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The Effects of an Upper Body Conditioning Stimulus on Lower Body Post-Activation Performance Enhancement (PAPE): A Pilot Study

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ABSTRACT

Complex training where a high-load conditioning stimulus (CS) is performed prior to a biomechanically similar plyometric movement has been demonstrated to acutely enhance the performance of the plyometric movement in a phenomenon called post-activation performance enhancement (PAPE). Despite the positive influence PAPE can have on power production, the abundance of research has only investigated PAPE locally while comparing biomechanically similar movements. The purpose of this study was to determine if a heavy barbell bench press could elicit PAPE in a lower body plyometric movement. Eight (n = 8) resistance-trained males performed one set of countermovement jumps (CMJs) before (pre-CS) and three sets of CMJs after (post-CS) a heavy bench press set. Changes in muscle activation, jump height, work, power output, and rate of force development (RFD) during the early (E-RFD) and late (L-RFD) stages were compared between pre-CS and post-CS. The level of significance was set at $p < .05$. There were no significant differences in muscle activation, jump height, work, power output, or E-RFD ($p > .05$). There was a significant increase in L-RFD between pre-CS and the final set of jumps post-CS ($p = .01$). These results suggest that an upper body CS may not influence PAPE in the lower body. However, pairing a high-load upper body exercise with a lower body plyometric does not seem disadvantageous, and could be implemented as a strategy to maximize workout time efficiency with proper fatigue management incorporation.

Keywords: bench press, power, rate of force development, muscle activation, plyometric

INTRODUCTION

Strength and conditioning professionals aim to ready athletes for a competition period by training and optimizing sports specific qualities such as muscular strength and rate of force development. To enhance these qualities, resistance training strategies for the athlete should include a mixed approach of both high-load, low-velocity movements as well as high-velocity, plyometric movements (26). One strategy used by strength and conditioning professionals to integrate both high-load resistance exercises and plyometric exercises in a training program is complex training. During traditional complex training, high-load resistance and plyometric movements that are biomechanically similar (such as pairing a heavy back squat with a jump) are alternated set-by-set in a training session to encourage both strength and power adaptations (5). An abundance of research investigating the efficacy of complex training suggests that when a high-load resistance exercise is performed just prior to a biomechanically similar plyometric movement, the performance of the plyometric movement is acutely enhanced (5).

The transient improvement in performance in a voluntary movement that occurs after a high-load conditioning stimulus (CS) is referred to as post-activation performance enhancement (PAPE) (3). It should be emphasized that PAPE should not be confused with post-activation potentiation (PAP). Previous sports science literature has erroneously led the two terms to become interchangeable although they both refer to different conditions, which can lead to confusion amongst researchers and practitioners (3). Thus, it should be made clear that PAPE refers to the performance increase in a voluntary contraction post-CS while PAP is instead the improvement in muscle force after an electrically induced contraction that has a short half-life (~28 s) (3). PAP is proposed to occur from peripheral factors, namely phosphorylation of the myosin regulatory light chain (RLC) (34). On the other hand, the key mechanisms that encourage PAPE are still being determined, although several peripheral and central factors have been investigated. Theorized factors that lead to PAPE include: increased higher-order motor unit recruitment (34), motor unit excitability (35), fluid shifts leading to increased muscle hydration (33), increased muscle temperature resulting in improved muscle metabolism and fiber conduction velocity (22, 27), and during longer periods between the CS and plyometric exercise, acute changes to muscle pennation angle may play a role (20).

Considering that a theorized mechanism of PAPE is a stimulation of the central nervous system (CNS) from a CS leading to increased motor unit activation, it is plausible that an upper body CS could elicit non-localized PAPE in a lower body plyometric movement. Although only exhibited between contralateral limb segments, there is evidence that training a limb unilaterally in isolation can improve or maintain strength in the untrained, contralateral limb in a phenomenon called the cross-education effect (25). The literature suggests that activation of the contralateral motor cortex or spinal excitation (18) lead to strength gains during cross-education, and the gains are independent of changes in local muscle morphology (16). Studies have also demonstrated significant changes in electromyographical data that corroborate the improved muscle excitation that occurs in the contralateral limb (14, 30), further suggesting the dependency of neural factors to drive cross-education changes. Other investigations have also established the existence of intrinsic neural coupling between the upper and lower limbs in locomotion tasks (37, 38), with one study from Huang and Ferris (2004) identifying an increase in lower body activation with recumbent stepper using the upper body only with relaxed legs.

