

Research article

Acute Post-Activation Performance Enhancement (PAPE) Effects of A Ballistic Medicine Ball Throw Versus Maximal Strength Activation on Upper Body Push Power

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Abstract

Upper body push power is a critical factor in numerous sports, and coaches often seek effective methods like conditioning activities (CA) to acutely enhance performance through post-activation performance enhancement (PAPE). While various CAs have been studied, comparisons between opposite ends of the intensity spectrum, high-load versus low-load ballistic activities, remain unclear in upper body research. Twenty-eight trained male athletes (age 24.86 ± 2.62 years) completed three conditions in a randomized within-subject crossover design: High-Load Bench Press (HLBP), Ballistic Medicine-Ball Throw (BMT), and an active Control Condition (CC). Participants were randomly allocated to one of the six possible condition orders (i.e., all permutations of HLBP, BMT and CC). Bench Press Throw performance (40% of 1RM) was assessed at baseline, 5 min and 10 min post-condition using the 1080 Quantum system. Peak Power Output (PPO) and Average Power Output (APO) and Peak Velocity (PV) formed the confirmatory family; the hypotheses were tested with difference-in-change contrasts between HLBP and BMT, with Holm-Bonferroni correction across the six contrasts (three outcomes $\times$ two time points). Average Velocity, Time to Peak Power Output and Time to Peak Velocity were exploratory. Significant Condition $\times$ Time interactions were found for PPO ($p = 0.023$, $\eta^2p = 0.099$) and PV ($p = 0.004$, $\eta^2p = 0.134$). In the confirmatory contrasts, the change from baseline to 5 min in HLBP differed from that in BMT by -97.7 W for PPO (95% CI -159.4 to -35.9 ; $dz = -0.61$; Holm-adjusted $p = 0.016$) and by -0.086 m·s $^{-1}$ for PV (95% CI -0.137 to -0.035 ; $dz = -0.65$; adjusted $p = 0.011$). No contrast was significant at 10 min, and APO did not differ at either time point. Within conditions, only HLBP changed relative to its own baseline, decreasing at 5 min for PPO (-67 W, $\approx 3.9\%$, $dz = -0.61$) and PV (-0.071 m·s $^{-1}$, $\approx 2.7\%$, $dz = -0.74$), with partial recovery at 10 min. For these two outcomes neither BMT nor CC differed from baseline, and BMT did not differ from CC. Although the standardized within-subject effects were moderate, the absolute changes were small and of limited practical relevance. Contrary to the first hypothesis, HLBP did not outperform BMT; the direct contrast at 5 min was significant in the opposite direction. The second hypothesis, which predicted greater peak velocity after BMT than after HLBP, was supported by the confirmatory contrast at 5 min. This difference arose from a decrement after HLBP rather than from potentiation after BMT, which changed neither from its own baseline nor relative to the control condition, and the result should therefore not be read as evidence of potentiation. Neither conditioning activity produced acute performance enhancement under the investigated protocols, suggesting that the fatigue induced by two sets at 90% 1RM outweighed any potential potentiation effects within that timeframe.

Key words: Post-activation performance enhancement, upper body power, ballistic, bench press, post-activation potentiation.

Introduction

Marginal improvements in athletic performance can be decisive at the elite level, where differences of centimeters or milliseconds frequently determine competitive outcomes. Upper body push power in particular is a critical determinant of success across a range of sports, motivating coaches and practitioners to seek evidence-based methods for its acute enhancement.

Maximum power training is widely known as an effective method to increase throwing performance (Kyriazis et al., 2009). Similarly, elite anaerobic endurance athletes generally produce more power than nonelite endurance athletes (Lorenz et al., 2013). Landolsi et al. (2014) showed that especially maximum power output in the lower body influences e.g., the shot put performance significantly. Moderate to high correlations of peak power ($r = 0.72$) and maximum force ($r = 0.85$) output on cycle ergometer and shot put performance were found. Additionally, further variables such as leg muscle volume, body mass, and leg length have a moderate to high correlation ($r = 0.87$; $r = 0.70$; $r = 0.59$) on absolute power output (W) on a cycle ergometer in national-level shot put athletes (Landolsi et al., 2014). Haff and Nimphius (2012) argued that power training is most effectively approached through a mixed-methods strategy, combining low-load, high-velocity exercises with high-load, low-velocity exercises across a continuum ranging from unloaded movements up to 90% of 1RM. The terms complex and contrast training are often used interchangeably, leading to terminological confusion. To ensure terminological clarity, the present study adopts the definitions proposed by Cormier et al. (2022). Cormier et al. (2022) define complex training as an umbrella term of 4 different methods: contrast, ascending, descending and French Contrast Method. Whereas contrast training is defined as alternating intensities of high load and low load, ascending and descending complex training is seen as either several sets low load and several sets high load exercises or vice versa. French Contrast Method is a mix of 4 different exercises/intensities, with a heavy compound (80 - 90% of the participant's 1-repetition-maximum (RM)), a ballistic (bodyweight), a light to moderate compound (40% of 1RM) and another ballistic (bodyweight) exercise. This variation should be carried out exactly in the mentioned order, to be considered as French Contrast Training (Cormier et al., 2022).

To clear any misinterpretation, contrast or complex training is a form of how to organize different exercises, to

ensure, that athletes can perform at an optimal level. The order and type of exercises can lead to performance enhancement effects like “Post Activation Potentiation” (PAP) and “Post Activation Performance Enhancement” (PAPE). PAP is defined as “the increase in electrically-evoked twitch force/torque following submaximal and maximal conditioning contractions”, whereas PAPE is suggested to “indicate the enhancement of maximal voluntary strength, power or speed following a conditioning contraction” (Prieske et al., 2020, p. 1563). In general, PAP and PAPE are defined as the effects that are elicited by the conditioning activity (CA) (Blazevich and Babault, 2019; Vandervoort et al., 1983; Cuenca-Fernández et al., 2017). To avoid further terminological confusion, the present study focuses on the effect of PAPE and the potential performance enhancement of different types of CAs on upper body push power.

To identify possible effects, many studies investigated different types of CAs, recovery times, number of sets, as well as whether relative strength levels and training experience have an impact on potential outcomes. According to Seitz and Haff’s (2016) review, traditional high intensity and plyometric strength training on lower body have the highest effect size of all CA types. However, the review of Krzysztofik et al. (2021) showed, that in upper body, the best pre activation activity would be at an intensity range between 60% and 84% of the participant’s 1RM. This statement was also supported by a review of Wilson et al. (2013).

Although various studies on upper body PAPE effects exist, comparisons of opposite intensities of the power spectrum (5% and 90% of 1RM) in the upper body still remain rare. While syntheses of upper-body conditioning generally identify an effective intensity window of approximately 60 - 84% 1RM (Krzysztofik et al., 2021; Wilson et al., 2013), the boundaries of this window have been established almost exclusively from moderate-load protocols, and the responses to loads at the extreme ends of the force-velocity spectrum remain poorly characterized in the upper body. The present study therefore deliberately contrasts a very high load (90% 1RM), which maximizes mechanical tension and motor-unit recruitment, against a very low load (5% 1RM) executed ballistically, which maximizes movement velocity. Examining these two extremes allows the relative contributions of the high-force and high-velocity ends of the spectrum to acute upper-body potentiation to be probed directly, rather than re-testing the moderate loads on which existing recommendations are already based. All things considered, the purpose of this study is to identify which conditioning activity, High Load Bench Press (HLBP) (90% of 1RM) or Ballistic Medicine Ball Throw (BMT) (5% of 1RM), is more effective for peak and average power output (W) and peak barbell velocity (m/s) during the ballistic bench press throw (40% of 1RM). Average barbell velocity, time to peak power and time to peak velocity were additionally recorded and are reported as exploratory outcomes.

