elicited significant decreases in vertical jump performance for resistance-trained women. Future research should compare different volumes, intensities, and types of exercises (e.g., weighted jumps, box jumps, depth jumps), which have unique stretch-shortening cycle patterns to determine their effects on vertical jump performance. In addition, to properly determine the immediate or direct effects protocols have on vertical jump performance within-set measurements/assessments should be added. While the present investigation included resistance-trained individuals, the recovery responses may greatly differ compared to sedentary or older populations. Furthermore, the present study controlled for overall total volume between the training protocols. While this may be common for recreational and lab-based training, the present exercise protocols may not be applicable across all activity levels.

Knowing that a variety of populations implement compound movements into their resistance training routines, the present findings suggest that vertical jump performance may be negatively affected following a power-endurance or controlled heavy squat protocol. Thus, assessing vertical jump performance variables (PP, MP, PV, MV, and JH) following exercise may be valuable in identifying the immediate and residual consequences of fatigue over an acute recovery period. Furthermore, a recovery period of up to 20 minutes may yield impaired physiological and functional characteristics for individuals who perform tasks similar to the present study. Thus, clinicians, practitioners, and strength and conditioning professionals may use caution when designing lower-extremity exercises, as dynamic/functional characteristics may be diminished after the first set and for an acute period of time (0-20 minutes) post-exercise.

REFERENCES

1. Bigland-Ritchie B, Dawson N, Johansson R, Lippold O. Reflex origin for the slowing of motoneurone firing rates in fatigue of human voluntary contractions. J Physiol 379: 451-459, 1986.

2. Brown LE. Strength training. Champaign, IL: Human Kinetics; 2007.

3. Byrne C, Eston R. The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. J Sports Sci 20(5): 417-425, 2002.

4. Chiu L, Fry A, Schilling B, Johnson E, Weiss L. Neuromuscular fatigue and potentiation following two successive high intensity resistance exercise sessions. Eur J Appl Physiol 92(4-5): 385-392, 2004.

5. Conchola EC, Thiele RM, Palmer TB, Smith DB, Thompson BJ. Acute postexercise time course responses of hypertrophic vs. power-endurance squat exercise protocols on maximal and rapid torque of the knee extensors. J Strength Cond Res 29(5): 1285-1294, 2015.

6. Conchola EC, Thiele RM, Palmer TB, Smith DB, Thompson BJ. Effects of neuromuscular fatigue on the electromechanical delay of the leg extensors and flexors in young men and women. Muscle Nerve 52(5): 844-851, 2015.

7. Fitts RH. The muscular system: fatigue processes. ACSM's advanced exercise physiology. Philadelphia, PA: Wolters Kluwer; 2006.

8. Gilbert G, Lees A. Changes in the force development characteristics of muscle following repeated maximum force and power exercise. Ergonomics 48(11-14): 1576-1584, 2005.

9. Green H. Mechanisms of muscle fatigue in intense exercise. J Sports Sci 15(3): 247-256, 1997.

10. Häkkinen K. Neuromuscular fatigue and recovery in male and female athletes during heavy resistance exercise. Int J Sports Med 14(2): 53-59, 1993.

11. Hanson ED, Leigh S, Mynark RG. Acute effects of heavy- and light-load squat exercise on the kinetic measures of vertical jumping. J Strength Cond Res 21(4): 1012-1017, 2007.

12. Hattin HC, Pierrynowski MR, Ball KA. Effect of load, cadence, and fatigue on tibio-femoral joint force during a half squat. Med Sci Sports Exerc 21(5): 613-618, 1989.

13. Hester GM, Conchola EC, Thiele RM, DeFreitas JM. Power output during a high-volume power-oriented back squat protocol. J Strength Cond Res 28(10): 2801-2805, 2014.

14. Hester GM, Pope ZK, Sellers JH, Thiele RM, DeFreitas JM. Potentiation: effect of ballistic and heavy exercise on vertical jump performance. J Strength Cond Res 31(3): 660-666, 2017.

15. Jensen RL, Ebben WP. Kinetic analysis of complex training rest interval effect on vertical jump performance. J Strength Cond Res 17(2): 345-349, 2003.

16. Linnamo V, Häkkinen K, Komi P. Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. Eur J Appl Physiol Occup Physiol 77(1-2): 176-181, 1997.

17. Lowery RP, Duncan NM, Loenneke JP, Sikorski EM, Naimo MA, Brown LE, Wilson FG, Wilson JM. The effects of potentiating stimuli intensity under varying rest periods on vertical jump performance and power. J Strength Cond Res 26(12): 3320-3325, 2012.

18. Magrini MA, Colquhoun RJ, Sellers JH, Conchola EC, Hester GM, Thiele RM, Pope ZK, Smith DB. Can squat jump performance differentiate starters vs. nonstarters in division I female soccer players? J Strength Cond Res 32(8): 2348-2355, 2018.

19. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. J Strength Cond Res 18(3): 551-555, 2004.

20. Moir GL, Mergy D, Witmer C, Davis SE. The acute effects of manipulating volume and load of back squats on countermovement vertical jump performance. J Strength Cond Res 25(6): 1486-1491, 2011.

21. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

22. Paz GA, Robbins DW, de Oliveira CG, Bottaro M, Miranda H. Volume load and neuromuscular fatigue during an acute bout of agonist-antagonist paired-set vs. traditional-set training. J Strength Cond Res 31(10): 2777-2784, 2017.

23. Pincivero D, Green R, Mark J, Campy R. Gender and muscle differences in EMG amplitude and median frequency and variability during maximal voluntary contractions of the quadriceps femoris. J Electromyogr Kinesiol 10(3): 189-196, 2000.

24. Saez Saez de Villarreal E, González-Badillo JJ, Izquierdo M. Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. Eur J Appl Physiol 100(4): 393-401, 2007.

25. Scott SL, Docherty D. Acute effects of heavy preloading on vertical and horizontal jump performance. J Strength Cond Res 18(2): 201-205, 2004.

26. Smilios I, Pilianidis T, Sotiropoulos K, Antonakis M, Tokmakidis SP. Short-term effects of selected exercise and load in contrast training on vertical jump performance. J Strength Cond Res 19(1): 135-139, 2005.

27. Smilios I, Tsoukos P, Zafeiridis A, Spassis A, Tokmakidis SP. Hormonal responses after resistance exercise performed with maximum and submaximum movement velocities. Appl Physiol Nutr Metabol 39(3): 351-357, 2013.

28. Thiele RM, Conchola EC, Palmer TB, Defreitas JM, Thompson BJ. The effects of a high-intensity free-weight back-squat exercise protocol on postural stability in resistance-trained males. J Sports Sci 33(2): 211-218, 2015.

29. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. Sports Med 39(2): 147-166, 2009.

30. Walker S, Davis L, Avela J, Hakkinen K. Neuromuscular fatigue during dynamic maximal strength and hypertrophic resistance loadings. J Electromyogr Kinesiol 22(3): 356-362, 2012.

31. Witmer CA, Davis SE, Moir GL. The acute effects of back squats on vertical jump performance in men and women. J Sports Sci Med 9(2): 206-213, 2010.