Mechanistic data to support the theory that CNS stimulation could result in non-localized performance changes comes from Gullich and Schmidtbleicher (1996), who demonstrated that inducing a tetanic isometric contraction by stimulation of afferent fibers leads to corticospinal excitation across the spinal cord, lasting for several minutes following cessation of the contraction stimulus. The state of excitation results in an augmented transmittance of post-synaptic potentials for the same pre-synaptic potential during subsequent activity (11, 19). It is proposed that the elevated transmittance of action potentials across the synapse is a result of decreased neurotransmitter failure (19). Specifically, tetanic contraction is theorized to decrease neurotransmitter failure by increasing the quantity of neurotransmitters released at the pre-synaptic terminal, increasing neurotransmitter efficiency, or reducing branch-point failure along the afferent fibers, all of which could occur at a central level (6). Thus, the possibility remains that neural conditioning from an upper body CS may potentiate electrical transmission to the lower body nerve roots through these mechanisms, influencing non-localized PAPE from an upper body CS to a lower body plyometric exercise.

Despite the positive influence that PAPE can have on power production, research has only investigated the possibility of localized PAPE, where an upper body CS is used to potentiate an upper body plyometric exercise or a lower body CS is used to potentiate a lower body plyometric exercise. Determining the feasibility of non-localized PAPE while pairing upper and lower body exercises during complex training is a useful tool to circumvent the local neuromuscular fatigue accrued from the pairing of biomechanically similar exercises (34). To the best knowledge of the authors, only a single pilot study has attempted to investigate the potential of non-localized PAPE using both upper and lower body CS to stimulate lower body PAPE (4). Although some performance potentiation was demonstrated in the study, the authors remark that the design of the protocol prevents a conclusion towards if an upper body CS could influence lower body PAPE. Therefore, the purpose of this study is to determine if an upper body CS can elicit non-localized PAPE in a lower body plyometric exercise via neural mechanisms.

METHODS

Participants

Eight (n = 8) healthy, resistance-trained adult males participated in this study (23.5 ± 2.7 y; 177.5 ± 3.2 cm; 81.7 ± 5.8 kg). Inclusion criteria specified that participants had >1 year of continuous, structured resistance training, could perform a >1.5× bodyweight back squat to parallel and >1.25× bodyweight bench press, and were familiar with jumping. Participants were required to submit a Physical Activity Readiness Questionnaire (2019 PAR-Q+) and be cleared to participate in the study. Participants with any cardiovascular, metabolic, or musculoskeletal conditions, or on any medications that could affect safety or performance were excluded from the study. Participants were also instructed to not participate in exercise 48 hours prior or consume any caffeine or stimulants in the hours before the preliminary and testing sessions. The study procedures were in accordance with the principles of the Declaration of Helsinki and all participants provided informed consent according to the approved procedures by the local Institutional Review Board.

Table 1. Participant Demographic Data*

Participant Characteristics	(*n*=8)
Age (years)	23.5 ± 2.7
Height (cm)	177.5 ± 3.2
Weight (kg)	81.6 ± 5.8
Resistance Training Experience (years)	8.9 ± 2.8
Bench Press 1RM (kg)	118.0 ± 10.3