It was hypothesized that the high-load, low-velocity HLBP condition at 90% of 1RM would produce greater improvements in peak and average power output compared to the low-load BMT condition.

Furthermore, it was hypothesized that the high-velocity nature of the BMT at 5% of 1RM would result in greater improvements in peak barbell velocity compared to the HLBP condition.

Methods

Experimental approach

Participants attended one familiarization session and three intervention sessions, separated by at least 72 hours and no more than 7 days. This window was chosen to allow full recovery from the near-maximal bench-press condition while keeping training status and testing conditions as stable as possible across the three sessions. In the first session (familiarization), the objective was to determine the 1RM bench press performance using the Quantum syncro device (1080 Motion, Sweden), a digital strength system that functions similarly to a Smith machine by utilizing synchronized motorized cables to provide controlled, linear resistance. Furthermore, in the familiarization session the intervention exercises, the ballistic medicine-ball throw and the one-arm dumbbell row (low-intensity activation for the control condition to avoid temperature loss between pre- and post-intervention tests), as well as the pre- and post-intervention exercise, the bench press throw, were practiced to avoid learning effects during the interventions. Additionally, anthropometric and demographic data were collected, including body mass, height, age and training experience (years). The three intervention sessions consisted of the ballistic medicine-ball throw (BMT), the high-load bench press (HLBP) and the control condition (CC). Each participant was individually randomized to one of the six possible condition orders using the online randomization tool Randomizer.org. Because allocation was individually random rather than block-balanced, the resulting sequence distribution was uneven: HLBP-CC-BMT ($n = 6$), BMT-CC-HLBP ($n = 6$), BMT-HLBP-CC ($n = 5$), CC-BMT-HLBP ($n = 5$), HLBP-BMT-CC ($n = 3$) and CC-HLBP-BMT ($n = 3$). All six orders were therefore represented, but the design was randomized rather than fully counterbalanced. Period and order effects were examined statistically and are reported in the Results.

Participants

An a priori sample size estimation was conducted in G*Power 3.1 (Faul et al., 2009) using F tests $\rightarrow$ ANOVA: Repeated measures, within factors, with number of groups = 1, number of measurements = 3, correlation among repeated measures = 0.5, nonsphericity correction $\epsilon = 1$, effect size $f = 0.25$, $\alpha = 0.05$ and power = 0.80. This specification returned a required total sample size of $N = 28$ (actual power = 0.813). It should be noted that this routine evaluates an omnibus within-subject effect with three levels rather than the four-degree-of-freedom Condition x Time interaction, so the sensitivity analysis reported below, which was computed for the contrasts that actually test the hypotheses, provides the more relevant statement of the study’s resolving power. The effect size $f = 0.25$ corresponds to a medium effect (Cohen, 1988) and was based on the systematic review with meta-analysis by Finlay et al. (2022), who reported effects of bench press condition-

ing activities on ballistic bench press throw power output that ranged from trivial to large across seven studies ($ES = 0.06 - 1.34$) and characterized the pooled effect of a bench press conditioning activity at $\geq 80\%$ 1RM on the subsequent ballistic bench throw as moderate. On the basis of this a priori estimation, 28 trained male participants from a variety of sports took part in this study. A sensitivity analysis was subsequently computed for the paired contrasts that test the hypotheses; it is reported for transparency and did not inform the sample size. It indicates that, with $n = 28$ and power = 0.80, the smallest detectable effect is $dz = 0.55$ for a two-sided test at $\alpha = 0.05$ and $dz = 0.70$ for a two-sided test at the most stringent Holm step ($\alpha = 0.05/6 = 0.0083$); all confirmatory contrasts were two-sided. The mean age of the participants was 24.86 ± 2.62 years and their training experience was 8.11 ± 3.68 years. Further information can be retrieved from Table 1.

Table 1. Participants characteristics (n = 28).

Variables	Mean $\pm$ SD	Min - Max
Age [y]	24.86 ± 2.62	18 - 32
Height [m]	1.84 ± 0.07	1.70 - 1.97
Bodyweight [kg]	87 ± 11	71 - 117
1RM Bench Press [kg]	101 ± 16	82.5 - 145
Relative Strength [kg/kg Bodyweight]	1.17 ± 0.15	0.83 - 1.52
Training Experience [years]	8.11 ± 3.68	2 - 19

1RM: 1 repetition maximum; SD: standard deviation; Min: minimum; Max: maximum

Moreover, every participant was informed about the study design and protocol as well as the potential risks that may arise during the testing sessions and had to sign a consent/information paper. The study was approved by the university of Graz ethics committee (GZ. 39/158/63 ex 2024/25).

Participants were eligible if they were aged between 18 and 35 years, were free of upper-body injuries that could affect performance during the testing procedures, and had at least two years of continuous strength training experience. Any participant who suffered an injury in the lead-up to or during the course of the study was excluded from the analysis. Furthermore, participants were excluded if they failed to adhere to the prescribed timeframe between interventions (minimum 72 hours and maximum 7 days). The participants' 1RM had to be at least 82.5kg, which was tested in the 1st session. All 28 recruited participants met the inclusion criteria, completed all three conditions, and were included in the analysis. The only exception was the TTPPO outcome, for which three participants were excluded owing to a measurement-detection error of the 1080 Quantum system, resulting in $n = 25$ for this variable (see Statistical Analysis).

1RM testing

Participants estimated their current 1RM bench press, which was used to carry out a standardized warm-up protocol before testing the actual 1RM bench press. The warm-up protocol was based on Tsoukos et al. (2021) and slightly adjusted to fit the requirements of the high intensity of the intervention exercises. The first session

therefore started on a cycle ergometer for 5 min at an intensity of 60 W and a cadence of 70 - 80 revolutions per minute. After 2 min, three bench press sets consisting of 6 - 10 repetitions at 40%, 3 - 5 repetitions at 70%, and 1 - 2 repetitions at 80% of the estimated 1RM were carried out. Subsequently, weight was increased by 5 - 10% after the predefined warm-up protocol until participants reached their individual 1RM. Rest periods of 3 min after the 40% and 70% warm-up sets and 5 min after every other set were used. A specific bench press cadence was prescribed, in which the eccentric phase had to last at least 1 s but no longer than 2 s to ensure a controlled repetition (Wilk et al., 2020). During the concentric phase participants had to push the weight as fast as possible. Grip width, shoulder and forearm position, and barbell-chest contact were identical for the 1RM test and the bench press throw.

Experimental procedure

In the other three sessions, the participants started with the standardized warm up protocol. To collect the parameters of the acute PAPE effects, the bench press throw in the Quantum 1080 was carried out before and after the intervention. The detailed intervention and warm up protocols are displayed in Table 2.

