International Journal of EXERCISE SCIENCE

Original Research

Effects of Supramaximal Anderson Quarter-squats as a Potentiating Stimulus on Discus Performance in Division I Throwers: A Pilot Study

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ABSTRACT

International Journal of Exercise Science 17(6): 99-114, 2024. No study has assessed supramaximal (over 100% 1RM) back squat variations as a potentiating stimulus in collegiate throwers. The purpose of this study was to test the hypothesis that a supramaximal Anderson (bottom-up) quarter squat potentiating stimulus would improve discus throw performance in Division I throwers compared to a dynamic warm-up alone. Nine NCAA division I thrower athletes (age: 20.1±1.4 years; 1RM back squat/body weight: 2.5±0.4 kg) randomly completed two sessions separated by at least 72 hours. One session involved a standardized dynamic warm-up alone (DyWU) followed by three trials of maximal discus throwing. The other session involved a dynamic warm-up with a supramaximal (105% 1RM) Anderson (bottom-up) quarter-squat set of 5 repetitions post activation performance enhancement stimulus (DyWU+PAPE) followed by three trials of maximal discus throwing. A two-way (warm-up strategy x time) ANOVA with repeated measures for each time point was used, with significance set at $p < 0.05$. There were no significant ($p > 0.05$) differences between DyWU alone versus DyWU+PAPE stimulus for discus throw distances at either 8 min. (31.7±5.6 vs 30.6±6.5 meters, respectively; d = -0.18), 11 min. (33.4±3.6 vs 31.3±4.7 meters, respectively; d = -0.52), or 14 min. post warm-up (34.1±3.9 vs 32.3±5.3 meters, respectively; d = -0.40). Compared to a dynamic warm-up alone, supramaximal Anderson quarter-squats following a dynamic warm-up had trivial/small to moderate detrimental effects on discus throw performance between 8-14 minutes post stimuli in Division I trained throwers, likely due to excess fatigue/PAPE inhibition.

KEY WORDS: Post-activation potentiation, strength-power-potentiation complex, track and field

INTRODUCTION

Every year, approximately 29,000 men and 30,000 women registered with the National Collegiate Athletic Association (NCAA) actively participate in track and field events (36). Within these events are four primary throwing categories: shot put, javelin, hammer, and discus. This investigation narrows its focus to the discus throw, a sport known for its physical intensity and technical complexity (11, 32, 50). Central to the performance in discus throw is the athlete's ability to apply force quickly, thereby achieving a high rate of force development during competition (22, 30, 32). Discus throw performance is influenced by various factors, including maximal strength and power (26, 43, 51), rate of force development (51), lean body mass (51), type II fiber composition (34, 45, 51), and specific muscle architecture, such as vastus lateralis thickness and fascicle length (3, 4, 34, 51). Training strategies should emphasize muscle hypertrophy to a certain extent (51), and the development of strength and power to optimize outcomes in this challenging sport (3, 4, 53).

Outside of training muscle hypertrophy to develop lean body mass in less trained or lower experience athletes, focusing on developing strength, power, and rate of force development, such as a mixed methods approach (20) is crucial for discus throwers (3, 4, 20, 51–53). Further, the use of complex training, or combining strength and power exercises in the same workout session, has been shown to be beneficial for throwers (4, 29, 43, 53). One such method of complex training uses strength-power-potentiation complexes, which couples a maximal or near-maximal conditioning activity (CA) with a subsequent strength/power exercise to enhance the subsequent exercise (8, 51). Regarding the CA used in strength-power-potentiation complexes, recent exploration has highlighted differences between classical post-activation potentiation (PAP) and post-activation performance enhancement (PAPE) (8). The main differences between PAP and PAPE are determined by the conditioning muscle contraction (i.e., electrically or voluntarily elicited, respectively), the peak strength/power response timing post-CA (i.e., ~<5 min. or ~5-15+ min., respectively), and the functional outcome (i.e., enhancement of muscle function is measured with twitch contractions or voluntary contractions, respectively) (8). This investigation will use PAPE as the focus is on voluntary throwing performance enhancement following a CA.

Using strength-power-potentiation complexes in training or in competition, throwing performance can be enhanced by an upper-body PAPE stimulus (15), such as using upper-body sport-specific overweight implements to improve throwing distance (5, 15, 24, 25). However, others have found lower body PAPE CA to enhance throwing performance, such as countermovement jumps (27, 45) enhancing throwing distance. Another study utilized a CA of heavy (80% 1RM) hang cleans and found enhanced throwing performance in Division I collegiate athletes (13). Further, in a recent meta-analysis, a heavy intensity (>85% 1RM) CA was more effective than moderate intensity (30-84% 1RM) CA, especially in stronger (>1.5-1.75x body weight back squat) individuals (42). Also, very limited studies (12, 14, 15, 18, 47) have examined a supramaximal (i.e., over 100% 1RM) CA for PAPE, despite reported benefits (1, 12, 14, 15, 18, 28). In particular, eccentric supramaximal (105-130% 1RM – based on concentric 1RM) CA has been found to enhance upper body explosiveness (12, 14, 18), including one study involving throwers with 130% 1RM eccentric loads (18). Further, even fewer studies have examined supramaximal concentric CA for PAPE (6). Specifically, to our knowledge, in the only study to use a concentric supramaximal CA for PAPE, a 3 second functional isometric concentric back squat (quarter squat) at 150% of 1RM was used for the CA and the authors reported significant vertical jump enhancement in stronger individuals only (6). Thus, there is a critical need to examine supramaximal concentric only CA for PAPE in various settings for potential training value.

