May a Nonlocalized Postactivation Performance Enhancement Exist Between the Upper and Lower Body in Trained Men?

Published Version:
Bartolomei, S., De Luca, R., Marcora, S.M. (2023). May a Nonlocalized Postactivation Performance Enhancement Exist Between the Upper and Lower Body in Trained Men?. JOURNAL OF STRENGTH AND CONDITIONING RESEARCH, 37(1), 68-73 [10.1519/JSC.0000000000004243].

Availability:
This version is available at: https://hdl.handle.net/11585/900945 since: 2024-04-10

Published:
DOI: http://doi.org/10.1519/JSC.0000000000004243

Journal of Strength and Conditioning Research

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--Manuscript Draft--

Manuscript Number:	JSCR-08-17622R2
Full Title:	May a non-localized post activation performance enhancement exist between the upper and the lower body in trained men?
Short Title:	Non-localized PAPE between upper and lower body
Article Type:	Original Research
Keywords:	resistance exercise; Power; cross-education; bench press
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Manuscript Region of Origin:	ITALY
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May a non-localized post activation performance enhancement exist between the upper and the lower body in trained men?

Abstract

The aim of this study was to establish if a resistance exercise for the upper body may generate a post activation performance enhancement (PAPE) in the lower body.

Thirteen resistance-trained men (age=26.4±3.3 years; body mass=76.9±6.3 kg; height=177.6±5.2 cm) participated in the present investigation and were tested for upper and lower body power [bench press throw (BPT) and countermovement jump power (CMJP) tests]. Participants were also tested for maximum force and electromyographic activation (EMG) of quadriceps muscles while performing an isometric leg extension. All assessments were performed pre and 8-min following a high intensity (HI: 5 sets of 1 rep at 90% of 1RM) bench press protocol, a high power protocol (POW: 5 sets of 1 rep at 30% of 1RM with maximum explosive intent) and a control trial (CON). Participants performed all trials in randomized order and on different days.

A significant trial x time interaction was detected for CMJP (*p*=0.049). This parameter was significantly increased following the HI protocol only (*p*=0.024). A significant interaction was also noted for EMG with a significant improvement following the HI protocol (*p*=0.032) and a significant decrese following the POW protocol (*p*=0.020). No other significant effects were detected (*p*>0.05). Results of this investigation indicate that a HI bench press protocol may produce a PAPE in the lower body power and increase the neuromuscular activation of leg extensor muscles. The POW bench press protocol did not show any positive effects on lower body performance. Athletes and practitioners may take advantage from the inclusion of upper body HI resistance exercises throughout complex resistance workouts to improve lower body power output.

Keywords: resistance exercise, power, cross-education, bench press

Introduction

Post activation potentiation (PAP) has been traditionally defined as an increase in the isometric force produced during a twitch contraction after a conditioning contraction (28). More recently, the possibility that acute performance improvements can be achieved following voluntary conditioning contractions, without confirmatory evidence of PAP, has been defined post activation performance enhancement (PAPE) (10). Several studies to date report acute enhancements of both upper (5, 36) and lower body performance (20) following resistance exercise in trained individuals. Localized PAPE have been associated to changes in the phosphorylation of the myosin regulatory light chains that increase calcium sensitivity at the actomyosin complex level in the working muscles (10). Traditional high intensity resistance exercises have been associated with greater PAPE compared to both isometric or pure concentric contractions (32, 37). Moreover, acute performance enhancements in sprint and vertical jump were obtained following ballistic contractions such as weighted jumps (11) and plyometric exercises (15), respectively. Despite the fact that a fewer number of studies have been conducted on the upper body (24), some authors speculated that different strategies should be used compared to the lower-body (23). In addition, many factors such as the participants resistance training experience and athlete strength levels, may influence the acute potentiation effect following a conditioning intervention. Greater PAPE indeed have been detected in strong resistance trained individuals (32) and in strength and power athletes with more than 3 years of experience (37), compared to weaker and less experienced individuals (18).

Contrary to localized PAPE, little is known about the possibility to obtain a non-localized PAPE on muscles that were not involved in the resistance exercise protocol. Despite several studies demonstrating that a cross-education may be produced by unilateral resistance training (3), Andrews et al. (4) reported that a single leg squat protocol, performed with the dominant leg, did not elicit any improvement in the power performance of the contralateral leg. To the best of our knowledge, only Cuenca-Fernández et al. (17) have investigated the existence of a non-localized PAPE between the upper and the lower body. No significant effects were reported by these authors. Such non-localized PAPE however, may occur because of the systemic effect of exercise-induced elevation in plasma concentration of epinephrine and norepinephrine (13).

