Antagonist activation exercises elicit higher post-activation performance enhancement than agonist activities on throwing performance

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Research article

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Abstract

**Background:** This study aimed to determine the acute effect of agonist and antagonist conditioning activities (CA) on medicine ball throw performance among female softball players.

**Methods:** Thirteen national level female softball players (age 22.2 ± 3.1 years; body mass 68.3 ± 11.3 kg; softball experience 7.3 ± 2.4 years) performed 3 medicine ball chest throws before CA and after CA respectively in 3rd, 6th, and 9th minute. CA was the bench press (BP) and bent-over barbell row with 2 sets of 4 repetitions at 60% and 80% of one-repetition maximum, and 2 sets 4 repetition bodyweight push up.

**Results:** Two-way ANOVA revealed an increase in throwing distance (p < 0.001) after bent over barbell row exercise and in throwing speed (m/s) (p < 0.001) after BP and bent over barbell row. The throwing distance was highest after bent over barbell row (Cohen's d 0.41). Although the BP had the highest effect (Cohen's d 0.41) to increase the throwing speed, its effect on throwing distance was not significant.

**Conclusions:** We conclude that upper body throwing performance is higher after antagonist exercise than agonist CA and both agonist and antagonist CA increases power. In the resistance training practice, we recommend the interchange of agonist and antagonist PAPE stimulation at push-up bodyweight or BP and bent over raw submaximal (80% of 1 RM) intensity to succeed PAPE on upper limbs.

1. **Background**

Besides anthropometric characteristics and throwing technique, explosive strength is crucial for throwing in overhead athletes. Upper body explosiveness is an essential ability also in softball, where throwing performance is highly influenced by the rate of power development [1]. Therefore, the softball players and other overhead athletes are using advanced training methods like post-activation performance enhancement (PAPE) in long-term training programs. PAPE is an efficient method for an acute increase in explosive strength [2-6], which requires a precise selection of conditioning activity (CA) [7,8]. Although PAPE is based on post-activation potential which increases the sensitivity of actomyosin filaments to Ca$^{2+}$, enhances recruitment of higher-order motor units, and changes in pennation angle [9,10], the exercise selection is one of the key factors to modulate the magnitude of PAPE [11].

It has been clearly shown that stronger individuals manage to reach greater post-activation responses and express it earlier than weaker counterparts [12]. However, to evoke the PAPE phenomenon, there needs to be a maintained balance between fatigue and potentiation, where the fatigue-potentiation response depends highly on activation exercise selection, load, and volume [10]. In resistance training methods it has been shown that exercise fatigue can be reduced by antagonist training, which increases exercise volume and intensity with concurrent shortening of rest intervals between two exercises [13,14]. The intermuscular agonist and antagonist coordination are one of the elementary adaptations to resistance training which increases strength and torque [15]. This is achieved by the neural strategy of enhanced reciprocal inhibition of antagonist musculature [16], where varied resistance and concentric antagonist speed of contractions affect subsequent concentric agonist effort. For instance, if contraction of the flexor muscle stimulates Golgi tendon organs that depolarize the Ib axon and fire nerve impulses that are disseminated to the spinal cord. This subsequently leads to a reduction of the flexor muscles tension associated with the extensor muscle spindles depolarization, thus leading to a more efficient contraction of the extensor [17]. This neural reciprocal effect may be the reason, why antagonist training can cumulate exercise volume or intensity and might be a potential aggregator of successful PAPE.

Most of the current literature, including ballistic movements for improving upper body explosive power, has focused on male athletes [2,5,18,19]. Only a few existing studies are focusing on its effect on female professionals [20-22]. It has been shown that 86% of women handball players are PAPE responders in throwing velocity to variable resistance intra-repetition method, and 93% of them positively respond to isometric CA [6]. In the exercise selection studies, the bench press (BP) CA increased throw distance in women's shot put [20], and maximal rowing exercise increased rowing speed[23] with the same PAPE effect.
for males and females rowers. Thus, the agonist PAPE has been shown in women athletes while the antagonist CA effect remains unknown.

The effect of antagonist muscle loading might be beneficial for the PAPE effect, which requires high motor unit pre-activation with low exhaustion of prime movers for performing an exercise. To our knowledge, there is limiting research on PAPE exercise selection in professional female athletes, and antagonist muscle activation effect, which has high practical use potential. Therefore, the study aimed to determine the acute effect of agonist and antagonist CA on medicine ball throws performance among female softball players. We hypothesize that antagonist CA should have a higher potentiation effect on power performance than agonists exercises.

2. Methods

Experimental Approach to the Problem

A randomized crossover and counterbalanced design were used to compare the effect of bent over barbell row as antagonist CA against agonist bench press and push-up CA on ball throwing distance. Before launching 3 of the main experiment trials, subjects participated in 10 weeks of resistance training program to be familiarized with testing protocols, improve chosen exercises’ techniques, and increase strength. Moreover, during the last week of familiarisation, subjects performed 3 medicine ball throws (as used during the experiment) after each training visit to familiarize themselves with the throwing technique.