Therefore, the purpose of this study was to determine if a dynamic warm-up combined with a supramaximal concentric PAPE CA exercise can improve performance in discus throw distance more than a dynamic warm-up alone. We hypothesized that, compared to a dynamic warm-up alone (DyWU), a dynamic warm-up with a supramaximal (105% 1RM) Anderson (bottom-up) quarter squat PAPE (DyWU+PAPE) CA would improve discus throw performance in Division I throwers. This study helps to elucidate the role a supramaximal concentric squat CA has on discus throw performance in well-trained collegiate throwers.

METHODS

Participants
A convenience sample of nine male and female NCAA Division I throwers (6 women, 3 men, aged 18-22 years old) at a university in the U.S.A. volunteered to participate (Table 1). For inclusion, all participants had to have discus as their primary or secondary event and were required to be active Division I throwers without injuries that would limit squatting or throwing performance. Permission to conduct the study was granted from the Southern Utah University Institutional Review Board (IRB; #08-022023b). Further, IRB-approved informed consent was obtained from the athletes before the study initiation. Permission was also granted from all coaches. The study was conducted in accordance with the ethical standards set forth by the Declaration of Helsinki. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (35).

Table 1. Table caption in sentence format.

Variable	Mean ± SD
Age (yrs)	20.1±1.4
Height (m)	1.8±0.1
Body Mass (kg)	94.4±18.7
Discus Experience (kg)	6.0±2.0
Resistance Training Experience (yrs)	4.6±3.1
Back Squat 3RM (kg)	202.6±67.7
Estimated 1RM (kg)	236.0±74.0
1RM/Body Mass (kg)	2.5±0.4
Discus Throw Personal Record in Competition (m)	42.7±4.5

*SD = standard deviation, yrs = years, m = meters, kg = kilograms.

A priori power analyses were conducted with G*POWER 3.1.9.2 (Universitat Kiel, Germany) software. A meta-analysis across 32 primary studies reported an average effect size of 0.81 (0.44 – 1.19 95% CI) for athletes to have a PAPE of subsequent muscle power activities at 7-10 minutes following a CA (49). Thus, for a statistical power of $1-\beta = 0.80$, $\alpha = 0.05$, and with an effect size of 0.81 as meaningful can be achieved with 9 participants across 2 groups. The sample size in the current investigation was n = 9 participants across 2 within-subjects' groups.

Protocol
This study followed a randomized within-subjects experimental design (Figure 1). All participants were randomly assigned (using a random number generator) to complete either a dynamic warm-up (DyWU) or a dynamic-warm-up followed by a post-activation performance enhancement (DyWU+PAPE) CA stimulus prior to maximal standing discus throw distance at set time intervals (8 min., 11 min., and 14 min. post stimuli). The same researchers implemented the two warm-up strategies and throwing protocols on separate days (and thus could not be blinded), with at least 72 hours between efforts. All other variables (e.g., practices, training volume, nutrition, hydration, recovery strategies, testing times) remained constant for all participants. The warm-up strategies were conducted in the same performance center and all standing discus throws were performed on the same turf field for all participants.