Thus, the aim of the present study was to compare the acute effects of different resistance exercise protocols for the upper body on the lower body performance and electromyographic activation in resistance trained individuals. Another aim of the present investigation was to investigate the possible relationships between non-localized PAPE with the participants strength and power performance and muscle thickness of upper and lower body muscles. The authors hypothesized that a non-localized PAPE may occur in the lower body muscles following a high intensity resistance exercise protocol for the upper body, and the effect may be correlated with the individuals muscle size and maximal strength.

Methods

Experimental approach to the problem

The experimental protocol consisted of a counterbalanced cross-over research design. Participants were requested to report to the laboratory on four separate occasions. During the first visit, they were assessed for anthropometric measures, muscle thickness and bench press 1 repetition maximum (1-RM). Participants were also familiarized with the strength and power assessments for the upper and the lower body included in the present investigation. They reported back to the laboratory at least 72 h following the first visit and were randomized into the high intensity (HI), power (POW) or control (CON) exercise protocol using a random number generator. Assessments of strength and power performances were conducted immediately prior (PRE) and 8-min following (POST) each exercise protocol. Some authors indeed (10, 37) suggested that the peak performance enhancement may occur 6-10 min following the resistance exercise. Post-tests started 8 min following the last rep of HI or POW protocol and ended 18 min following the conditioning protocol (see Figure 1). Participants performed each protocol, following at least 1 week of washout between them. During HI, participants were asked to perform 5 sets of 1 repetition of the bench press with a load corresponding to the 90% of the 1-RM and observing a recovery time between sets of 3 min. The same HI protocol, with a rest time of 2 min between sets, has been previously adopted by Chiu et al. (16). During the POW protocol participants performed 5 sets of 1 repetition at the bench press throw (BPT) at 30% of the 1-RM, using a smith machine. The same load has been previously used at the bench press throw by West et al. (36), promoting acute power responses in rugby players. In the present study however, the authors
During the CON protocol, participants were asked to stand
quietly for 15 minutes, equal to the time required to perform the HI and POW protocols, and were tested 8 min post. All the exercise protocols and assessments were supervised by the same qualified investigators. 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 (29).

[Place Figure 1 here]

Participants

Thirteen experienced, resistance-trained men (mean±SD; age: 26.4±3.3 years; body mass: 76.9±6.3 kg; height: 177.6±5.2 cm) volunteered to participate in this study. Inclusion criteria required participants to be between the ages of 18 and 35 years, a minimum of 2 years of resistance training experience (average: 5.3±3.5), and the ability to bench press at least their body mass (average: 1.3±0.2 kg/bw). Subject were not permitted to use any additional dietary supplementation, and did not consume any androgens or other performance enhancing drugs. Screening for performance enhancing drug use and additional supplementation was accomplished with a questionnaire completed at the recruitment stage. Exclusion criteria included injuries occurred in the year prior to the study. The investigation was approved by the University of Bologna review board (Protocol 46864). Testing procedures were fully explained to each subject before obtaining individual written informed consent.

Strength and power testing

Prior to 1-RM bench press testing, participants performed a standardized warm-up consisting of five 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 (7). The 1-RM test for the barbell bench press was performed using methods previously described by Hoffman (22). Briefly, each participant performed two 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 3-5 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. 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), a countermovement jump test (CMJ) and an isometric leg extension maximum force test (LEF). The BPT test was performed using a smith machine as previously described by Bartolomei et al. (7). 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. 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 2 min. During all repetitions, an optical encoder (Tendo Unit model V104, Tendo Sports Machines, Trencin, Slovak Republic) measured the mean power (BPT) expressed by the participants. Intraclass coefficient for BPT was 0.96 (SEM: 17.5 w). The countermovement jump (CMJ) test was performed using photoelectric cells (Optojump, Microgate, Bolzano, Italy). Subject 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 (31): Peak Power=60.7 x jump height + 45.3 x body mass – 2055.