Measurements

Bench Press Throw. After the standardized warm-up protocol, the pre-intervention test in the form of a ballistic bench press throw was carried out. The bench press position was defined as follows. Grip width was defined as one fist outside shoulder width. At the bottom of the movement (barbell touching the chest), the forearms had to be oriented vertically to ensure an optimal direction of force, and the shoulder abduction angle was approximately 45° . Participants were instructed to perform 3 repetitions with 10 - 15 s of rest between repetitions. Participants started in a position with extended elbows. After the supervisor signaled the start, participants initiated the movement with an eccentric phase lasting approximately 0.5 - 0.6 s followed by a concentric phase performed with maximum intent. Participants were instructed to throw the barbell of the Smith machine as high as possible and to maintain a smooth transition from the eccentric to the concentric phase in order to ensure maximum intensity and an optimal acceleration profile. Participants performed the throw and caught the barbell themselves. The following variables were recorded: Peak Power Output (PPO), Average Power Output (APO), Peak Velocity (PV), Average Velocity (AV), Time to Peak Power Output (TTPPO) and Time to Peak Velocity (TTPV).

For both the 1RM bench press test and the bench press throw test, a 1080 Quantum, a digital strength system that functions similarly to a Smith machine by utilizing synchronized motorized cables to provide controlled, linear resistance, was used. General settings for the testing sessions were set to "Non-Flying Weight" and "No Pulley" for less resistance but a faster retraction speed. If needed, more resistance was added with weight plates. The weight on the 1080 Quantum cables was set to 3 kg per side (6 kg in total) for every participant, which was necessary to ensure that the retraction speed of the cables was at its maxi-

imum of $6 \text{ m} \cdot \text{s}^{-1}$. Additional weight was added with physical plates and was entered manually into the 1080 Quantum software.

Power, velocity and timing variables were computed in real time by the 1080 Quantum system and exported repetition by repetition from the 1080 Motion Web App. Microsoft Excel was used only to organize these device-native values and to apply the selection rules, that is, identification of the repetition with the highest peak power output for the peak variables and averaging of the three repetitions for the average variables. No variable was recalculated from raw displacement, force or time signals outside the device software.

Intervention exercises

The BMT intervention was carried out with medicine balls whose load was set to 5% of the individual 1RM bench press. The prescribed load, derived from each participant's measured bench-press 1RM, was $5.07 \pm 0.78 \text{ kg}$ (range 4.13 - 7.25 kg). Because the wheel weights were available in 100 g increments, each ball was loaded to the nearest 0.1 kg, giving achieved masses of $5.1 \pm 0.8 \text{ kg}$ (range 4.1 - 7.2 kg) and a maximum deviation from the prescribed load of 0.05 kg ($\leq 1.2\%$ of the load). In order to provide the prescribed weight as closely as possible, wheel weights were attached to the medicine balls by taping them to the outer surface of the ball. As shown in Table 2, participants performed 2 sets of 4 repetitions with 5 min rest between sets. Regarding body and shoulder position, these were set to be similar to the bench press and the bench press throw. Only the wrist and forearm position was slightly more pronated and internally rotated to provide a better grip and control over the medicine ball. Participants were instructed to start with extended elbows and to perform an eccentric and a concentric phase with a throw off towards the ceiling. Participants were instructed to perform the movement with maximum intent in order to throw the medicine ball as high

as possible. No specific duration of the eccentric phase was prescribed. After the throw, the ball was caught by the supervisor.

The intensity of the HLBP intervention was set to 90% of the participant's individual 1RM, corresponding to $91.3 \pm 14.0 \text{ kg}$ (range 74.3 - 130.5 kg). In each of the 2 sets, participants performed repetitions at 90% 1RM until they judged that one further repetition could still have been completed (one repetition in reserve), corresponding to 2 - 3 repetitions at this load. RIR was self-estimated and confirmed by the supervisor, and sets were separated by 5 min of rest. Body, shoulder and wrist position were exactly as in the 1RM bench press test and the bench press throw. The eccentric phase was set to a duration of 1 - 2 s.

To ensure that participants maintained their body temperature and physical readiness during the control condition session without directly fatiguing the primary agonist muscles, an active control condition was implemented. During this control session, participants performed a one-arm dumbbell row. This exercise was chosen to maintain core temperature and general arousal without directly loading the agonist push-musculature.

Participants were instructed as follows: the non-pulling side was supported with the knee and the palm of the hand on a bench; the leg on the pulling side was planted on the ground; the spine was held in a neutral position; and the dumbbell was pulled towards the navel. The exercise was performed on both sides, with 2 sets of 8 repetitions per side at 3 - 4 repetitions in reserve and 5 min of rest between sets. Repetitions in reserve were estimated by the participant and were supervised and confirmed by the investigator on every set. The dumbbell load was selected individually for each participant so that a set of eight repetitions terminated with three to four repetitions in reserve, and this judgement was supervised rather than left to the participant alone.

Table 2. Detailed intervention protocol.

Intervention Protocol			
General Warm-Up		5min cycle ergometer (at 60W)	
		2min rest	
		Bench Press	
		1x8 repetitions at 40% of 1RM	
Specific Warm-Up		3min rest	
		Bench Press	
		1x5 repetitions at 70% of 1RM	
		7min rest	
		Bench Press Throw	
Baseline-Test		3x max effort Bench Press Throw (10 - 15sec rest in between reps)	
		7min rest	
Conditioning Activity	Bench Press (HLBP)	Med Ball Throw (BMT)	Control Condition Dumbbell Row (CC)
	2x2 - 3 repetitions at 90% of 1RM (5min rest in between sets)	2x4 repetitions at 5% of BP-1RM (5min rest in between sets)	2x8 repetitions one arm dumbbell row per side with 3 - 4 RIR (5min rest in between sets)
		5min rest	
Post-Intervention-Test (5 min)		Bench Press Throw	
		3x max effort Bench Press Throw (15sec rest in between reps)	
		5min rest	
Post-Intervention-Test (10 min)		Bench Press Throw	
		3x max effort Bench Press Throw (15sec rest in between reps)	

1RM: 1 repetition maximum, RIR: Repetitions in reserve.

Statistical analysis

Device-native values were exported from the 1080 Motion Web App to Microsoft Excel, where the repetition-level values for PPO [W], APO [W], TTPPO [s], PV [$\text{m}\cdot\text{s}^{-1}$], AV [$\text{m}\cdot\text{s}^{-1}$] and TTPV [s] were selected and averaged as described in the Measurements section; no variable was recalculated outside the device software. Normality of distribution was assessed with the Shapiro-Wilk test, and data are expressed as mean $\pm$ standard deviation.

Statistical analyses were performed using JASP (Version 0.95.4). For each outcome, a two-way fully within-subject repeated-measures ANOVA was conducted, with Condition (BMT, HLBP, CC) and Time (Pre, 5 min post, 10 min post) as within-subject factors and the Condition $\times$ Time interaction as the omnibus effect of interest. Sphericity was assessed separately for each within-subject effect using Mauchly's test; where sphericity was violated, the Greenhouse-Geisser correction was applied and the corrected fractional degrees of freedom, the epsilon value and the corrected p-value are reported. Results are reported as F (degrees of freedom), p , and partial eta-squared (η^2p).