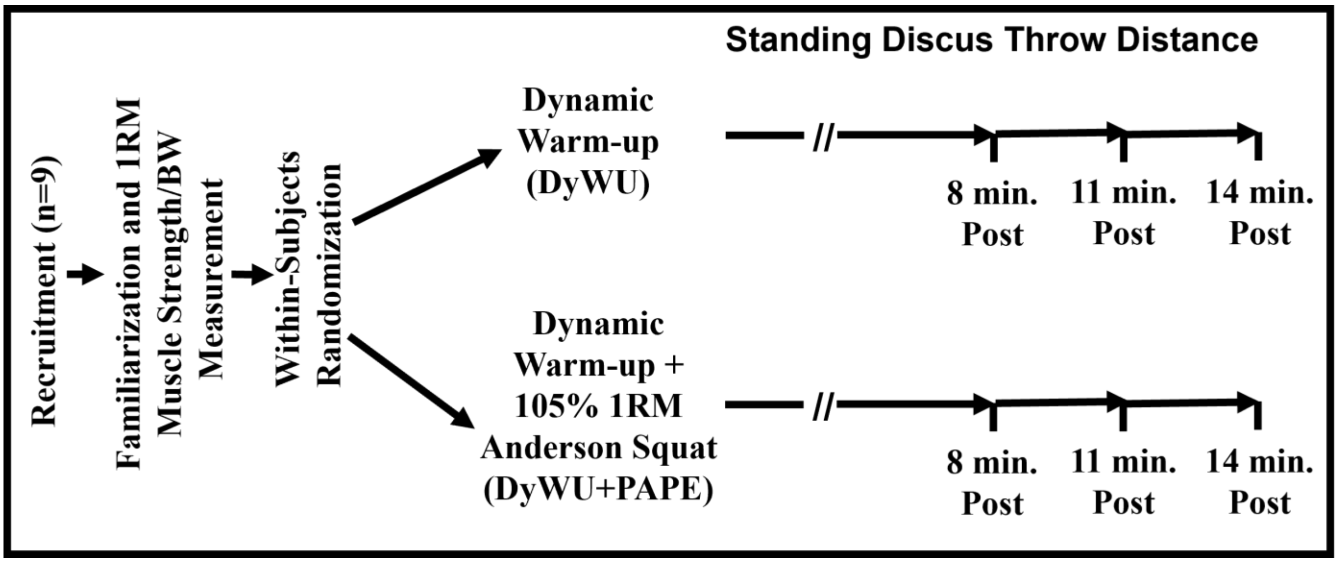

Figure 1. Overview of experimental within-subjects design. NCAA Division I thrower athletes (n=9 total; n=6 women, n=3 men) randomly performed a dynamic warm-up only (DyWU) and a dynamic warm-up with post-activation performance enhancement (DyWU+PAPE) stimulus using a supramaximal (105% of 1 repetition maximum; 1RM) Anderson (bottom-up) quarter squat set. Regardless of warm-up strategy, maximal standing discus throws were attempted at 8, 11, and 14 min. post warm-up. Warm-up sessions were separated by at least 72 hours.

Familiarization: Prior to the initial warm-up strategies and throwing sessions, all participants completed a familiarization session. In this session participants' age, height, weight, discus throwing experience, and lower body maximal strength (e.g., 3 repetition maximum or 3RM) were measured. All participants actively used the Anderson (bottom-up) squats (described below) as well as safety squat bar back squats in training, but were allowed to re-familiarize themselves with the specific movements that would be conducted in the study.

Back Squat 3RM to Estimate 1RM: Lower body muscular strength was determined using a safety squat bar (Power Lift, Conner Athletic Products, Inc., Jefferson, IA, USA) back squat 3RM following the published National Strength and Conditioning Association (NSCA) 1RM back squat protocol (19). The back squat was performed following NSCA technique recommendations involving a full depth squat, using a natural foot position that is about shoulder-width wide, with no restrictions on anterior displacement of the knees, keeping an upright trunk, and using a forward and upward gaze (10, 31). When using the safety squat bar all participants used a neutral and closed grip on the handles of the bar (10, 31). Using a safety squat bar, participants first performed a warm-up set with low intensity for 6-8 repetitions followed by 1 minute of rest. Participants then performed two more additional higher-intensity warm-up sets increasing weight ~10-20% for each set, and decreasing the repetition range (e.g., 5-7 repetitions on the first set, 4-6 repetitions on the second set), with 2 minutes of rest between sets. Participants then attempted at a 3RM until a true 3RM was accomplished, with less than 5 attempts needed for each participant. All participants were actively resistance training and had been previously trained in proper technique of back squat exercise with a safety squat bar, and proper technique (10, 31) was ensured by the research team, including the same NSCA certified strength and conditioning specialist (CSCS). A 1RM and 3RM are valid and reliable measures ($r \geq 0.90$ and ICC ≥ 0.90) of muscle strength (7, 44). The true 3RM value was then used to estimate a 1RM safety bar back squat value using the following equation from Reynolds et al. (38): (1RM [kg] = 1.09703 (3RM weight [kg]) + 14.2546). When using the developed prediction equation, Reynolds et al. has reported that up to 5RM testing (as opposed to 10RM or 20RM) yields highly valid ($r \geq 0.96$) upper and lower body strength estimated 1RM values compared to true 1RM strength (38).

Dynamic Warm-up: Both warm-up protocols (DyWU or DyWU+PAPE) utilized the same standardized dynamic warm-up led by the same researcher for every participant. The warm-up exercises included 1 set of each of the 12 following exercises: 20 yard (~18.29 meters) walking arm swings, 20 yard inchworms, 20 yard bear crawls, 20 yard figure 4 stretches, 20 yard high skips, 20 yard walking quadricep stretch, 20 yard walking hamstring stretch, 20 yard walking lunge with T-spine rotations, 20 yard backwards lunge, 20 yard walking knee hugs, 10 pushups, and 3 countermovement jumps with each jump progressively increasing intensity (i.e., jump height).