Subjects performed 2 jumps with a 2-minute rest between each jump. The intraclass coefficient calculated for the CMJP in the present study was 0.96 (SEM: 122.0 W). An isometric leg extension (LEF) assessment was performed using a custom-built instrumented leg extension machine (30), following the CMJ test. Participants were firmly secured with adjustable straps to the leg extension machine with hip and knee joint angles of 90° (full extension = 180°). Joint angles were measured using a goniometer while the participant was seated and stabilized to the device, with the right leg attached to the lever arm. A strength gauge (Ergo Tester, Globus Inc., Codognè, Italy) was attached to the end of the lever arm and perpendicular to it. The lever arm was attached to the leg at the 15% of tibial length above the medial malleolus. All the isometric assessments were performed using the same setting and position. Participants were asked to press against the lever arm as hard as possible for 5 s. Each participant performed two LEF and a recovery time of 2 min was observed between the attempts. For LEF, peak force was measured and peak rate of force development (LEpRFD) was calculated using a 20-ms window as suggested by Haff et al. (21). Intraclass coefficients for LEF were 0.98 (SEM: 86.5 N) and 0.62 (SEM = 970.3 N s^{-1}) for peak force and pRFD, respectively.

Ultrasound Measurements

Noninvasive skeletal muscle ultrasound images were collected from the participant's right side. Before image collection, all anatomical locations of interest were identified using standardized landmarks for the pectoralis major muscle (PEC) and for the vastus lateralis muscle (VL). PEC muscle thickness (PEC MT) was measured at the site between the third and fourth costa under the clavicle midpoint (2). The VL MT was measured along its longitudinal distance at 50% from the proximal insertion of the muscle. The length of the VL encompassed the distance from the lateral condyle of the tibia to the most prominent point of the greater trochanter of the femur. Measurements were performed while the participant stood in supine decubitus and in lateral decubitus, for PEC and TR measurements, respectively. The participants were asked to lie on the examination table for a minimum of 15 minutes before images were collected. The same investigator performed all landmark measurements for each participant. A 12-MHz linear probe scanning head (Mindray MD20, Mindray Bio-Medical Electronics Co., Ltd., Shenzen, China) was coated with water-soluble transmission gel to optimize spatial resolution and used to collect all ultrasound images. The probe was positioned on the surface of the skin without depressing the dermal layer (gain = 50 dB; image depth = 5 cm). During the measurements, participants were asked to relax their muscles and maintain the supine or the left lateral decubitus position with a 10° bend angle in the knees (9). All ultrasound images were taken and analyzed by the same expert technician. Muscle thickness (MT) measures were obtained using a longitudinal B-mode image. Three consecutive MT images were captured and analyzed for each muscle. For each image, MT was measured with a single perpendicular line from the superficial aponeurosis to the deep aponeurosis. The average of the 3 MT measures was used for statistical analyses. Intraclass correlation coefficients were 0.95 (SEM = 0.95 mm) and 0.96 (SEM = 0.63 mm) for PECMT and VLMT, respectively.

Electromyographic measurements

Electromyographic data were acquired by a Free-EMG 1000 (BTS Bioengineering Inc., Italy) and signals were recorded at a sampling rate of 1000 Hz. We used surface electromyography (EMG) to acquire the electromyographic activity of the vastus medialis and vastus lateralis muscle during the isometric leg extension assessment. To improve the contact, the skin of each subject was shaved and abraded in accordance with International Society of Electrophysiology and Kinesiology and the Surface Electromyography for the Non-Invasive Assessment of Muscles (33). Then the Ag/AgCl disposable electrodes 32 × 32 mm with an active area of 0.8 cm^2 and an inter-electrode distance of about 2 cm (RAM apparecchi medicali s.r.l. Genova, Italy) were placed using in a bipolar configuration. Electrodes were positioned on the belly of each muscle, in the right side of the body. To optimize the ability to detect the target muscle's signal the surface electrodes were placed parallel to the direction of the fibers of the vastus medialis VM and vastus lateralis (VL) muscle.

Statistical analyses were performed on single muscle and trial with highest values of force (LEF) were considered for EMG calculation. The first part of the analysis consisted in the signal positive rectification and band-pass filtering (Butterworth, 20–450 Hz) using SMART analyzer (BTS Bioengineering Inc.). Average EMG amplitude (mV) of the linear envelope was then determined for each attempt and used for further analysis. The average amplitude during the last 4 sec of the isometric contraction was calculated and used for further analysis.