Six outcomes were recorded. The confirmatory family was defined so as to correspond exactly to the two a priori hypotheses stated in the Introduction: PPO and APO for the first hypothesis (power output) and PV for the second hypothesis (peak velocity). The remaining three variables (AV, TTPPO and TTPV) were treated as exploratory and are reported descriptively, without confirmatory inference. Average velocity was placed in the exploratory set even though average power was confirmatory, because the second hypothesis refers specifically to peak barbell velocity, whereas the first refers to both peak and average power output. It should be stated explicitly that this primary/exploratory hierarchy was not documented in a dated protocol or analysis plan predating inspection of the data. It is a revision-stage analytical decision, taken in order to align the inferential structure with the hypotheses as originally stated, and it should be interpreted as such rather than as a pre-specified multiplicity strategy. Because each hypothesis is comparative and because both post-condition time points were of interest, the confirmatory family comprised six tests: three outcomes $\times$ two time points (5 min and 10 min post-condition). The familywise error rate across these six tests was controlled using the Holm-Bonferroni procedure at $\alpha = 0.05$.

The hypotheses were tested with difference-in-change contrasts. For each confirmatory outcome and each post-condition time point, the within-participant change from baseline was computed separately for HLBP and for BMT, and the two change scores were compared using a paired-samples t -test. This contrast tests directly whether the change in HLBP differs from the change in BMT, which is what the hypotheses predict; acceptance or rejection of the hypotheses is based on these contrasts. Where a contrast supports a hypothesis, the accompanying within-condition changes are used only to describe how that difference arose, not to overturn the contrast. Results are reported as the mean difference in change in raw units with 95% confidence intervals, Cohen's d_z with 95% confidence intervals with values of 0.2, 0.5 and 0.8 interpreted

as small, medium and large, respectively (Cohen, 1988), and Holm-adjusted p -values. The Holm-Bonferroni adjustment was applied to the p -values only; the accompanying 95% confidence intervals are unadjusted and should therefore not be interpreted as simultaneous intervals. The equivalent contrasts against the control condition are reported as supporting, non-confirmatory information. Separately, and for description only, within-condition changes were examined with Bonferroni-corrected paired-samples t -tests across the three time points (three comparisons within each condition, so the Bonferroni family is three tests per condition), conducted where the Condition $\times$ Time interaction was significant. These within-condition tests indicate whether a condition changed relative to its own baseline and are not used to infer differences between conditions. All data are presented as mean $\pm$ SD. For the TTPPO outcome, data from three participants could not be computed because the 1080 Quantum system failed to correctly detect the individual repetitions in these cases. These participants were therefore excluded from the TTPPO analysis only, resulting in $n = 25$ for this outcome; no data were imputed, and all other outcomes were analyzed with the full sample of $n = 28$. Two individual minimum values in the TTPPO data (0.092 s in CC at baseline and 0.071 s in HLBP at 5 min post-condition; Table 3) lie far below all remaining minima, which range from approximately 0.23 to 0.24 s. They are regarded as residual repetition-detection artifacts of the same type that led to the exclusion of the three participants above, and they are the most likely source of the violation of sphericity observed for this variable. Because TTPPO is an exploratory outcome that is reported descriptively and is not used for any confirmatory inference, these two values were retained in the descriptive statistics of Table 3. Period effects were examined by comparing baseline values and baseline-to-5-min changes across the three sessions.

Results

Baseline (pre-condition) values were comparable across the three conditions for every outcome and are reported descriptively in Table 3. No equivalence testing was performed, and the absence of a detected difference is not interpreted as evidence of baseline equivalence. No period effects were detected: baseline values did not differ across the three sessions (PPO: $F(2, 54) = 0.31$, $p = 0.737$; APO: $F(2, 54) = 0.12$, $p = 0.886$; PV: $F(2, 54) = 0.33$, $p = 0.718$; AV: $F(2, 54) = 0.21$, $p = 0.814$). Because allocation to sequences was uneven, the three sessions differed slightly in their condition composition (session 1: 11 BMT, 9 HLBP, 8 CC; session 2: 8 BMT, 8 HLBP, 12 CC; session 3: 9 BMT, 11 HLBP, 8 CC), so a pooled comparison of change scores across sessions would confound period with condition. The baseline-to-5-min change was therefore compared across sessions separately within each condition, and no period effect was found for any of them (PPO all $p \geq 0.673$; APO all $p \geq 0.282$; PV all $p \geq 0.446$). First-order carryover was examined for the three confirmatory outcomes at both post-condition time points, by testing within each condition whether the change from baseline depended on the condition performed in the preceding session (18

tests in total, restricted to sessions two and three). Two tests were nominally significant before correction for multiplicity (APO after BMT at 5 min, $p = 0.031$; PV after BMT at 10 min, $p = 0.048$) and none survived correction, which is what would be expected by chance at this number of tests. These analyses rest on 6 to 11 participants per cell, so their sensitivity is low, and the absence of a detected carryover effect should not be read as evidence that none is present.

Table 4 presents the omnibus repeated-measures ANOVA results together with the Bonferroni-corrected within-condition post-hoc comparisons, Table 5 the raw within-subject changes from baseline, Table 6 the confirmatory between-condition difference-in-change contrasts, and Table 3 displays means, standard deviations, and ranges for all outcomes across all conditions and time points.

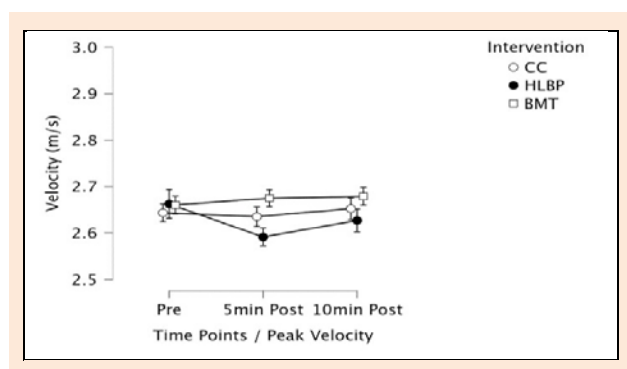


Figure 1. Peak Velocity (PV) of each condition at pre-, 5 min post-, and 10 min post-intervention. Error bars represent standard deviation. CC: Control Condition, HLBP: High-Load Bench Press, BMT: Ballistic Medicine-Ball Throw.

Peak Velocity (PV)

A significant main effect of Time, $F(2, 54) = 4.21$, $p = 0.020$, $\eta^2p = 0.135$, and a significant Condition $\times$ Time interaction, $F(4, 108) = 4.16$, $p = 0.004$, $\eta^2p = 0.134$, were found for PV (Figure 1); Mauchly's test indicated that

sphericity was tenable for both effects ($p = 0.140$ and $p = 0.271$, respectively). Descriptive within-condition comparisons revealed a significant decrease in PV from Pre to 5 min post-intervention in the HLBP condition ($p = 0.002$, $dz = -0.74$, 95% CI -1.18 to -0.30; mean change $-0.071 \text{ m}\cdot\text{s}^{-1}$, 95% CI -0.109 to -0.034), followed by a partial recovery from 5 to 10 min ($p = 0.022$, $dz = 0.55$, 95% CI 0.13 to 0.96; mean change $+0.036 \text{ m}\cdot\text{s}^{-1}$, 95% CI 0.010 to 0.061). In absolute terms the decrement corresponded to approximately $0.07 \text{ m}\cdot\text{s}^{-1}$ ($\approx 2.7\%$); the change was therefore small in practical magnitude despite the moderate standardized effect. No significant changes were observed in the BMT or CC conditions at any time point.