Supramaximal Anderson Quarter-Squat Potentiating Stimulus: Following the standardized dynamic warm-up, participants completed 2 warm-up sets of the back squat exercise at full range of motion using a safety squat bar (Figure 2) of 4-6 repetitions at 40-60% 1RM, with 1-2 minutes rest between sets. Then, participants performed 1 set of 5 repetitions at over 100% 1RM (105% 1RM) of Anderson (bottom-up) quarter-squat as the post-activation performance enhancement stimulus (Figure 2). For the Anderson quarter-squat, the J hooks that the safety squat bar rests on within the power rack were lowered 2 levels below where the athletes would typically have them for starting (Figure 2). The safety cross bars on the power rack were raised so that they were just underneath the J hooks. To perform the exercise, athletes were instructed to quickly drive the bar up, taking it off the J hooks then return it to the hooks in a controlled manner to reset for each repetition (Figure 2). A single set of 5 repetitions of the supramaximal quarter squats was chosen for these assumed to be strong athletes (i.e., strength was not assessed prior to study initiation, but as these athletes were Division I strength/power athletes they were assumed to be strong) in this study as a single set CA (ES = 0.44) was found to be superior to a multiple set CA (ES = 0.21) in stronger individuals (42). Further, above parallel CA were also found to be better (ES = 0.60) than below parallel squat CA in strong individuals (42), and also followed the supramaximal (150% 1RM) concentric quarter squat functional isometric employed in previous work (6). The 105% of estimated back squat 1RM (or ~120% of 3RM) was chosen based on pilot work with throwers and what the majority of throwers were able to successfully complete in the Anderson quarter squat. We based 5 repetitions on previous studies using near maximal (90-100% 1RM) back squat using 5 sets of 1 repetition (9, 17) as well as 1 set of 5 with maximal drop jumps (45). With pilot work we found we could achieve a CA with 1 set of 5 repetitions with 105% 1RM, which again follows that single set CA being better than multiple set CA (42). The bottom-up squat was originally described by the strongman Paul Anderson as part of his squat training, which resulted in Anderson squatting a reported incredible 545.5kg (2). Further, the Anderson squat training methods (including the bottom-up quarter squat employed in this investigation), were found to result in greater increases in strength and power than traditional full range of motion training (48).

Figure 2. Overview of Anderson (bottom-up) quarter-squat supramaximal (105% 1RM) post-activation performance enhancement stimulus exercise.

Maximal Standing Discus Throw: Regardless of warm-up strategy (DyWU or DyWU+PAPE), participants performed 3 maximal standing discus throw attempts from the power position at the same exact time intervals (8 min., 11 min., or 14 min.) post warm-up. The exact time intervals were achieved by staggering when participants started their warm-up strategies and using a unique (but identical) stop-watch for each participant. Irrespective of the warm-up strategy (DyWU or DyWU+PAPE) participants all were transported (via vehicle) from the weight room (where they performed the warm-up) to the same turf football field where they completed their discus throw attempts. Between their warm-up and discus throw attempts, participants were supervised by the research team to ensure equal rest with minimal exertion (i.e., slow walking or sitting). On the same turf field, every participant set up to throw from the exact same starting point (goal line). The men's discus size was 22cm in diameter and weighed 2kg. The women's discus size was 18cm in diameter and weighed 1kg. All participants were experienced with maximal standing discus throws and were instructed to throw maximal distance for each attempt. Each attempt was measured with standard measuring tape by the same researcher. At least 72 hours between each warm-up and maximal discus throw session (two of them in a randomized order) was used. The phases of the discus throw technique can be divided into the wind-up, the sprint, the power position, the release and the recovery (22, 30, 32). Maximal standing discus throws from the power position are not full rotation competition throws and thus athletes personal record in a competitive performance are also presented (Table 1).

Statistical Analysis
The study used a randomized cross-over experimental design (Figure 1). The discus throw distance at each time point were the dependent variables analyzed. A two-way (warm-up strategy x time) analysis of variance (ANOVA) with repeated measures was used for any measurements with multiple time points, with statistical significance being set *a priori* at $p < 0.05$. We also calculated effect sizes using Cohen's d with the following interpretations using participants resistance training status of <0.25 = trivial, 0.25-0.50 = small, 0.50-1.0 = moderate, >1.0 = large (16, 39). Prior to any statistical analyses the data were tested for normal distribution and equal variances to determine the appropriate statistical test. All statistical analyses and graphs were made using GraphPad Prism 9 (GraphPad, San Diego, CA, USA). Data are presented as means ± SD.