Statistical Analyses

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 (trial × time) analysis of variance (ANOVA) with repeated measures to evaluate the differences between the acute effects of the resistance exercise protocols (HI, POW, and CON). In the event of a significant F ratio, dependent *t* tests with Bonferroni correction were used to determine pairwise differences. Pearson product–moment correlations were used to examine selected bivariate relationships. Where appropriate, percent changes were calculated as follows: [(post-exercise mean

– pre-exercise mean)/pre-exercise mean] ×100. For effect size, the partial eta-squared statistic was reported and according to Stevens (34), 0.01, 0.06, and 0.14 represents small, medium, and large effect sizes, respectively. All data were analyzed using SPSS 20 for Windows (SPSS Inc., Chicago, IL) and are reported in the text as mean±SD. Significance level was set for $p \leq 0.05$.

Results

Strength and Power Assessments

The mean value (± SD) for the bench press 1-RM test was 99.5 ± 10.5 kg. All results for strength and power assessments and percentage changes following HI, POW and CON trials are reported in Table 1 and Figure 2, respectively. A significant trial x time interaction was found for CMJP (F = 3.570; p = 0.049; η^2 = 0.245). Post-hoc tests revealed that CMJP was elevated following the HI protocol only (p=0.024). No significant trial x time interactions were detected for LEF (F = 1.584; p = 0.229; η^2 = 0.126), LEpRFD (F = 0.032; p = 0.964; η^2 = 0.003), BPT (F = 0.009; p = 0.994; η^2 = 0.001).

No significant main effects of time were found for CMJP (F = 0.032; p = 0.964; η^2 = 0.003), LEF (F = 0.032; p = 0.964; η^2 = 0.003), LEpRFD (F = 0.032; p = 0.964; η^2 = 0.003) and BPT (F = 0.032; p = 0.964; η^2 = 0.003).

[Place Figure 2 here]

Electromyographic measurements

Results for electromyographic measures and percentage changes form baseline are reported in Table 1 and Figure 3, respectively. A significant trial × time interaction was found for VM EMG (F = 8.759; p = 0.003; η^2 = 0.220). This parameter was significantly increased (+ 4.4 %; p = 0.032) following the HI protocol and significantly decreased (−8.2%; p = 0.020) following the POW protocol. No significant trial × time interactions were detected for VL EMG (F = 2.333; p = 0.148; η^2 = 0.189). No significant main effects of time were detected for VM EMG (F = 2.828; p = 0.124; η^2 = 0.220), and for VL EMG (F = 3.665; p = 0.085; η^2 = 0.268).

[Place Table 1 and Figure 3 here]

Correlations between variables

No significant correlations were detected between the increase in CMJP following the HI protocol (ΔCMJP) and bench press 1RM (r = −0.24; p = 0.442), BPT (r = −0.22; p = 0.496), LEF (r = 0.25; p = 0.423). In addition, no significant correlations were found between ΔCMJP and both VLMT (r = 0.38; p = 0.271) and PECMT (r = 0.412; p = 0.237).

Discussion

The aim of this study was to compare the non-localized acute effects of two different upper body resistance exercise protocols (High intensity: HI; power: POW) and a control trial (CON) on the lower body strength and power performance and EMG activation in resistance trained individuals. The main finding of the present investigation is that a post activation performance enhancement (PAPE) was obtained in the lower body following a HI resistance exercise protocol for the upper body. In particular, acute performance enhancements were registered in CMJP, 8-min following a bench press protocol consisting of 5 sets of 1 repetition at 90% of 1RM.

This non-localized PAPE induced by HI resistance exercises may be explained by greater elevations in circulating catecholamines compared to resistance exercises performed at lower intensities (12, 27). Increased levels of catecolamines are known to enhance force production in both fast and slow muscle fibers (14). Moreover, HI resistance exercises may exert a positive effect on neuromuscular function during maximal voluntary contractions via psychological mechanisms such as increased arousal condition and activation (6). In the present study, a rise in neural drive after the HI protocol is suggested by the significant enhancement of EMG activation of the vastus medialis (VM EMG) registered following this conditioning protocol. However, no significant improvements were noted in the vastus lateralis (VL EMG) and in maximum isometric force registered at leg extension (LEF) following the HI protocol. Conversely, a significant decrease in VM EMG and no changes in any lower body strength and power assessments were detected following the POW protocol. Thus, the POW protocol may be less effective than the HI protocol in inducing non-localized PAPE. A study by Cuenca-Fernandez and colleagues (17) reported an acute improvement in squat jump following both a bench press exercise session and a bench press and squat workout in male and female swimmers. A similar improvement however, was registered following the control protocol and the acute effect was lower following the bench press protocol compared to the bench press and squat protocol. The authors speculated that bench press may be detrimental for squat jump performance and that the small PAPE registered, may be due to the specific warm-up performed before the assessments (17). In addition, the maximum strength level of the swimmers participating in this study was lower (0.91 kg/bw for bench press) (17) compared to the resistance trained individuals participating in the present investigation (1.3 kg/bw).

