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A Comparison between Non-Localized Post-Activation Performance Enhancements Following Resistance Exercise for the Upper and the Lower Body

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Abstract: The aim of the present investigation was to compare the acute non-localized post-activation performance enhancement (PAPE) of an exercise protocol involving either the upper or the lower body muscles. Twenty-four resistance trained men participated in the present study and were randomly assigned to an upper body (UB) or to a lower body (LB) group. Both groups tested for upper and lower body power (bench press throw (BPT) and countermovement jump power (CMJP) tests). Participants in the UB group were tested pre and post a high-intensity (HI) and a high-power (POW) bench press protocol while participants in the LB group performed a HI squat and a jump session (POW). A significant group x time interaction was found for CMJP in HI (p = 0.012). Post hoc tests revealed that CMJP was elevated in UB group only (+1.6%; p=0.025). No other significant interactions were detected. Results of this study indicate that a non-localized PAPE on the lower body may be induced by a HI bench press protocol while a HI squat protocol may not increase upper body power. In particular, the squat protocol performed in the present study (5 sets of 1 rep) may be too demanding to produce a non-localized PAPE.

Keywords: strength; cross-education; acute effects

Citation: Bartolomei, S.; Lanzoni, I.M.; Fantozzi, S.; Cortesi, M. A Comparison between Non-Localized Post-Activation Performance Enhancements Following Resistance Exercise for the Upper and the Lower Body. *Appl. Sci.* **2022**, *12*, 1639. https://doi.org/10.3390/app12031639

Academic Editor: Nikolaos Zaras

Received: 23 December 2021
Accepted: 2 February 2022
Published: 4 February 2022

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1. Introduction

Post-activation potentiation (PAP) has been defined as an enhancement in the contractile response, measured with supramaximal electrical stimulation, following an intense voluntary contraction [1]. On the contrary, the ergogenic effect of a resistance exercise on subsequent power output has been defined as post-activation performance enhancement (PAPE) [2]. This physiological effect, reported by several studies on both the upper and lower body [3,4], has been frequently attributed to local factors such as muscle excitability and contractility due to increased phosphorylation of the myosin regulatory light chains [5]. However, some authors hypothesized that a relevant role may be played by the increased neural drive, activation of the central nervous system and by circulating catecholamines [6]. Considering the nature of PAPE, the acute effects could involve muscles that were not previously engaged in the conditioning intervention, producing a non-localized effect. This non-localized effect may induce an increase in the performance of the lower body when the upper body muscles have been exercised, and vice versa. Chronic influences of different lower body resistance exercise protocols on the upper body strength adaptations have been previously reported [7]. Furthermore, some authors investigated the acute non-localized effects of both upper and lower body resistance exercises. Wong et al. [8] and Andrews et al. [9] investigated the acute effects of a monolateral exercise session for the upper body on the contralateral arm. No non-localized PAPE, however, were detected in these studies. Consistently, Laskin et al. [10] did not report significant non-localized PAPE 15 sec, 90 sec and 3 min following a conditioning intervention consisting of bench press and vertical jumps. Although these studies did not show any significant non-localized effect, several parameters may be responsible for the lack of ergogenic effects on performance. The type of resistance exercise and muscle contractions performed in the conditioning intervention, as well as the amount of muscle mass involved, affect localized PAPE [11,12] and may also affect non-localized PAPE. A single set of a high-intensity resistance exercise, including concentric contractions, has been shown to induce greater localized-PAPE compared to solely concentric contractions [2]. In addition, acute improvements in sprint and vertical jump performance were registered following power exercises such as weighted jumps [13] and plyometric exercises [14]. The recovery time between the last set and the assessment may represent another important variable. A time of 8-12 min has been reported by the literature as optimal to dissipate fatigue and to magnify PAPE [15]. The same recovery time may be optimal to detect non-localized effects.

Despite the aforementioned studies have investigated the acute localized effects of a resistance intervention, no studies to date have studied the non-localized effects of a resistance training protocol including high-intensity or power exercises focused on different muscle groups. Indeed, some exercises and training protocols may be more appropriate than other to induce non-localized PAPE.

Thus, the aim of the present study was to compare the non-localized PAPE of an upper body exercise session on the lower body performance to the acute effects of a lower body exercise session on the upper body. Another aim was to compare the non-localized PAPE following a high-intensity resistance exercise session and a power session for either the upper or the lower body. The authors hypothesized that non-localized PAPE may be different based on the muscle groups involved in the intervention.