RESULTS

All nine participants completed the study and their baseline measurements were made (Table 1). Of note, female (n=6) estimated 1RM was 193.0±25.4 kg, whereas the males (n=3) estimated 1RM was 322.05±74.0kg. No significant main effects ($p = 0.106$ for time or $p = 0.438$ for warm-up strategy) or interaction ($p = 0.822$) were observed between DyWU or DyWU+PAPE for standing discus throw distance at 8 min. (31.7±5.6 vs 30.6±6.5 meters, respectively; $d = -0.18$), 11 min. (33.4±3.6 vs 31.3±4.7 meters, respectively; $d = -0.52$), 14 min. (34.1±3.9 vs 32.3±5.3 meters, respectively; $d = -0.40$) post warm-up CA, or averaged across the 3 timepoints (33.1±4.1 vs 31.4±4.8 meters, respectively, $d = -0.38$) (Figure 3).

Further, individual participant maximal standing discus throw distances following warm-up strategies are reported for each timepoint post-CA; 8 min. (Figure 4A), 11 min. (Figure 4B), and 14 min. (Figure 4C).

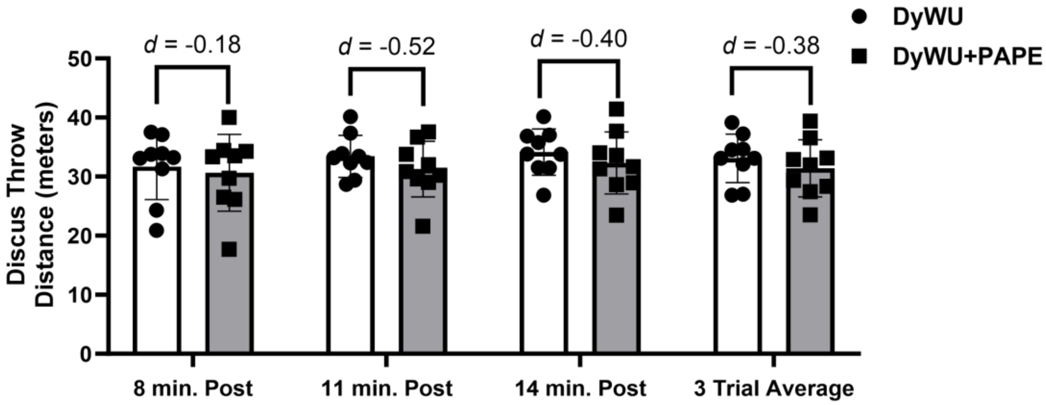

Figure 3. Maximal standing discus throw distance by time point and averaged across all 3 trials (8, 11, and 14 min.) following a standardized dynamic warm-up (DyWU) or DyWU with a supramaximal Anderson squat set post-activation potentiation enhancement stimulus (DyWU+PAPE) in NCAA Division I thrower athletes (n=9). Values are mean ± SD. A two-way ANOVA (warm-up x time, with repeated measures for time) was used, with significance set at $p < 0.05$.

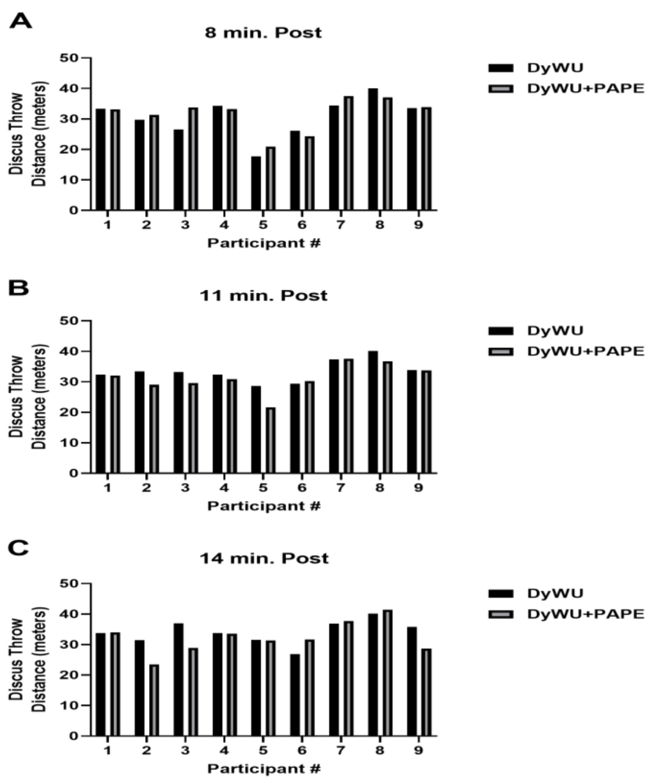

Figure 4. Individual participant (n=9) maximal standing discus throw distance at 8 min. post (**A**), 11 min. post (**B**), and 14 min. post (**C**) following a standardized dynamic warm-up (DyWU) or DyWU with a supramaximal Anderson squat set post-activation potentiation enhancement stimulus (DyWU+PAPE) in NCAA Division I thrower athletes.