Strong individuals are known to benefit more from localized PAPE following heavy resistance exercise compared to less experienced (38) or weaker individuals (19). Strong individuals and strength and power athletes indeed, recover from peripheral fatigue more quickly and benefit more from a greater phosphorylation of myosin light chain, as a result of a greater percentage of fast fibers compared to weaker individuals (1). As previously reported by Chiu et al. (16), recreationally trained individuals exhibited a decline in vertical jump performance 5 min post a squat protocol consisting of 5 sets of 1 rep at 90% of 1RM, while the same conditioning intervention led to a 1-3% improvement in jump performance in competitive athletes. Participants in the present study were resistance trained men recruited from the university weight-training classes and were not strength and power athletes. Our findings however, did not show any significant correlations between the non-localized power enhancement detected on CMJP and the individuals maximum strength, or muscle thickness. Maximum strength and muscle mass of the participant may be less important for non-localized PAPE, compared to localized PAPE, since faster recovery of peripheral muscle fatigue is not relevant to performance-enhancement in muscle groups that have not been involved in previous exercise.

Both HI and POW protocols did not result in any acute performance changes in the upper body muscles that were involved in the exercise performed. Conversely, significant improvements in bench press throw were reported following high intensity or power exercises in resistance trained men (35, 36). Although significant acute performance improvements have been attributed to ballistic contractions such as ballistic push-ups or bench press throw (35, 36), concentric-only exercises, were considered less effective than eccentric contractions in acute power development (25).

A recent literature review (26), showed that only small acute effects on bench press throw power can be obtained following high intensity resistance training protocols (32) and even smaller effects following ballistic-plyometric exercises. In addition, multiple sets are known to produce relevant fatigue without providing additional benefits on localized PAPE compared to a single set (16). This is consistent with Krzysztofik and colleagues (24), who reported a significant acute bench press power enhancement following the first set of ballistic push-ups, while no improvements were registered following the second and the third sets of the same exercise. Thus, the HI bench press protocol may have produced peripheral fatigue of the upper body muscles while inducing a non-localized PAPE on the lower body through the enhancement of central neural drive via hormonal and/or psychological mechanisms.

Countermovement jump test has been shown to be more sensitive to fatigue and muscle damage in the recovery phase following resistance exercise, compared to isometric assessments such as isometric squat or isometric leg extension (8). The present study indicated that CMJ may be more appropriate than isometric leg extension to detect a non-localized PAPE. In addition, this effect may be more pronounced when power multi-joint exercises, including a stretch-shortening cycle, are performed following a HI exercise protocol compared to isometric tests.

A limitation of the present study is that peripheral muscle fatigue and effort were not measured pre and post the different resistance exercise protocols. The degree of peripheral muscle fatigue following both resistance exercise protocols, could give relevant information to better understand the lack of localized PAPE registered in the present study. Another possible limitation may be that muscle temperature was not measured during the three trials. Changes in this parameter indeed, may influence PAPE (10).

Practical Applications

Findings of the present investigation showed that a non-localized PAPE may occur when a upper body-high intensity resistance exercise is performed prior to a lower body power assessment. These results may open a new perspective for the prescription of complex training programs to improve performance. A "complex-cross" workout may alternate a high intensity resistance exercise performed with the upper body muscles with a power exercise for the lower body (e.g. bench press and countermovement jump) in order to take advantage of the first exercise on the latter. In addition, non-localized PAPE may induce acute performance improvements without the local neuromuscular fatigue that may be present when biomechanically similar exercises are paired. This finding may be also useful for coaches in the optimization of the warm-up prior to competitions or workouts. In this phase, the inclusion of a high intensity resistance exercise not involving sport-specific muscles, may result in an elevation of performance, without the negative effects of local fatigue.