*Data are reported as mean ± SD

Measures

Assessment of muscle activation

The amount of muscle activation was quantified using surface electromyography (sEMG) sampled at a rate of 1500 Hz using 16-bit data acquisition system (TeleMyo DTS; Noraxon USA Inc.; Scottsdale, AZ). Although sEMG directly measures muscle excitation and not activation, the two processes are reasonably coupled in human movement and activation can be justifiably estimated (36). The sEMG sensor included a surface pre-amplifier (500× amplification) and an active probe with a common mode rejection rate and input impedance of > 100 dB and > 100 MΩ, respectively (DTS EMG Sensor; Noraxon USA Inc.; Scottsdale, AZ). A band-pass filter of 10-500 Hz was used. Prior to placement of electrodes, the skin sites were shaven, lightly abraded with fine sandpaper, and cleansed with an alcohol wipe to allow for proper electrode adherence and conduction. Self-adhesive, pre-gelled Ag/AgCI bipolar dual surface electrodes with a 2.0 cm interelectrode distance (Noraxon USA Inc; Scottsdale, AZ) were placed on the gluteus maximus (one-half the horizontal distance between the greater trochanter and sacral vertebra at the level of the trochanter, on an oblique angle parallel to the muscle fibers), vastus lateralis (3-5 cm above the patella, at an oblique angle lateral to midline), and gastrocnemius (distal from the knee, 1-2 cm lateral from midline) muscle groups to measure electrical potentials generated. These muscle groups were chosen for measurement of muscle activation for their role as primary agonists for the CMJ (31). All electrodes were placed on the participant's dominant lower extremity, determined by asking participants which side they would kick a ball with. The electrode and sensor were firmly secured on the participant using elastic bands and athletic tape so that the apparatus would not shift during the CMJ. The sEMG data were analyzed by full-wave rectification and then smoothing using a root-mean-square (RMS) algorithm with a window length of 50 ms (Noraxon MR3; Noraxon USA Inc.; Scottsdale, AZ). The average mean amplitude of whole CMJ movement (from start of eccentric phase to end of the takeoff phase) for the three CMJs for each jump time point was calculated and determined to represent the muscle activation for that time point.

Assessment of jump performance

Power output, jump height, total work performed, and RFD were measured using a force plate with a sampling rate of 500 Hz (Quattro Jump – Type 9290DD; Kistler Instrument Corp; Winterthur, SUI). The best single jump of each CMJ time point (pre-CMJ and post-CMJs) that provided the greatest peak relative power output, relative total work, and jump height was considered to represent that jump time point. Jump height was calculated using the instantaneous take off velocity determined by Kistler Measurement, Analysis & Reporting Software

(MARS) for Quattro Jump. Early phase RFD (E-RFD; < 100 ms) and late phase RFD (L-RFD; > 100 ms) were calculated by sampling the concentric force-time curve of the concentric action of the CMJ at a frequency of 10 ms. E-RFD and L-RFD were analyzed independently as different physiological factors influence the expression of each phase (9). The maximum instantaneous slopes of the concentric force-time curve were considered to represent the RFD generated during E-RFD and L-RFD.

Design and Procedures

To determine the effect of an upper body CS on lower body PAPE, a within subjects, repeated measures design was incorporated where participants underwent a familiarization session that included a one repetition maximum (1RM) bench press testing followed by an experimental session. The experimental testing session was held no sooner than 72 hours after the familiarization session, to allow for recovery from the maximal bench press testing. During the experimental session, changes in activation of the gluteus maximus, gastrocnemius, and vastus lateralis were assessed between pre-CS and post-CS time points. Changes in jump height and kinetic variables such as total work, power, E-RFD and L-RFD were also measured and compared between the pre-CS and post-CS jumps.

Preliminary session

Participants underwent a preliminary session that included 1RM testing on the barbell bench press and familiarization to the protocol prior to the experimental session. Prior to study inclusion, participants were informed about the study, provided written consent, and completed the PAR-Q. After inclusion to the study, participants underwent 1RM testing of the bench press to establish a baseline utilizing the National Strength and Conditioning Association's (NSCA) testing protocol. After 1RM testing, the participants were given a general overview of what to expect during experimental session, and were given brief instruction and practice with a CMJ on a force plate to familiarize them with the protocol.