DISCUSSION

The purpose of this study was to determine if a dynamic warm-up combined with a supramaximal concentric PAPE CA can improve performance in discus throw distance more than a dynamic warm-up alone. The main findings from this study were that compared to a dynamic warm-up alone, a supramaximal (105% 1RM) Anderson (bottom up) quarter-squat PAPE CA resulted in a trivial/small to moderate (d = -0.18 to -0.52) decrease in discus throw performance between 8-14 minutes post-CA in well-trained and strong Division I throwers. The main reasons for the potential trivial/small to moderate detrimental throwing outcomes observed were likely that fatigue/inhibition of potentiation was present following the supramaximal PAPE CA used, the timing of the discus performance measurements post-CA stimuli did not capture any PAPE, or the sample of individual throwers used in this study were unresponsive to the CA used.

The responsiveness of strength-power-potentiation complexes using a CA for muscle force/power performance is largely considered to be due to a net balance between fatigue/inhibition and potentiation, which can co-exist (37, 41, 46). Specifically, muscle force/power performance enhancement can occur when potentiation is greater than fatigue/inhibition, muscle force/power performance remains unchanged when potentiation and fatigue/inhibition are equal, and muscle force/power performance shows decreases when fatigue/inhibition is greater than potentiation (37, 41, 42, 46). There also appears to be differences in the potentiation and fatigue/inhibition mechanisms between PAP and PAPE (8). Regardless of the exact mechanisms responsible for PAPE potentiation and inhibition, it is clear from the current study that the supramaximal (105% 1RM) Anderson quarter-squat CA resulted in inhibition of voluntary discus throwing potentiation at 8-14 min. post-CA (albeit only trivial/small to moderately).

One potential reason for the trivial/small to moderate fatigue/inhibition of discus performance being greater than potentiation is the intensity of the stimulus used (i.e., 105% 1RM Anderson quarter-squat). Supramaximal potentiating CA's have been used to enhance concentric performance using both eccentric (12, 14, 18) and concentric (6, 47) loads. The purported rationale for using supramaximal loads in training includes maximal activation of muscle fibers through hyperstimulation of the nervous system and motor units, including those associated with type II fibers (6, 23). Importantly, type II muscle fibers contribute to discus throwing performance success from their role in muscle strength, power, and rate of force development (34, 45, 51). Additionally, in a meta-analysis of 47 studies (42) in stronger (i.e., >1.5-1.75x body weight back squat) and well-trained (i.e., over 2 years of resistance training experience) individuals with a high-intensity (>85% 1RM) CA was reported as superior (ES = 0.54) to a moderate-intensity (30-84% 1RM) CA using resistance training exercises (e.g., back squat). Further, a repetition maximum (100% 1RM) CA was also found to be superior (ES = 0.60) compared to a submaximal (<100% 1RM) CA in strong individuals using resistance training exercises in the same meta-analysis (42). Also, heavy back squats (~90-150% 1RM) CA have been shown to augment performance potentiation (PAP/PAPE) in numerous sports movements for

4-15+ min. post-CA (6, 9, 17, 33, 40). Therefore, following the above rationale there was support for using a supramaximal concentric Anderson quarter-squat CA to elicit PAPE in strong (~2.5x body weight back squat 1RM) Division I collegiate discus throwers from 8-14 minutes post-CA, even though our study demonstrated trivial/small to moderate negative discus throwing outcomes.

The majority of track throwing studies, as opposed to bench press ballistic throwing studies which are outside the scope of this study (15), strength-power-potentiation complexes using a CA to enhance throwing performance have used upper-body overweight implement throws (5, 15, 24, 25) with much less load (~1-2.27 kg) than can be applied with resistance exercises. These studies (5, 24, 25) have found improvements of ~1.7 to 8.5% in throwers at 3 min. post-CA, but did not tease out strength levels or measure any other time points. Other studies (27, 45) have used body weight plyometric activities (e.g., countermovement vertical jumps) as a CA and have shown enhanced throwing performance. However, in the aforementioned meta-analysis (42) a body weight plyometric CA (ES = 0.47) was reported to be similar to a high-intensity (>85% 1RM) resistance exercise CA (ES = 0.41) across all individuals (weaker and stronger combined). Yet, even though the authors (42) did not explicitly report the effects of a plyometric CA in strong individuals, when strong individuals were analyzed for a resistance exercise CA, it was clear that a high intensity (>85% 1RM or 100% RM) CA was better than a moderate intensity (~30-84%) CA, and perhaps a body weight CA. Also, Ulrich & Pastorfer (47) compared a CA of 1 set of plyometric push-ups, a CA of 1 set of 3 repetitions at 80% 1RM concentric bench press, and a CA of 1 set of 3 repetitions at 120% of concentric 1RM on upper-body ballistic bench press throw performance in recreational athletes (47). Both the body weight plyometric CA (ES = 0.31) and moderately heavy concentric bench press CA (ES = 0.38) improved significantly, but the supramaximal eccentric CA (ES = 0.11) did not (47). These results, along with the current investigations findings, potentially highlight the trivial/small to moderate negative effects of supramaximal CA loads for throwing performance versus a body weight CA or a high intensity resistance exercises CA.