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Figure captions:

Figure 1. Timeline of the post-tests performed 8 min following the intervention. BPT=bench press throw; CMJ= countermovement jump; LEF=leg extension force.

Figure 2. Percentage changes in strength and power assessments (BPT=bench press throw power; CMJP=countermovement jump power; LEF=isometric leg extension force; LEpRFD=isometric leg extension peak rate of force development) following the high intensity (HI), power (POW) and control (CO) protocols. * indicates a significant difference ($p<0.05$) from baseline.

Figure 3. Percentage changes in electromyographic activation of vastus medialis (VM EMG) and vastus lateralis (VL EMG) following the high intensity (HI), power (POW) and control (CON) protocols. * indicates a significant difference ($p<0.05$) from baseline.

Table 1. Results of the performance and electromyographic assessments. BPT=bench press throw; CMJP=countermovement jump power; LEF=leg extension force; LEpRFD=leg extension peak rate of force development; VM=vastus medialis; VL=vastus lateralis. *indicates a significant difference between Pre and Post.

Protocol / Assessment	HI		POW		CON	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
BPT (w)	415.9±54.8	411.2±49.4	406.8±41.4	401.5±39.6	416.7±50.4	411.5±44.3
CMJP (w)	3918.0±443.1	3980.7±237.3*	3955.4±393.1	3945.8±406.8	3947.8±439.0	3936.7±437.2
LEF (N)	430.1±55.9	424.5±49.2	421.3±59.4	425.9±60.3	414.6±58.5	405.1±54.8
LEpRFD (N/sec^{-1})	3336.3±853.1	3497.7±844.4	3176.9±930.8	3244.3±802.3	3105.4±1056.0	3177.8±835.9
VM EMG (mV)	381.1±119.1	397.8±113.7*	393.7±102.0	361.4±100.6*	377.3±120.7	364.6±116.9
VL EMG (mV)	325.4±122.4	308.9±120.4	306.4±93.4	294.1±89.6	309.9±130.6	307.8±126.1

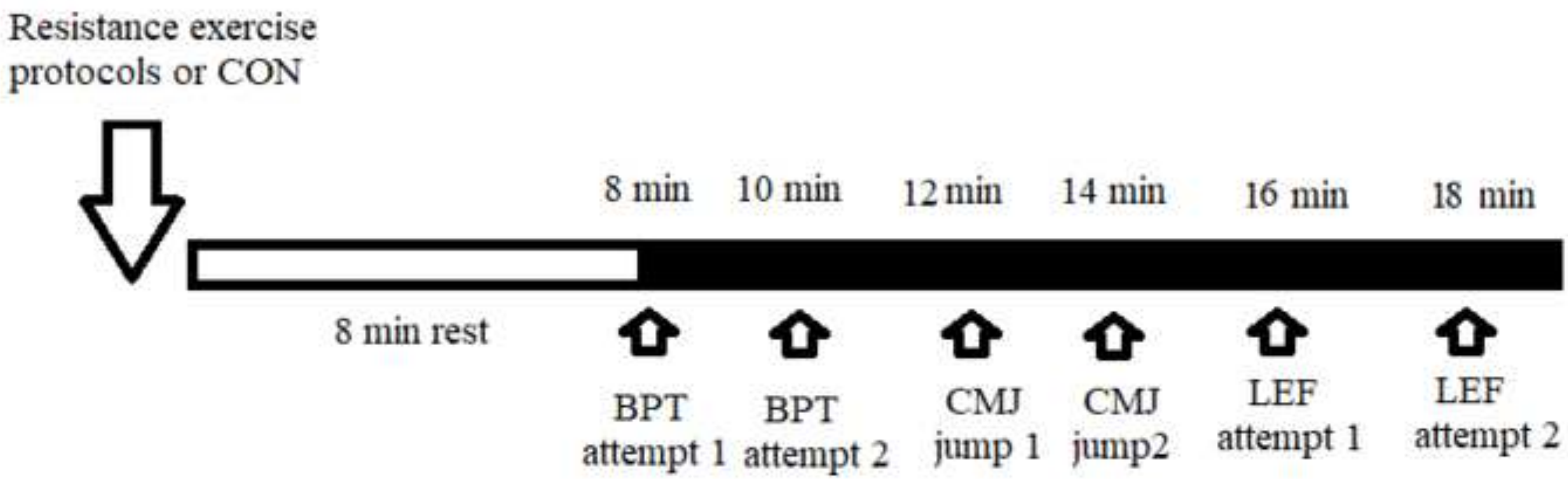
Resistance exercise protocols or CON
8 min
10 min
12 min
14 min
16 min
18 min
8 min rest
BPT attempt 1
BPT attempt 2
CMJ jump 1
CMJ jump2
LEF attempt 1
LEF attempt 2