2. Materials and Methods

2.1. Study Design

Participants were randomly assigned to an upper body (UB) or to a lower-body (LB) experimental group and were requested to report back to the laboratory on three separate occasions. Both groups performed a high-intensity (HI) and a power resistance exercise session (POW) performed in separate days, in random order. In the UB group, acute effects on both upper and lower body performance were evaluated prior to and after an upper body exercise (bench press), while in the LB group, upper and lower body performance assessments were performed before and after a lower body resistance exercise (squat). During the first visit, participants were assessed for anthropometric measures, bench press and squat 1 repetition maximum (1-RM). Participants were also familiarized with the assessments for the upper and the lower body power included in the present investigation. Participants of both groups reported back to the laboratory at least 72 h following the first visit and performed the high-intensity (HI) or power (POW) exercise protocol. Assessments were conducted immediately prior (PRE) and 8 min post (POST) each exercise protocol. Participants of both groups were asked to avoid resistance training for 72 hours prior to each protocol. A washout period of at least 1 week was observed between the two protocols. In the HI protocol, participants were asked to perform 5 sets of 1 repetition with a load corresponding to the 90 % of the 1-RM at the bench press or at the parallel squat press in the UB or LB group, respectively. During both protocols, a recovery time of 3 min was observed between the sets. During the POW protocol participants performed 5 sets of 4 repetitions at the bench press throw (BPT) with the 30% of the bench press 1RM or 5 sets of 4 jumps on a 40 cm height box in UB and LB group, respectively. Participants were asked to perform each repetition with maximum explosive intent. All the exercise protocols and assessments were supervised by the same qualified investigators (i.e. Master's Degree in Sport Science). The estimated sample size was 11 to detect a between-trials difference of 25 W in the bench press throw with a power of 0.80.

2.2. Participants

Twenty-four resistance trained men volunteered to participate in this study. Participants were randomly assigned to one of the following groups: UB (mean ± *SD*: n = 12; age: 26.5 ± 3.4 years; body mass: 77.9 ± 6.9 kg; height: 176.7 ± 4.8 cm) or LB (n = 12; age: 27.2 ± 4.8 years; body mass: 76.6 ± 7.8 kg; height: 174.3 ± 5.9 cm). Inclusion criteria required participants to be between the ages of 18 and 35 years, a minimum of 2 years of resistance training experience (average: 4.7 ± 2.5 years), and the ability to bench press at least their body mass (average: 1.2 ± 0.3 kg/bw). Subjects were not permitted to use any dietary supplementation, and did not consume any androgens or other performance enhancing drugs. Screening for ergogenic substances and additional supplementation was accomplished with a questionnaire completed at the recruitment stage. Exclusion criteria included injuries which occurred in the year prior to the study. Participants missing one of the assessment sessions provided by the study design were excluded. The investigation was approved by the local university institutional review board. Testing procedures were fully explained to each subject before obtaining individual written informed consent.

2.3. Strength and Power Testing

Prior to 1-RM bench press testing, participants performed a standardized warm-up consisting of 5 min on a cycle ergometer against a light resistance, 10 body weight squats, 10 body weight walking lunges, 10 dynamic walking hamstring stretches, and 10 dynamic walking quadriceps stretches [16]. The 1-RM test for the barbell bench press and squat was performed using methods previously described by Hoffman [17]. Briefly, each participant performed 2 warm-up sets using a resistance of approximately 40–60% and 60–80% of his perceived maximum, respectively. For each exercise, 3-4 subsequent trials were performed to determine the 1-RM. A 35 min rest period was provided between each trial. Trials not meeting the range-of-motion criteria for each exercise or where technique was not appropriate, were discarded. Following the bench press 1RM, participants performed a squat 1RM test. Participants were asked to lower their body until upper thigh was parallel to the floor.