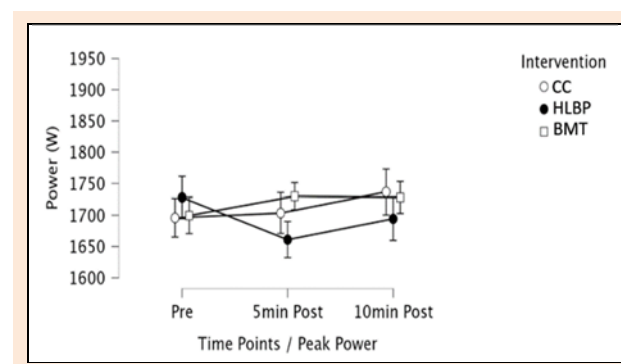


Figure 2. Peak Power Output (PPO) of each condition at pre-, 5 min post-, and 10 min post-intervention. Error bars represent standard deviation. CC: Control Condition, HLBP: High-Load Bench Press, BMT: Ballistic Medicine-Ball Throw.

Peak Power Output (PPO)

A significant Condition $\times$ Time interaction was found for PPO, $F(4, 108) = 2.96$, $p = 0.023$, $\eta^2p = 0.099$ (Figure 2); sphericity was tenable (Mauchly's test $p = 0.154$). Descriptive within-condition comparisons revealed a significant decrease in PPO from Pre to 5 min post-intervention in the HLBP condition only ($p = 0.010$, $dz = -0.61$, 95% CI -1.03 to -0.19), corresponding to a mean

Table 3. Sample size, mean $\pm$ SD and minimum-maximum for testing parameters.

Testing Parameter	n	Mean $\pm$ SD			Minimum - Maximum		
		Pre	5min Post	10min Post	Pre	5min Post	10min Post
PPO [W]	BMT	1699 $\pm$ 387	1730 $\pm$ 424	1728 $\pm$ 432	1089 - 2728	1027 - 2926	1018 - 2962
	HLBP	1728 $\pm$ 427	1661 $\pm$ 383	1694 $\pm$ 406	1019 - 2746	1008 - 2507	1176 - 2705
	CC	1696 $\pm$ 404	1703 $\pm$ 429	1737 $\pm$ 443	1086 - 2873	1023 - 3036	1053 - 2731
APO [W]	BMT	1010 $\pm$ 203	1012 $\pm$ 189	1016 $\pm$ 200	652 - 1445	670 - 1406	622 - 1428
	HLBP	1010 $\pm$ 189	987 $\pm$ 174	993 $\pm$ 192	629 - 1414	662 - 1375	688 - 1450
	CC	1023 $\pm$ 220	1002 $\pm$ 191	1023 $\pm$ 205	575 - 1531	626 - 1417	668 - 1438
PV [m/s]	BMT	2.660 $\pm$ 0.242	2.675 $\pm$ 0.247	2.679 $\pm$ 0.263	2.196 - 3.160	2.136 - 3.125	2.109 - 3.147
	HLBP	2.663 $\pm$ 0.253	2.591 $\pm$ 0.264	2.627 $\pm$ 0.282	2.165 - 3.181	2.098 - 3.100	2.105 - 3.147
	CC	2.644 $\pm$ 0.224	2.635 $\pm$ 0.241	2.653 $\pm$ 0.237	2.216 - 3.140	2.154 - 3.109	2.209 - 3.260
AV [m/s]	BMT	1.766 $\pm$ 0.147	1.780 $\pm$ 0.145	1.779 $\pm$ 0.152	1.462 - 2.046	1.467 - 2.064	1.403 - 2.002
	HLBP	1.772 $\pm$ 0.135	1.735 $\pm$ 0.138	1.749 $\pm$ 0.151	1.430 - 1.975	1.471 - 2.010	1.497 - 2.063
	CC	1.764 $\pm$ 0.147	1.748 $\pm$ 0.133	1.767 $\pm$ 0.146	1.340 - 2.034	1.415 - 2.021	1.481 - 2.031
TTPPO [s]	BMT	0.360 $\pm$ 0.050	0.368 $\pm$ 0.049	0.366 $\pm$ 0.048	0.243 - 0.440	0.242 - 0.430	0.242 - 0.440
	HLBP	0.363 $\pm$ 0.050	0.356 $\pm$ 0.078	0.369 $\pm$ 0.051	0.230 - 0.453	0.071 - 0.474	0.233 - 0.456
	CC	0.356 $\pm$ 0.076	0.367 $\pm$ 0.049	0.364 $\pm$ 0.048	0.092 - 0.465	0.227 - 0.447	0.240 - 0.449
TTPV [s]	BMT	0.409 $\pm$ 0.058	0.411 $\pm$ 0.056	0.413 $\pm$ 0.060	0.306 - 0.578	0.302 - 0.545	0.291 - 0.612
	HLBP	0.407 $\pm$ 0.050	0.408 $\pm$ 0.053	0.414 $\pm$ 0.053	0.284 - 0.500	0.282 - 0.512	0.299 - 0.515
	CC	0.408 $\pm$ 0.055	0.411 $\pm$ 0.054	0.404 $\pm$ 0.057	0.284 - 0.525	0.281 - 0.522	0.288 - 0.534

N: sample size; SD: standard deviation. PPO: Peak power output, APO: Average power output, PV: Peak velocity, AV: Average velocity, TTPPO: Time to peak power output, TTPV: Time to peak velocity, CC: Control Condition, HLBP: High-Load Bench Press, BMT: Ballistic Medicine-Ball Throw. The minimum TTPPO values of 0.092 s (CC, Pre) and 0.071 s (HLBP, 5 min post) are regarded as residual repetition-detection artifacts of the 1080 Quantum system; they were retained for completeness.

reduction of 67.1 W (95% CI -109.6 to -24.5; $\approx 3.9\%$ of baseline); the change was thus small in practical magnitude despite the moderate standardized effect. No significant changes were observed in the BMT or CC conditions, and the main effect of Time was not significant, $F(2, 54) = 2.45$,

$p = 0.096$, $\eta^2p = 0.083$. For APO, neither the main effect of Time, $F(2, 54) = 2.23$, $p = 0.117$, $\eta^2p = 0.076$, nor the Condition $\times$ Time interaction, $F(4, 108) = 1.41$, $p = 0.237$, $\eta^2p = 0.049$, was significant, and sphericity was tenable for both effects.

Table 4. Within-subject ANOVA effects and Bonferroni-corrected post-hoc comparisons.