Experimental session

At the start of the experimental testing session, surface electrodes were placed on the gluteus maximus, gastrocnemius, and vastus lateralis of the participant's dominant lower extremity. Next, the participants were guided through a general full-body warm-up moving from more general movement patterns (sets of 10 repetitions of quadruped reaches and rotations, hip bridges and abductions, shoulder flys) to more specific higher velocity, complex movements (10 mountain climbers, 10 lateral and crossover lunges, 20 jumping jacks, 10 burpees, high knees for two sets of 25 m, and cariocas for two sets of 25 m) to adequately ready the neuromuscular system for the CMJs. After the warm-up, participants were then instructed to perform three CMJs on the force plate, allowing a full reset between each jump (pre-CMJ). The instructions also included that the intent of each jump is to be explosive and reach a maximal jump height using a self-selected depth of the eccentric portion of the CMJ. All CMJs throughout the protocol were performed with hands on the hips to mitigate the effect of the upper body on lower body force production. The peak values of power output, jump height, and total work of the CMJ were recorded as well as muscle activation of the gastrocnemius, gluteus maximus, and vastus lateralis.

The participants then performed a bench press warmup and working set (the set considered to be the CS) by ramping up to a top working set of four (4) repetitions with 85% of 1RM. Following the working set, participants performed three sets of three repetitions of CMJ after the bench press (post-CMJ), staggered at three time points: immediately after the bench press CS, 90 s post-CS, and 3 min post-CS. These specific time points were chosen thoughtfully. The ideal time course between the CS and PAPE is still unclear with improvements identified immediately post-CS (10, 12) to up to 20 minutes post-CS (21). Methodological factors such as type of CS and participant characteristics may play a role in the variability. One meta-analysis demonstrated that between 8 to 12 minutes post-CS is the optimized recovery interval for PAPE to occur (13). However, employing such an interval is impractical in the training of sport athletes and instead aiming for a recovery period that allows for PAPE to occur without sacrificing time is prudent. The balance between potentiation from the CS and acute fatigue generated that can mask performance should be appropriate balanced. Hence, the authors chose shorter recovery intervals (up to 3 min-post CS) in this study for this reason, as local fatigue would not be as large of an issue as the bench press CS targets different muscle groups than the CMJ.