During all other visits the same standardized warm-up, as described above, was repeated. Prior to and following each protocol, participants were required to perform a bench press throw test (BPT) and a countermovement jump test (CMJ). The BPT test was performed using a Smith machine, as previously described by Bartolomei et al. [18] Participants laid down on a bench in supine position with the bar on their chest. They were instructed to push as explosively as possible until complete extension of the arms and to throw the bar as high as possible, through a ballistic, concentric-only contraction. Two spotters were placed at each side of the Smith machine to decelerate the bar during the descending phase. Participants pressed loads corresponding to 30 % of their 1RM. Two trials were performed with a recovery time of 3 min. During all repetitions, an optical encoder (Tendo Unit model V104, Tendo Sports Machines, Trencin, Slovak Republic) measured the mean power expressed by the participants. Intraclass coefficient for BPT was 0.97 (SEM: 16.8 W). The countermovement jump (CMJ) test was performed using photoelectric cells (Optojump, Microgate, Bolzano, Italy). Subjects were instructed to maximize the height of each jump while keeping the hands on their hips. Flight time was calculated as the time interval from toe off to landing. Peak power (CMJ power (CMJP), expressed in W) was calculated by the jump height and the subject's body mass using the following equation [19]: Peak power = 51.9 × jump height + 48.9 × body mass – 2007.

Subjects performed 2 jumps with a 2-minute rest between each jump. The intraclass coefficient calculated for the CMJP in the present study was 0.95 (SEM: 131.1 W).

2.4. Statistical Analysis

A Shapiro–Wilk test was used to test the normal distribution of the data. If the assumption of sphericity was violated, a Greenhouse–Geisser correction was applied. Data were analyzed using a two-factor (group × time) analysis of variances (ANOVA) with repeated measures to evaluate the differences between the acute effects of the conditioning protocols (UB and LB). In the event of a significant F ratio, dependent *t* tests with Bonferroni correction were used to determine pairwise differences. Where appropriate, percent changes were calculated as follows: ((post-exercise mean – pre-exercise mean)/pre-exercise mean) ×100. For effect size (ES), the partial eta-squared statistic was reported and according to Stevens [20], 0.01, 0.06, and 0.14 represents small, medium, and large effect sizes, respectively. In addition, Cohen's d was calculated for pre-post differences. All data are reported as mean ± SD and significance level was set for $p \leq 0.05$. Data were analyzed using SPSS version 23 (SPSS Inc. Chicago, IL, USA).

3. Results

The mean value (± SD) for the bench press 1-RM test was 100.5 ± 10.2 kg. All results for strength and power assessments are reported in Table 1. In addition, percentage changes in the UB and LB groups, following both the HI and POW protocols, are reported in Figure 1 and Figure 2, respectively. A significant group x time interaction was found for CMJP in the HI protocol (F = 7.625; $p = 0.012$; $\eta^2 = 0.266$). Post hoc tests revealed that CMJP was elevated (+1.6%) in the UB group only ($p = 0.025$). No significant group x time interactions were detected for CMJP in the POW protocol (F = 3.600; $p = 0.072$; $\eta^2 = 0.153$) and for BPT in both the HI (F = 1.320; $p = 0.718$; $\eta^2 = 0.006$) and the POW protocols (F = 1.571; $p = 0.225$; $\eta^2 = 0.073$).

Significant main effects of time were found in the POW protocol for CMJP (F = 5.500; $p = 0.029$; $\eta^2 = 0.216$) and for BPT (F = 12.206; $p = 0.002$; $\eta^2 = 0.379$). No significant main effects were noted in the HI trial for CMJP (F = 0.456; $p = 0.507$; $\eta^2 = 0.021$) and for BPT (F = 0.134; $p = 0.264$; $\eta^2 = 0.059$). Figure 3a and 3b shows the individual changes following the HI protocol in the UB and LB groups, respectively. As reported in Figure 3, eight of the twelve participants of UB group obtained an improvement in CMJP following the HI bench press protocol, while only two participants of LB group improved in the same assessment following the HI squat protocol. These Figures, together with Figures 1 and 2, shows the variability in the individual response following the HI protocol for the upper and the lower body.

Table 1. Results of the performance assessments performed pre and post the two resistance exercise protocols. UB = upper body; LB = lower body; BPT = bench press throw; CMJP = countermovement jump power; * indicates a significant difference between pre and post.