Variables	Effect / Post-hoc comparison	F (df)	p	η^2p	dz [95% CI]
PPO	Time	$F(2, 54) = 2.45$	0.096	0.083	
	Condition $\times$ Time	$F(4, 108) = 2.96$	0.023	0.099	
	HLBP: Pre vs. 5 min		0.010		-0.61 [-1.03, -0.19]
APO	Time	$F(2, 54) = 2.23$	0.117	0.076	
	Condition $\times$ Time	$F(4, 108) = 1.41$	0.237	0.049	
	HLBP: Pre vs. 5 min		0.002		-0.74 [-1.18, -0.30]
PV	Time	$F(2, 54) = 4.21$	0.020	0.135	
	Condition $\times$ Time	$F(4, 108) = 4.16$	0.004	0.134	
	HLBP: 5 vs. 10 min		0.022		0.55 [0.13, 0.96]
AV	Time	$F(2, 54) = 1.53$	0.225	0.054	
	Condition $\times$ Time	$F(4, 108) = 2.51$	0.046	0.085	
TTPPO	Time	$F(2, 48) = 1.33$	0.275	0.052	
	Condition $\times$ Time	$F(2.41, 57.89) = 1.19$ ($\epsilon = 0.60$)	0.317 †	0.047	
TTPV	Time	$F(2, 54) = 0.42$	0.659	0.015	
	Condition $\times$ Time	$F(4, 108) = 1.70$	0.156	0.059	

PPO: peak power output; APO: average power output; PV: peak velocity; AV: average velocity; TTPPO: time to peak power output; TTPV: time to peak velocity; HLBP: High-Load Bench Press; BMT: Ballistic Medicine-Ball Throw; CC: Control Condition; η^2p : partial eta-squared; dz: Cohen's d for paired samples; CI: confidence interval; ϵ : Greenhouse–Geisser epsilon. Within-condition post-hoc comparisons are Bonferroni-corrected paired-samples t-tests. Bold values indicate statistical significance ($p < 0.05$); the exploratory outcomes (AV, TTPPO and TTPV) are not marked. † Greenhouse–Geisser-corrected p-value with corrected fractional degrees of freedom, applied where Mauchly's test indicated a violation of sphericity.

Table 5. Raw within-subject changes from baseline for the three confirmatory outcomes (n = 28).

Variables	Condition	Change Pre to 5 min, mean [95% CI]	Change Pre to 10 min, mean [95% CI]
PPO [W]	BMT	+30.6 [-5.3, 66.5]	+28.6 [-12.0, 69.1]
	HLBP	-67.1 [-109.6, -24.5]	-33.8 [-84.2, 16.7]
	CC	+7.5 [-34.5, 49.6]	+40.8 [-7.2, 88.9]
APO [W]	BMT	+1.5 [-18.1, 21.1]	+5.7 [-15.3, 26.8]
	HLBP	-23.3 [-50.8, 4.3]	-17.1 [-45.2, 11.0]
	CC	-20.6 [-39.1, -2.1]	+0.5 [-21.6, 22.6]
PV [$\text{m}\cdot\text{s}^{-1}$]	BMT	+0.015 [-0.011, 0.041]	+0.019 [-0.009, 0.046]
	HLBP	-0.071 [-0.109, -0.034]	-0.036 [-0.079, 0.008]
	CC	-0.008 [-0.035, 0.018]	+0.009 [-0.021, 0.039]

PPO: peak power output; APO: average power output; PV: peak velocity; HLBP: High-Load Bench Press; BMT: Ballistic Medicine-Ball Throw; CC: Control Condition; CI: confidence interval. Values are mean within-participant changes from the pre-condition measurement in raw units.

Table 6. Difference-in-change between the High-Load Bench Press and the Ballistic Medicine-Ball Throw condition.

Variable	Time point	Difference in change, HLBP - BMT [95% CI]	dz [95% CI]	p (unadjusted)	p (Holm)
PPO [W]	5 min	-97.7 [-159.4, -35.9]	-0.61 [-1.04, -0.19]	0.003	0.016
	10 min	-62.4 [-128.4, 3.7]	-0.37 [-0.77, 0.03]	0.063	0.223
APO [W]	5 min	-24.7 [-52.6, 3.2]	-0.34 [-0.74, 0.06]	0.080	0.223
	10 min	-22.8 [-52.0, 6.4]	-0.30 [-0.70, 0.09]	0.121	0.223
PV [$\text{m}\cdot\text{s}^{-1}$]	5 min	-0.086 [-0.137, -0.035]	-0.65 [-1.08, -0.23]	0.002	0.011
	10 min	-0.054 [-0.110, 0.001]	-0.38 [-0.78, 0.02]	0.056	0.223

PPO: peak power output; APO: average power output; PV: peak velocity; HLBP: High-Load Bench Press; BMT: Ballistic Medicine-Ball Throw; CI: confidence interval; dz: Cohen's d for paired samples. The Holm–Bonferroni correction was applied across the six confirmatory contrasts to the p-values only; the 95% confidence intervals reported here are unadjusted and are therefore not simultaneous intervals.

Confirmatory contrasts between conditions (HLBP vs. BMT)

For PPO, the change from baseline to 5 min differed significantly between HLBP and BMT: the mean difference in change was -97.7 W (95% CI -159.4 to -35.9), $dz = -0.61$ (95% CI -1.04 to -0.19), Holm-adjusted $p = 0.016$, corresponding to approximately 5.7% of the pooled baseline. For PV the corresponding contrast was -0.086 $\text{m}\cdot\text{s}^{-1}$

(95% CI -0.137 to -0.035), $dz = -0.65$ (95% CI -1.08 to -0.23), Holm-adjusted $p = 0.011$, corresponding to approximately 3.2% of the pooled baseline. Neither contrast remained significant at 10 min (PPO: -62.4 W, 95% CI -128.4 to 3.7, adjusted $p = 0.223$; PV: -0.054 $\text{m}\cdot\text{s}^{-1}$, 95% CI -0.110 to 0.001, adjusted $p = 0.223$), and no contrast was significant for APO (5 min: -24.7 W, 95% CI -52.6 to 3.2, adjusted $p = 0.223$; 10 min: -22.8 W, 95% CI -52.0 to 6.4,

adjusted $p = 0.223$). In every case the point estimate favored BMT over HLBP; no contrast favored HLBP at any time point. The supporting contrasts against the control condition showed the same pattern: HLBP differed from CC at 5 min for PV ($-0.063 \text{ m}\cdot\text{s}^{-1}$, 95% CI -0.112 to -0.015 , unadjusted $p = 0.013$), whereas BMT did not differ from CC for either confirmatory outcome at either time point (all unadjusted $p \geq 0.06$).

The three exploratory outcomes (AV, TTPPO and TTPV) are reported descriptively in Tables 3 and 4 and were not subjected to confirmatory interpretation. For AV, the Condition $\times$ Time interaction reached the conventional threshold, $F(4, 108) = 2.51$, $p = 0.046$, $\eta^2p = 0.085$, with sphericity tenable (Mauchly's test $p = 0.447$); the pattern mirrored that of PV, but because AV was not part of the confirmatory family this result is reported without inferential claim. For TTPPO, sphericity was violated for the interaction (Mauchly's test $p < 0.001$) and the Greenhouse–Geisser correction was applied ($\epsilon = 0.60$), $F(2.41, 57.89) = 1.19$, $p = 0.317$. Across the exploratory variables, mean values remained largely stable over time in all conditions.