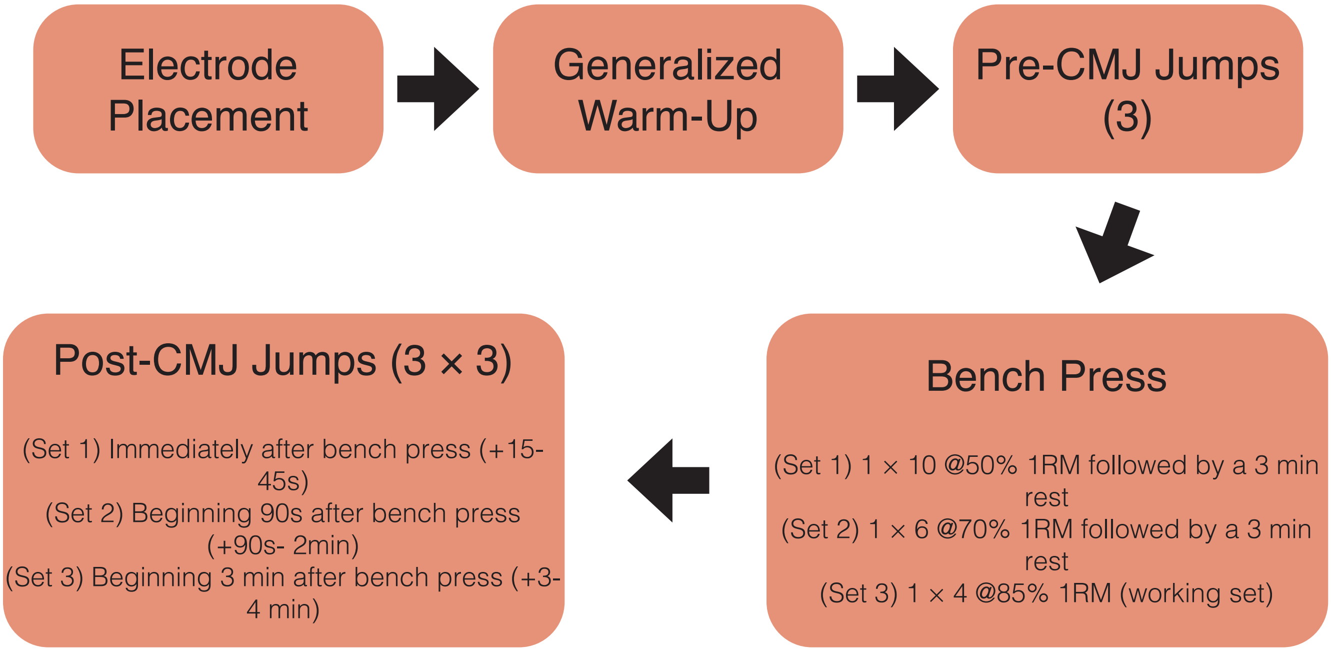

Figure 1. Overview of the experimental session

Statistical Analysis

A Shapiro-Wilks test for normality was performed which determined a non-normal distribution of data. A non-parametric Friedman's test was recruited to analyze differences between pre-CMJ and post-CMJ time points (immediately after the CS, 90 s post-CS, and 3 min post CS). Wilcoxon signed-rank tests were performed post hoc with a Bonferroni correction to identify individual differences between the time points. The level of significance was set to a p-value < .05. All statistical analyses were performed using IBM SPSS Statistics software (Version 27).

RESULTS

Muscle activation

No significant differences were found in muscle activation of any of the muscles measured using sEMG, although increases over time were observed. Table 2 reports percent changes of muscle activation normalized to pre-CS measurements.

Table 2. Muscle Activation

		Post-CS			
Muscle	**Pre-CS**	**+15-45s**	**+90s-2min**	**+3-4min**	***p*-value**
Vastus Lateralis	Baseline	4.8 ± 18.8%	8.9 ± 15.9%	9.1 ± 18.3%	.08
Gastrocnemius	Baseline	.35 ± 10.5%	9.8 ± 17.9%	1.8 ± 11.2%	.49
Gluteus Maximus	Baseline	12.8 ± 25.2%	17.9 ± 24.0%	11.2 ± 20.8%	.25

*Data are reported as mean ± SD

Table 3. Jump Height, Work, Power and Early Phase of RFD*

		Post-CS			
Variable	**Pre-CS**	**+15-45s**	**+90s-2min**	**+3-4min**	***p*-value**
Jump Height (m)	.57 ± .12	.57 ± .12	.54 ± .10	.53 ± .10	.68
Work (J/kg)	10.2 ± 4.0	10.0 ± 11.4	9.2 ± 3.9	9.2 ± 4.0	.72
Power (W/kg)	10.2 ± 4.0	10.0 ± 11.4	9.2 ± 3.9	9.2 ± 4.0	.09
Early RFD (N/s)	6912 ± 1920	6158 ± 2745	7762 ± 2632	8142 ± 4487	.52