	Group	**UB**			**LB**		
Trial	Assessment	Pre	Post	Cohen's d	Pre	Post	Cohen's d
HI	BPT (W)	414.9 ± 54.8	411.3 ± 49.4	0.06	438.9 ± 53.0	441.4 ± 57.6	0.045
	CMJP (W)	3882.4 ± 433.2	3943.8 ± 445.6*	0.14	4007.8 ± 504.2	3983.0 ± 520.6	0.17
POW	BPT (W)	430.1 ± 55.9	424.5 ± 49.2	0.10	421.3 ± 59.4	425.9 ± 60.3	0.07
	CMJP (W)	3914.4 ± 389.9.6	3906.2 ± 404.4	1.27	4130.3 ± 491.4	4052.4 ± 437.2	0.18

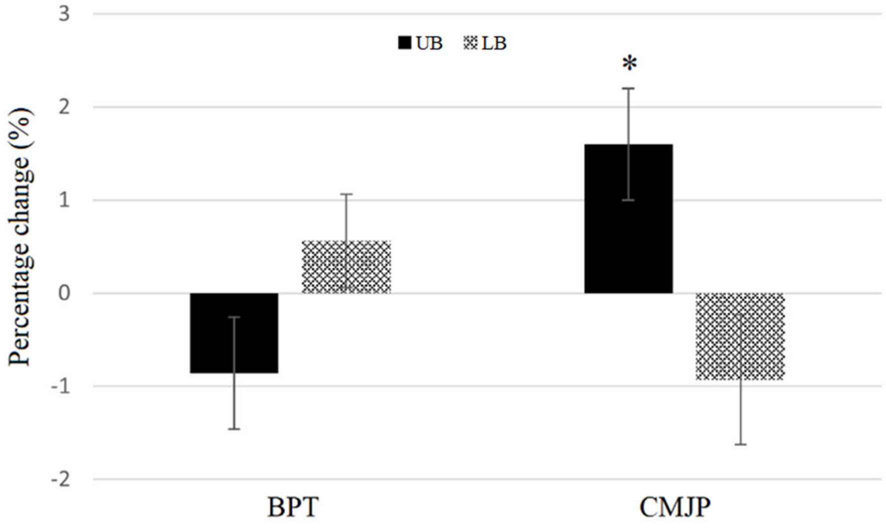

Figure 1. Percentage changes in power assessments (BPT = bench press throw power; CMJP = countermovement jump power) following the high-intensity protocol (HI) in both UB (upper body) and LB (lower body) group. * indicates a significant difference between the two groups ($p < 0.05$).

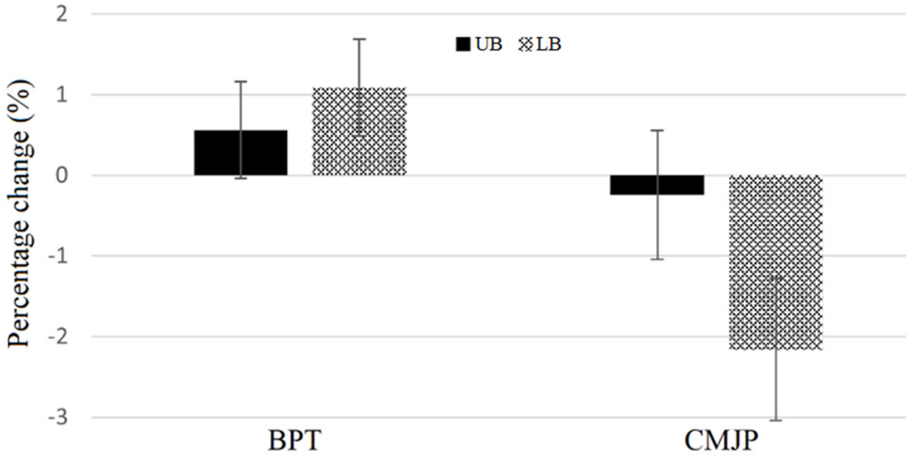

Figure 2. Percentage changes in power assessments (BPT = bench press throw power; CMJP = countermovement jump power) following the power protocol (POW) in both UB (upper body) and LB (lower body) group. * indicates a significant difference between the two groups ($p < 0.05$).