Discussion

The primary objective of this study was to compare the acute effects of two contrasting CAs, HLBP at 90% 1RM and BMT at 5% 1RM, on upper body push power. The key finding was that, five minutes after the conditioning activity, the change from baseline in the HLBP condition differed significantly from the change in the BMT condition for both peak power output (-97.7 W , 95% CI -159.4 to -35.9) and peak velocity ($-0.086 \text{ m}\cdot\text{s}^{-1}$, 95% CI -0.137 to -0.035). This difference was driven by a decrement in the HLBP condition: only HLBP declined relative to its own baseline ($dz = -0.61$ for PPO and $dz = -0.74$ for PV), whereas BMT differed neither from its own baseline nor from the active control condition. Contrary to the first hypothesis, HLBP therefore did not outperform BMT; the contrast was significant in the opposite direction. The second hypothesis was supported: peak velocity at 5 min was significantly higher after BMT than after HLBP. The direction of that difference, however, was produced by the decline after HLBP and not by any gain after BMT, which changed neither from its own baseline nor relative to the control condition, so the result does not demonstrate potentiation. Neither intervention produced an acute performance enhancement.

To contextualize these findings, it is necessary to distinguish between the time courses of PAP and PAPE. While PAP, which is commonly attributed to the phosphorylation of myosin regulatory light chains, peaks immediately after a CA and dissipates within minutes, PAPE is thought to reach its highest point between 5 and 10 minutes post-intervention (Blazevich and Babault, 2019; Fischer and Paternoster, 2024). As the present study measured only voluntary performance and did not assess evoked contractile properties, the subsequent interpretation refers to the net voluntary outcome rather than to PAP-specific mechanisms. Ultimately, the net performance outcome at any given time is determined by the balance between muscular fatigue and the potentiation of the neuromuscular system

(Tillin and Bishop, 2009).

In the case of the HLBP condition, the significant performance drop in PPO and PV at 5 minutes indicates that this recovery interval was insufficient to overcome the fatigue induced by the 90% 1RM load. It is worth noting that, although the standardized within-subject effects were moderate ($dz = -0.61$ for PPO and $dz = -0.74$ for PV), the absolute decrements were small ($\approx 3.9\%$ and $\approx 2.7\%$, respectively). The changes were therefore consistent across participants yet of limited practical magnitude. It is probable that the high neural cost of this specific CA generated a level of fatigue that masked a potential PAPE enhancement at the 5-minute mark. The partial recovery in PV from 5 to 10 minutes post-intervention ($p = 0.022$, $dz = 0.55$) suggests that as fatigue dissipated, athletes returned toward baseline without any potentiation effect. Furthermore, while previous literature suggests optimal PAPE results are typically observed 7 to 12 minutes post-CA (Blazevich and Babault, 2019), our data showed only a return to baseline at the 10-minute mark. This absence of a delayed performance spike may be attributable to two factors. First, it is possible that the 5-minute post-test itself acted as an additional fatiguing stimulus, blunting any expected potentiation at the 10-minute interval. Second, the general and specific warm-up protocols performed prior to baseline testing may already have induced a potentiation state (Blazevich and Babault, 2019; Fischer and Paternoster, 2024). Because no index of baseline neuromuscular state was collected in the present study, this second possibility remains a secondary speculative explanation that these data can neither confirm nor evaluate, and it is offered as one candidate account among several rather than as an interpretation supported by the present results. Beyond the potential confounding effects of the testing protocol, PAPE is highly multifactorial, particularly concerning upper-body interventions. Variables such as intensity, volume, recovery intervals, relative strength, and strength training experience play a critical role in finding the optimal stimulus for upper-body PAPE (Finlay et al., 2022; Krzysztofik et al., 2021; Seitz and Haff, 2016; Wilson et al., 2013). Regarding intensity, while near-maximal loads are frequently employed to trigger PAPE, Krzysztofik et al. (2021) suggest that for upper-body exercises an intensity range of 60% to 84% 1RM might be more efficacious. The 90% 1RM load utilized in this study likely exceeded this range, generating excessive acute fatigue rather than optimal pre-activation. Although Krzysztofik et al. (2021) noted that rest intervals of 5 to 7 minutes or ≥ 8 minutes could be equally effective for intensities above 85% 1RM, the 5-minute recovery in the present protocol resulted in measurable performance decrements. This aligns with broader literature indicating that the optimal recovery window following such high-load conditioning typically falls around 7 to 8 minutes (Bevan et al., 2009; Ferreira et al., 2012; Kilduff et al., 2007; Vrcić et al., 2018). Direct evidence from the same test exercise reinforces this interpretation. Tsoukos et al. (2019) found that bench-press-throw velocity was enhanced between the fourth and twelfth minute of recovery only after a 60% 1RM set terminated at a 10% velocity loss, whereas lighter loads produced no enhancement. Another study using a heavier 80% 1RM load likewise elicited potentiation

across a broad fourth-to-twelfth-minute window (Tsoukos et al., 2021). Together these findings suggest that it is the fatigue generated by a conditioning activity, determined jointly by load and volume rather than by load alone, that governs the outcome: the RIR-regulated set at 90% 1RM used here (2 - 3 repetitions performed to one repetition in reserve) plausibly induced greater fatigue, whereas the 5% load appears to have remained below an effective threshold in this sample. The first hypothesis, that HLBP would produce superior improvements in PPO and APO, must therefore be rejected: the direct contrast at 5 minutes was significant in the opposite direction for PPO, and no contrast favored HLBP at any time point or for any confirmatory outcome.

The BMT condition produced no change relative to either its own baseline or the active control condition, and therefore provides no evidence of potentiation. The confirmatory contrast for peak velocity therefore supports the second hypothesis as it was formulated, that is, as a comparison between conditions. It should be stated plainly that this support is formal rather than substantive: the hypothesis was motivated by the expectation of a velocity gain after the ballistic throw, and no such gain occurred. Several interconnected factors may explain this null result. Most directly, the 5% 1RM load may have provided too small a stimulus to elicit a meaningful PAPE response. The most effective intensity range identified for upper-body PAPE lies between 60% and 84% 1RM (Krzysztofik et al., 2021); that window, however, was derived almost exclusively from bench-press-type conditioning activities expressed as a percentage of the 1RM of the same movement. A medicine-ball throw loaded at 5% of bench-press 1RM is not mechanically equivalent to such a protocol, and a resistance-training intensity window cannot be transferred directly across these modalities without specific evidence. The present null result should therefore be read as consistent with an insufficient stimulus rather than as establishing a minimum threshold for ballistic upper-body conditioning activities; the load-response relationship for ballistic throws remains to be characterized directly (Seitz and Haff, 2016; Wilson et al., 2013). A further possibility is that the standardized warm-up had already elevated neuromuscular readiness, leaving little additional potentiation for a low-intensity CA to contribute (Blazevich and Babault, 2019; Fischer and Paternoster, 2024; Rappelt et al., 2024); because baseline neuromuscular state was not measured, this remains speculative. In this sense the BMT may have been largely redundant relative to the warm-up already performed, neither adding potentiation nor inducing sufficient fatigue to impair performance.