*Data are reported as mean ± SD

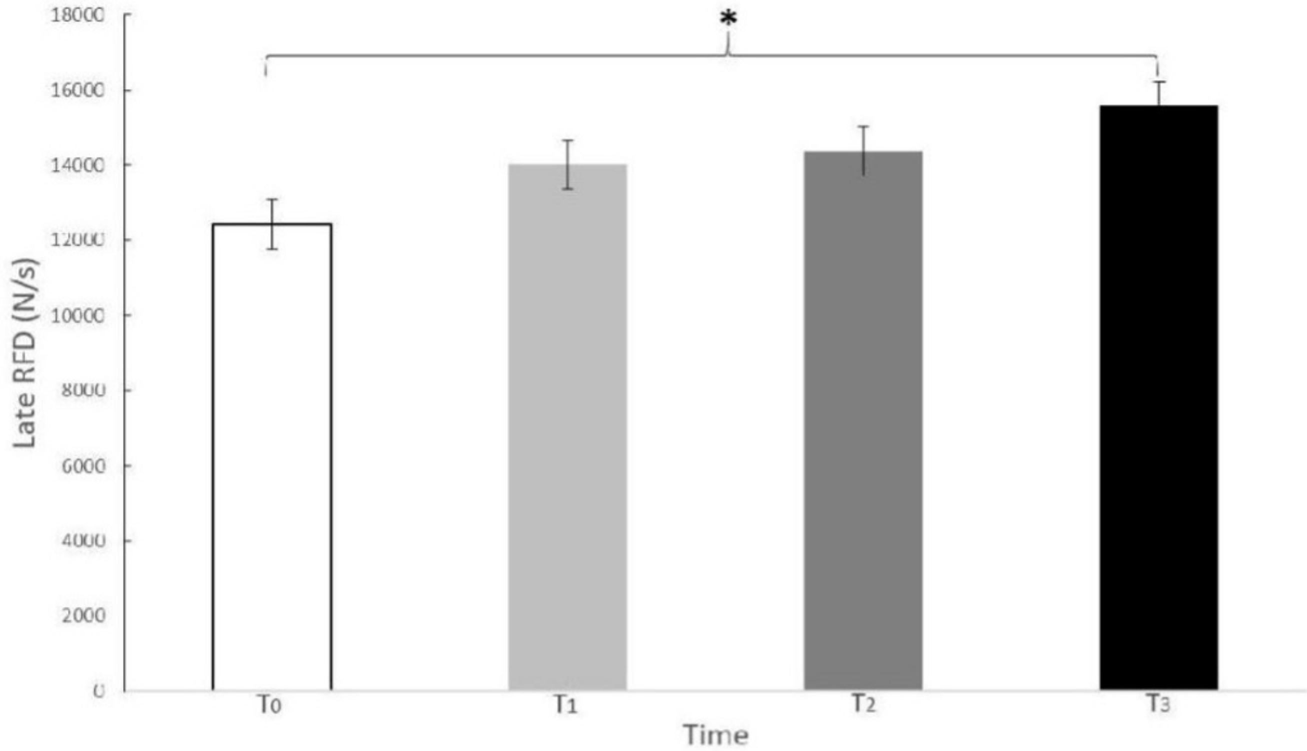

Figure 2. The late stage of RFD during CMJs as a function of time; T0 = Pre-CS; T1 = Immediately post-CS; T_2 = 90 sec post-CS; T_3 = 3 min post-CS; *There was a significant difference ($p < .05$) in late RFD between T_0 and T_3

A Wilcoxon signed-rank test was used to determine where the significant increase in L-RFD was observed. Pairwise comparisons between the individual time points demonstrated a significant difference between the pre-CS jump time point and the final jump time point (3 min post-CS; $p = .01$), as demonstrated in Figure 2.

DISCUSSION

Muscle activation and post-activation performance enhancement

To the authors' knowledge, no studies have investigated changes in muscle activation in the lower body during a jump after conditioning the upper body musculature. Surface electromyography was used to quantify the amount of muscle activation in the vastus lateralis, gastrocnemius, and gluteus maximus. No significant differences were noted for any of the muscle groups pre-CS compared to any of the time points post-CS, although relative but non-significant increases were observed. One proposed mechanism of PAPE is an increase in higher-order motor unit activity of the working muscles, resulting from decreased neurotransmitter failure (34). Higher-order motor units are generally comprised of fast-twitch muscle fibers that lend themselves to produce larger forces and faster contraction velocities (28). The threshold of depolarization is much greater for these motor units, leading to larger amplitudes on electromyography if greater recruitment takes place (32). The electromyographical data from the three major muscle groups involved in the jump do not support the idea that the neural activity generated from an upper body CS leads to enhanced muscle activation in the lower body muscles during a CMJ.

The lack of differences in the muscle activation pre-CS and post-CS are consistent with some studies investigating PAPE in the lower body (8, 29) although the results are conflicting, with other studies finding increased activation under similar conditions (10). Interestingly, many of the studies that have found no changes in sEMG amplitude have still seen significant differences in power performance post-CS (8, 29) emphasizing the fact that other factors besides neural changes could elicit PAPE, such as increased muscle temperature, hydration, or acute changes in muscle architecture (20, 27, 33).