In support of higher intensity resistance exercises for throwing PAPE, in the few studies (13, 21) that have used resistance exercises to enhance track throwing performance both have used lower-body exercises (e.g., hang cleans and jerks) at higher intensities (80-85% 1RM). Harris et al. (21) reported that compared to a standardized dynamic warm-up alone, a CA of 3 sets of 2 repetitions at 85% 1RM using the power jerk exercise augmented shot put exit velocity for 5-11 min. post-CA in NCAA Division I collegiate throwers. Moreover, Dolan et al. (13) found that compared to a dynamic warm-up alone, a CA of 1 set of 3 repetitions at 80% 1RM using the hang clean and jerk exercise significantly (3.6%) improved shot put throwing distance for 8-14 min. post-CA in NCAA Division I throwers. Also of note, both resistance exercises used (i.e., hang clean and jerk) in the previous PAPE throwing studies (13, 21) are recommended to train muscular power (20), unlike our current supramaximal Anderson quarter-squat which focuses more on training peak muscular strength (20). Taken collectively, the existing literature suggests that overweight implements, body weight plyometric CA, or high intensity (~80-85+% 1RM) resistance exercise CA using exercises recommended to train muscle power can enhance throwing performance between ~3-14+ min post-CA. Still, a supramaximal concentric back squat variation targeted towards peak muscular strength results in a trivial/small to moderate detriment in throwing performance during an 8-14 min. window post-CA.

Conversely, another potential reason for the observed lack of potentiation/fatigue was that the stimulus intensity (i.e., 105% 1RM) was proper, but that the volume (i.e., number of repetitions) was too great, leading to fatigue/inhibition being greater than potentiation. Five repetitions was again based on pilot work with the intensity, as well as previous studies showing 5 repetitions in the back squat, albeit across multiple sets, to cause PAP/PAPE (9, 17) as well as with 5 repetitions of maximal drop jumps [considered the most intense plyometric exercise (19)] enhancing throwing performance and thus there was support. However, in other throwing PAP/PAPE studies (13, 21, 24, 25) showing throwing performance PAP/PAPE used a volume under 5 repetitions. Thus, the lack of effect on throwing performance enhancement could be due to the volume and not the intensity, or alternatively, a combination of the two.

Another potential reason for the trivial/small to moderate decreases in throwing performance observed in the current investigation is that the time frame throwing was measured (8-14 min. post-CA) did not capture potentiation, and potentially earlier time points could have. Our rationale for choosing an initial time point of 8 min. and up to 14 min. came from a number of previous studies (13, 21, 49) as well as logistics (discussed below). In previous studies, including a meta-analysis of 32 studies previously mentioned (49), potentiation following a CA was found to peak between 7-10 min. (8, 49). Also, as described above, the two studies (13, 21) using a higher-intensity resistance exercise CA found throwing performance to be enhanced between ~5-14 min. post-CA. Despite the above rationale, it is possible that PAPE potentiation could have been seen prior to 8 min. There is evidence from the same meta-analysis described above (42) that peak muscle force/power potentiation following a CA in stronger individuals is better at 5-7 min. (ES = 0.62) compared to 0.3-4 min. (ES = 0.15) and ≥ 8 min. (ES = 0.23). The 7-10 min. peak for muscle force/power potentiation in the other meta-analysis (49) did not tease out strength levels (combined weak and strong). Also, studies that have used supramaximal loads as a CA measured enhanced muscle function effects prior to 8 minutes (6, 18, 47). The 150% functional isometric squat CA study (6) found muscle power enhancements at 4-5 min. post-CA and the eccentric bench press 130% of concentric 1RM CA study (16) found muscle power potentiation at 4-8 min. post-CA, with most athletes peaking at 6 min. post-CA. One unique aspect of the study by Golas and colleagues (16) is that they determined individual rest intervals post-CA for each athlete. During preliminary testing, the subjects performed an explosive exercise and tested their power output at 2, 4, 6, and 8 minutes (16). An optimal rest interval for each subject was then used for the study (16). This could potentially be a reason why the current investigation saw no improvements. There is also some evidence of the interindividual differences by time point post-CA in the current investigations time frame (Figure 4), highlighting a need to determine individual rest intervals post-CA, as well as measure discus throw performance before 8 min. post-CA with the same CA. Nevertheless, our results clearly demonstrate that compared to a dynamic warm-up alone a supramaximal back squat variation CA resulted in a trivial/small to moderate detriment in throwing performance at 8-14 min. post-CA.