The prescribed volume warrants scrutiny across both interventions. While some literature advocates for multiple sets (2 - 3) of a CA to maximize potentiation (Bevan et al., 2009; Seitz and Haff, 2016; West et al., 2013), upper-body push power has demonstrated marginally higher effect sizes following a single set compared to multiple sets ($ES = 0.37$ vs. 0.29), though these differences are not statistically significant (Krzysztofik et al., 2021). For the HLBP, despite the low total volume of 2 sets of 2 - 3 repetitions performed to one repetition in reserve, the near-maximal load likely induced significant neural drive

inhibition. If a 5-minute rest is the maximum available time, a lower-intensity CA (60 - 84% 1RM) or a further reduced volume (for example, a single repetition) may be more appropriate, minimizing initial fatigue while potentially allowing potentiation to manifest sooner. For the BMT, conversely, the volume may have been adequate in quantity but the stimulus per repetition too weak to accumulate meaningful potentiation.

In contrast training, general training experience and relative strength are critical determinants of the PAPE response. Wilson et al. (2013) demonstrated markedly different effect sizes between untrained ($ES = 0.14$) and trained ($ES = 0.81$) participants following a single contrast training session. Furthermore, participants with a relative strength of ≥ 1.5 kg/kg body mass showed a strong correlation ($r = 0.87$) with positive power changes after just a 5-minute rest period (Smilios et al., 2017). While participants in the present study possessed considerable strength training experience (8.1 ± 3.7 years), their average relative strength of 1.17 ± 0.15 kg/kg body mass fell below this threshold. As this benchmark derives from a different population and protocol (Smilios et al., 2017), it can be applied to the present sample only to a limited extent; nevertheless, it may have contributed to the participants' inability to overcome the fatigue of the 90% 1RM load within the 5-minute window in the HLBP condition. A critical component of maximizing power output is understanding individual peak power thresholds. Research indicates that upper-body peak power typically manifests between 30 - 70% 1RM (Izquierdo et al., 2002; Thomas et al., 2007), with ballistic bench press throws specifically showing optimal power at 30% 1RM (Bevan et al., 2010; Soriano et al., 2017), though some studies suggest 40% 1RM as the optimal threshold (Da Silva et al., 2015). The 40% 1RM used in this study is consistent with the literature and unlikely to be the source of the null effects observed.

Taking all findings into account, a broader question remains: is PAPE a truly distinct mechanism, or is it functionally indistinguishable from a high-intensity warm-up? Rappelt et al. (2024) compared various isometric intervention protocols against a standardized 5-minute warm-up and found no significant differences in CMJ height, raising a parallel question for upper-body protocols. The failure of either active condition to exceed baseline performance in the present study is compatible with the notion that the specific warm-up employed may already have raised acute neuromuscular readiness substantially. This account is not testable with the present data, however, because no index of neuromuscular state was recorded before or after the warm-up. It is therefore offered as one candidate explanation among several, and it requires direct testing rather than being treated as an interpretation supported by these results.

Despite the insights gained from this study, several limitations must be acknowledged. First, although the participants were trained, the use of only one familiarization session may have been insufficient to fully eliminate learning effects. While strength-trained individuals adapt quickly, the unique resistance profiles of the equipment might require more extensive practice to ensure optimal movement consistency.

Furthermore, certain external variables were not strictly controlled. The researchers had no direct influence on the participants' nutritional intake or their pre-session fatigue levels prior to testing. Even though subjects were instructed to arrive well-rested and continue their normal eating habits, individual variations in daily recovery and caloric intake could have introduced minor fluctuations in performance data.

The idea of testing at two different post intervention time points (5min post and 10min post) could influence power or velocity outputs. Even though a bench press throw of 40% of the participants' 1RM seems very light, due to the requirement that all test subjects must perform the exercise with maximum intensity, neural fatigue can set in, influencing the potential PAPE effect at 10min post-intervention. Therefore, it would be better to split every intervention into two more conditions (5min or 10min rest time).

In addition, only male athletes were investigated. As sex differences in the load-power relationship have been reported (Thomas et al., 2007), the present findings may not generalize to female athletes.

Furthermore, the active control condition (one-arm dumbbell row, 2×8 repetitions per side at 3 - 4 RIR) was neither work- nor time-matched to the two experimental conditions, and cannot be considered a fully neutral reference. Although it was selected to maintain core temperature and neuromuscular readiness without directly loading the push-musculature, antagonist contractions may nonetheless influence agonist output through reciprocal inhibition and central mechanisms (Cuenca-Fernández et al., 2017; Ulrich and Parstorfer, 2017). Consequently, the absence of significant change in the CC does not unequivocally confirm an unpotentiated state. This is also apparent in the data themselves: within the control condition, average power output declined from baseline to 5 min (-20.6 W, 95% CI -39.1 to -2.1), and the largest 10-min change in peak power output of any condition occurred in the control condition ($+40.8$ W; Table 5). The reference against which BMT was judged was therefore itself moving, and the conclusion that BMT did not differ from the control condition should be read with this within-session variability in mind. Future studies should consider either a fully passive control condition or direct quantification of neuromuscular readiness at each time point.

It was observed as well, that benching with the Quantum strings felt significantly more difficult than performing the same exercise with free weights. This discrepancy suggests that the mechanical friction or the specific tension profile of the strings may provide a different stimulus than traditional resistance, potentially affecting the direct comparability of the two loading methods. Accordingly, the extent to which throw power generated on a motorized cable system transfers to free-weight or barbell-based ballistic pressing remains uncertain, and generalization of these findings to traditional free weights should be made with caution.

Finally, one limitation concerns the absence of device-specific reliability data. No intraclass correlation coefficients or coefficients of variation were established for the bench-press-throw outcomes on the 1080 Quantum

within the present sample. Although the device provides standardized, instrumented measurement and a familiarization session preceded all testing, the absence of formal reliability estimates means that the measurement error associated with the reported outcomes cannot be quantified.

A further limitation concerns statistical power. With $n = 28$, the design could reliably detect contrasts of approximately $d_z = 0.70$ under the Holm-adjusted criterion. The two contrasts that reached significance at 5 min ($d_z = -0.61$ for PPO and -0.65 for PV) lie close to this threshold, whereas the non-significant contrasts at 10 min ($d_z = -0.37$ and -0.38) and those for APO ($d_z = -0.34$ and -0.30) fall below it. These null findings therefore indicate an absence of evidence for effects of the size this study could detect, not evidence that no smaller effect exists.

Conclusion

In conclusion, under the protocols examined here the high-intensity HLBP intervention (90% 1RM) impaired acute upper-body power performance relative to the ballistic medicine-ball throw when only 5 minutes of recovery was provided, and neither conditioning activity enhanced performance relative to baseline or to the active control condition. For practitioners and coaches who require a performance peak specifically at the 5-minute mark, the study therefore suggests a necessary trade-off: either the volume or the intensity of the conditioning activity must be reduced, or the recovery interval after it must be extended.

Future research should consider focusing more on separating individual performance and strength groups to find the right conditioning activities as well as the right load and rest parameters for each performance level to maximize the PAPE effect output.

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Key points

- Under the protocols examined here - two sets of 2 - 3 repetitions at 90% 1RM and two sets of four medicine-ball throws loaded at 5% of bench-press 1RM - neither conditioning activity enhanced upper-body power in trained male athletes.
- In trained male athletes, a 5-minute rest was insufficient to restore explosive bench-press performance after two sets at 90% 1RM.
- PAPE may, in part, overlap with warm-up-induced readiness; however, this remains speculative and requires direct testing.

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