Figure2

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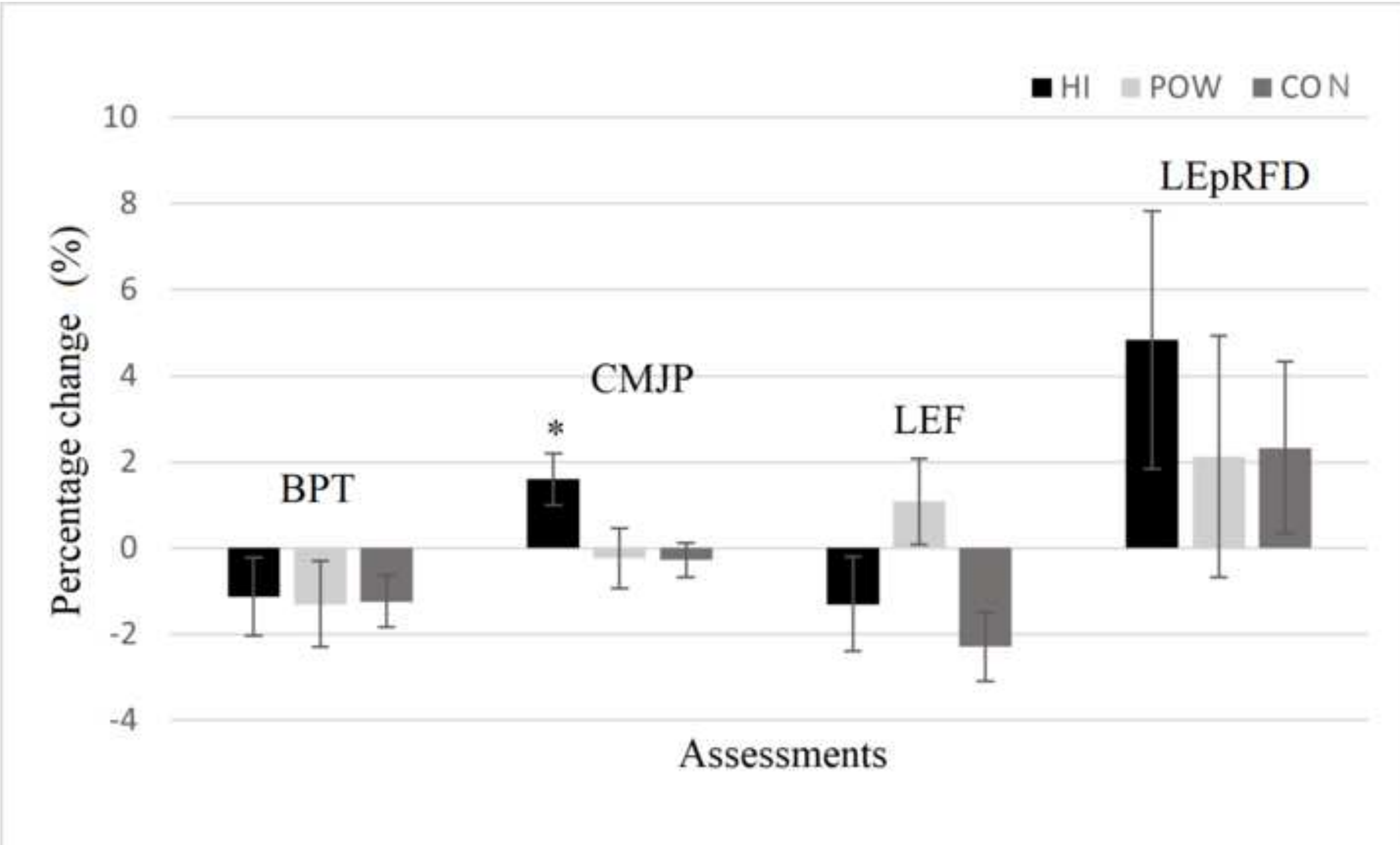

Figure3

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