The last potential reason for the lack of throwing potentiation in the current investigation is the individual throwers used in this study were unresponsive to the CA used. Strong (>1.5-1.75x body weight back squat 1RM) and well-trained (2+ years of resistance training) individuals respond to high intensity PAP/PAPE better than untrained (6, 42). The sample of the current investigation was both strong (~2.5x body weight back squat 1RM) and well-trained (~4+ years of resistance training experience), but that was not determined until after the study initiated and thus was not considered in designing the PAPE CA protocol used herein. Strong and well-trained individuals have been reported previously to respond well to supramaximal intensities (6, 18). Using a functional isometric squat CA at 150% 1RM has been shown to elicit a PAP enhancement at 4 and 5 min. post-CA from only trained (1.7x body weight back squat 1RM) individuals and not untrained (1.3x body weight back squat 1RM) men (6). However, this study (6) did not measure past 5 min. post-CA. Golas and colleagues (16) used either an eccentric bench press CA at 110% of concentric 1RM or 130% of concentric 1RM in well-trained (~8+ years of training experience, but strength levels not explicitly reported) athletes, including throwers (n=10 of 31 athletes) (16). Significant improvements in upper-body ballistic bench press throw performance between 4-8 min. post-CA were only seen in the 130% 1RM load CA and not the 110% 1RM load CA. The authors suggested that the well-trained athletes required more stimulation (16). Thus, it is possible that our well-trained and strong sample of throwers required a greater stimulus than the 105% 1RM used. Nevertheless, our results do not support the use of a supramaximal concentric back squat variation CA to enhance throwing performance in strong and well-trained collegiate throwers between the 8-14 min. post-CA.

The main limitation of this study is that we were unable to measure before 8 minutes. This study took place during winter. Due to logistical reasons (i.e., distance between locations and winter weather/available locations for throwing free of snow) in getting the athletes from where they performed their warm-ups (DyWU or DyWU+PAPE) to where they could throw safely, a time point before 8 min. was not feasible. However, the 8-14 min. time frame was well supported (13, 21, 49) and also was feasible to safely complete. Also, the 105% 1RM PAPE load used herein was based on the 1RM of a full depth 3RM back squat, and potentially basing the supramaximal load on the Anderson quarter-squat 1RM could produce different results. However, we followed a previous study (6) using a 150% 1RM functional isometric concentric back squat which based their 1RM on a full-depth back squat 1RM like our study and found augmented power performance. Further, this was a real-world, university-based, competitive study that provides unique insight into this specific sample and warm-up strategies, but had limitations in controlling for sport practice stress/volume, nutrition, recovery strategies, athlete's academic load, etc. Another limitation is that the depth and/or knee angles during the PAPE stimulus may not have been similar between athletes using the method of moving the J-hooks on the power rack 2 positions lower. Thus, controlling for depth/knee angles on quarter-squat stimuli in future studies may be needed, such as using a goniometer to match knee angles. However, as our investigation was a repeated measures within subjects' design with DyWU alone and DyWU+PAPE strategies, we can still report meaningful results. The current study compared a warm-up protocol consisting of dynamic exercises to a protocol that included the warm-up plus the PAPE stimulus of interest (i.e., supramaximal back squat variation). If a third warm-up protocol with a random PAPE stimulus was added it would have aided in determining if the CA served as more than just additional volume to a warm-up (8). However, as the only difference between the two warm-up protocols in the current investigation is the supramaximal Anderson quarter-squat CA, we can still report that the CA resulted in a trivial/small to moderate detriment to throwing performance when compared to the dynamic warm up alone at the timeframe measured.

In conclusion, data from the current study demonstrates that compared to a dynamic warm-up alone, supramaximal concentric Anderson quarter squats following a dynamic warm-up CA had a trivial/small to moderate negative affect on the distance of maximal standing discus throws at 8-14 min. post-CA in NCAA Division I well-trained and strong throwers. The lack of potentiating effects observed between 8 and 14 minutes is potentially due to the supramaximal CA itself causing too much fatigue/inhibition and blocking potentiation, the timing of when the throw measurements were made did not capture potentiation, or the thrower sample used herein requiring a more individualized approach (i.e., using more or less intensity/volume and/or determining optimal individual rest intervals post-CA). For either training or pre-competition warm-up purposes in well-trained and strong collegiate throwers, a supramaximal back squat variation CA should be avoided as there may be trivial/small to moderate negative discus throwing outcomes.

ACKNOWLEDGEMENTS

The authors declare that they do not have any competing interests associated with this work. The authors would like to extend our deepest gratitude to the coaches and athletes involved in helping complete this study. N.O. and M.L. were responsible for conception and design of the experiments, acquisition, analysis, and interpretation of data, and drafting and critically revising the manuscript. M.D. was responsible for critically revising the manuscript. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed. No funding was provided for this study and the authors have no conflict of interest related to this research.

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