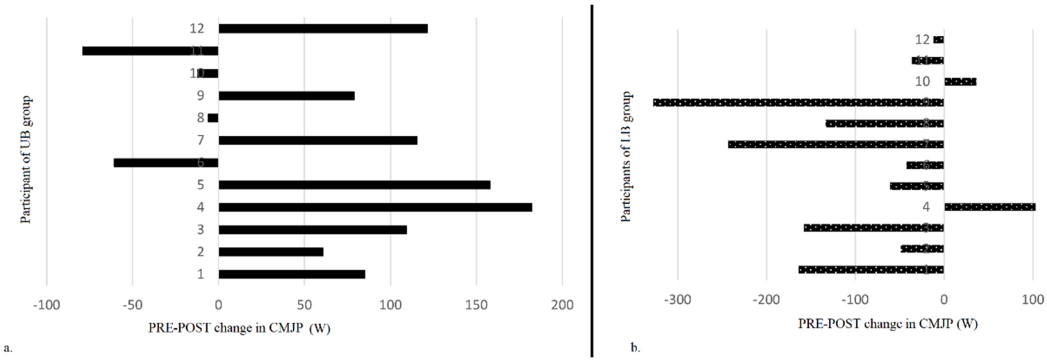

Figure 3. Individual changes in CMJP (in W) from prior to post the HI (high intensity) protocol in UB (upper body: a) and LB (lower body: b) group. Both groups were composed by 12 individuals. CMJP = countermovement jump power.

4. Discussion

The main aim of the present study was to compare the non-localized PAPE of a lower body vs. an upper body resistance exercise session. Results confirmed that a small but significant non-localized PAPE was activated by a high intensity-low volume resistance exercise protocol. However, our findings show that significant differences may exist when different muscle groups were involved. In particular, a non-localized PAPE was registered following the HI protocol in the UB group, while no improvements were detected in the LB group. Although different resistance exercises were performed in the two protocols (bench press and squat, respectively, in UB and LB), both HI protocols included the same number of repetitions, relative intensity and recovery time between sets. Our results also show that a big interindividual variability exists in the non-localized PAPE.

Previous investigations reported higher levels of perceived exertion and fatigue when the same exercise protocol was performed at squat compared to bench press [21]. Muscle fatigue is known to decrease the ability to completely activate the working muscle [22] and fatigue may also impair the performance of non-exercised muscles [23]. Furthermore, some muscles are more susceptible to non-local fatigue than other muscles [23]. In our study, central fatigue resulting from the HI squat protocol, consisting of 5 sets of 1 repetition at 90% of 1RM with 3 min of rest between sets, may have impaired the ability to fully activate upper body muscles in the subsequent BPT assessment. On the contrary, the potentiation effect resulting from the HI bench press protocol may have exceed the non-local fatigue caused by the same exercise, inducing an elevation in lower body power. Fatigue may be also the reason for the lack of localized-PAPE following the HI protocol in both UB and LB groups (e.g., Pectorals in UL and knee extensors and glutes in LB). Conversely, significant local effects on BPT and lower body power were previously reported following high intensity or power exercises in resistance trained men [24,25]. In most of these investigations however, participants performed only one set of a resistance exercise. In the present study, participants were asked to perform 5 sets of 1 rep of squat or bench press in LB and UB, respectively. As suggested by Krzysztofik and Wilk [26], the localized potentiation effect may be reduced following the second exercise set and multiple sets are known to produce fatigue without providing additional localized PAPE.

No significant localized and non-localized PAPE were detected following the POW protocols. Despite significant localized PAPE being registered following a single set of ballistic contractions, such as ballistic push-ups or bench press throw [25,27], concentric-only exercises, are known to be less effective than eccentric contractions for this purpose [28]. Localized PAPE has been attributed to increased phosphorylation of myosin regulatory light chains and to increased firing synchronicity of motor neurons [4]. Other mechanisms, such as elevation in plasma adrenaline and noradrenaline may also contribute to PAPE and produce a systemic effect on muscle performance [29]. Indeed, catecholamines are known to enhance force production in fast and slow muscle fibers [30,31]. A possible explanation for the lack of non-localized PAPE registered following the POW protocols, may be that fast concentric contractions are less effective than HI protocols including the eccentric phase, in inducing strong adrenergic responses. However, limitations of the present study are that plasma catecholamine concentration and perceived exertion were not measured. In addition, findings of the present study may not be generalizable to female participants since no women were assessed in this investigation.

In conclusion, the main finding of this study was that a small, non-localized PAPE may be obtained when a lower body power assessment is performed following an upper body HI resistance exercise. On the contrary, no positive acute effects were registered when a lower-body exercise was performed prior to an upper-body power assessment. Thus, the non-localized PAPE seems to be dependent by the exercise protocol and by the exercise performed.

Author Contributions: Conceptualization, S.B. and I.M.L.; methodology, M.C. and S.F.; investigation, S.B. and I.M.L.; writing—original draft preparation, S.B. and S.F.; writing—review and editing, I.M.L.; M.C. and S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the University of Bologna (protocol code 46865, 2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest

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