The lack of significant increased activation in lower body muscles in the current experiment could be explained by the fact that although the upper body CS may have activated higher-order motor units in the upper body, the neural effect was limited to the conditioned nerve roots or proximal nerve roots only, as found in cross-education. As a result, the potentiated neural transmission may not have been able to demonstrate an effect on motor units in the lower body. Additionally, the volume or intensity of the CS may have been too low to generate a strong enough central effect. Introducing a greater dosage of the upper body CS could result in greater activation and a longer lasting twitch response of upper body motor units, leading to a heightened transmission potential that could have effects at the lower body.

Jump performance and post-activation performance enhancement

The muscle activation data from the sEMG analysis was also complemented by measures of vertical jump performance and kinetics. Power output, total work, and jump height were not found to be significantly different between the pre-CS and post-CS conditions. The CMJ has specifically been used in PAPE studies investigating changes in lower body power production. The lack of differences in jump height performance after a CS found in this study are also found in others (2, 24), although other studies showing a significant positive improvement (7, 21, 23). Similarly, studies that have also chosen to measure power output have seen mixed results, with some studies realizing increases in power output (7, 21, 23) and others not (2, 24). Studies that have reported increases in jump height and associated kinetic variables in the CMJ have done so using a traditional CS that potentiates the same muscle groups such as back squats (2, 7), hex bar deadlifts (29) or flywheel cycling (21). It seems unlikely that the bench press CS elicits any meaningful central effect, although as discussed in the previous subsection, exploring a higher volume or intensity of the upper body CS may encourage different results.

Changes in rate of force development

Changes in RFD were different in the early (< 100 ms) and late stages (> 100 ms) of contraction. E-RFD did not a show a significant change between the pre-CS or post-CS conditions. However, L-RFD was shown to have a significant difference between the pre-CS jump condition and the final jump condition (3 min post-CS). The contrast in RFD responses based on contraction phase could be explained as the relative contributions of neural and intrinsic contractile properties that influence RFD change throughout the course of the jump. Increased neural drive to agonist muscles is suggested to contribute to improvements in E-RFD (1). In particular, the agonist sEMG activity is the greatest predictor of RFD during the first 25-75 ms of voluntary explosive contraction (9). Both the sEMG and the E-RFD data were found to have no significant differences, supporting the idea that neural activity of the lower body was not potentiated from the addition of the CS. Neural drive contributes less to L-RFD and instead intrinsic contractile characteristics such as muscle architecture and maximum force generating capacity may play a larger role (9).

Although techniques to directly measure peripheral changes to the intrinsic contractile components of the lower body were not used in this study, it is theorized that the positive change in L-RFD found could be explained by acute changes in the lower body musculature occurring from the volume of jumps. The upper body CS would be unlikely to have an effect on intrinsic changes to the lower body. Therefore, it is plausible that the CMJ volume and not the upper body CS could have resulted in peripheral conditioning, leading to augmented force production by mechanisms not examined in this study.

CONCLUSION

The results of the study suggest that an upper body CS may not be a useful tool to influence PAPE in the lower body. However, there seems to be no clear disadvantage to performing an upper body strength exercise complexed with a lower body plyometric exercise, and could still be a useful strategy to maximize workout efficiency and organization if proper fatigue management is incorporated. Therefore, strength and conditioning coaches desiring to implement an upper-lower complex need to individualize exercise volume, intensity, and rest periods to optimize the relationship between workout efficiency and fatigue. There were limitations of the study. The sample size was notably small, directly as a result of repercussions of the COVID-19 global pandemic on human subject research, which led to the local Institutional Review Board terminating data collection due to safety concerns for the participants. Methodologically, performance was only measured up to 3 min after CS and PAPE has been noted at longer recovery intervals (13). In addition, a bench press with a set volume and intensity was included to potentiate the lower body and may not represent the non-localized PAPE effects from longer rest intervals or conditioning stimuli. Further research will be required to elucidate the effectiveness of an upper body CS on lower body PAPE by implementing protocols with a different combination of exercises, volumes, intensities, and recovery intervals.

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