There were three experimental sessions 48 hours apart, where CA was included in randomized order for individuals (Figure 1). After standardized warm-up subjects completed 3 experimental trials involving a baseline ball throwing with a 2kg medicine ball followed by a CA. The push-up CA was performed in 2 sets of 4 repetitions with 3 minutes of rest between sets. Plyometric and isometric push-up exercises used as CA significantly improved shot put performance among female throwers [24], to adapt this exercise to the strength of the subjects it has been decided to perform push-ups as described below. The bent-over barbell row (ROW) and bench press (BP) was performed in 2 sets of 4 repetitions with respectively 60% and 80% one-repetition maximum (1RM) with 3 minutes rest between sets[25]. This intensity was chosen because both stronger and weaker individuals respond to CA better when stimuli are higher. Retesting of ball throwing was measured 3 times in total respectively after 3, 6, and 9 minutes. The load of 80% 1RM was chosen because it is enough to awake PAPE reaction with decreasing possible fatigue harmful effects on results [1]. Recovery time was based on prior studies which show that gender and strength level influence rest time [6,11,26].

Subjects

Power calculations indicated determined the minimum sample size of 12 participants would be required to detect an effect size of 0.4, collected from the average effect size reported in the Wilson metanalysis [27] (repeated measures, within-between interactions ANOVA power = 0.8, alpha = 0.05, correlation among rep measures = 0.8, number of groups = 3, number of measurements = 2; G*Power 3.1.9.4). Thirteen (n = 13) professional Czech softball players from National Team and 1st division Clubs volunteered in study (mean ± SD: age 22.2 ± 3.1 years; height 169 ± 4.5 cm; body mass (BM) 68.3 ± 11.3 kg; bench press 1RM 40.5 ± 6.8 kg; BP 1RM/BM 0.6 ± 0.1; bent over barbell row 1RM 39.5 ± 6.7 kg; ROW 1RM/BM 0.7 ± 0.1; softball experience 7.3 ± 2.4 years). Subjects were recruited on the basis that they were healthy, injury-free, and engaged in a resistance-training program for the last 10 weeks. They were able to perform bent-over barbell row and bench press with proper technique as assessed by certified strength and conditioning coach.

Experimental Procedures

Experimental trials were separated by 48 hours from each other (Figure 1). Moreover, subjects were instructed to avoid upper body workouts during the time of measurements. In the beginning, participants started with a standardized warm-up protocol
consisting of 5 minutes of running on a treadmill with a constant speed of 6 km/h followed by dynamic stretching with an emphasis on stretching the chest musculature. Two minutes after warm-up, subjects performed ball throw as pre-measurement, and 3 minutes after pre-measurements, participants in a randomized order completed CA of either bent over barbell row, bench press, or push-up. After PAP activation subjects rested for 3 minutes before starting POST measurements.

**Conditioning exercises and one-repetition maximum measurements**

**1 RM measurements**

1RM of bench press and bent over barbell row was measured at the end of 10 weeks of resistance training familiarisation. Before measuring 1RM, all participants underwent a standardized warm-up consisting of 5 minutes of running on a treadmill with a constant speed of 6 km/h followed by dynamic stretching with an emphasis on stretching the chest musculature. All subjects started the exercise with 8 repetitions at 50% 1RM measured during the preparatory 10 weeks resistance training period. Then subjects performed 4 repetitions at 70% 1RM and 3 repetitions at 80% 1RM, respectively. After the final warm-up, subjects began lifting 1RM with maintaining proper technique and a full range of motion with the weight starting from 5kg added to the previous 1RM. If an attempt was successful, 2.5kg were added with rest intervals between each attempt for 3 minutes until proper 1RM was reached. Bent over barbell row 1RM was measured using the same warm-up and measurement protocol as during bench press.

**Bench press technique**

During a bench press, subjects were instructed to lay prone on the bench with the leg resting on the floor where the knee was positioned at a 90° angle. The grip was pronated with hands spaced in the distance between each other of 1.5 widths of the shoulder. Subjects were required to control the bar's descent until the chest was touched approximately 3cm above to xiphoid process and, without pause, push it. The cadence of the move was 2 seconds down and voluntary tempo up in the concentric phase controlled by the coach.

**Bent over barbell row technique**

The bent-over barbell row position required the head to lean on a bench with high adjusted to each person to maintain 90 degrees of flexion in the hip with knees slightly bent (Figure 2). Participants were instructed to pull the bar at the height of the bottom of the sternum. The grip position was the width of the shoulders. The cadence of the move was 1 second up and 2 seconds down.

**Push up technique**

The push-up (PU) exercise was performed with wide hands positioned on the floor. It was completed from a plank position with the body remaining straight from the head to the heels. The starting position was with the placement of hands on the shoulder line with fingers pointing forward. When the view from the side, hands fell directly below the shoulders. From this position, subjects were instructed to lower the body with elbows directed to the sides until their chest almost touched the floor. After reaching that point subject changed direction without pausing. The cadence of the move was maintained 2 seconds down and voluntary tempo in the concentric phase.

**Medicine ball chest throw performance**
The medicine ball throwing test used during this measurement is recommended by Harasin et al. [28] to measure maximum throwing performance. The test was performed in a sitting position where both legs were placed on the ground with 90° flexion in the knee. During each throw head and shoulders had to be in touch with the wall, and the trunk had to be in touch with a chair. The 2kg medicine ball (circumference 65cm) was used for throwing as participants practiced this weight before. Each participant was instructed to throw the ball with maximal effort and possibly furthest. Throws started from the chest position with elbows abducted from the trunk (Figure 2). Measurement tape was placed on the ground to assess throw distance by an assistant with a distance meter. Each time ball had been thrown 3 times in the row without rest, the ball was passed to the participant immediately after a throw by an assistant. In front of the throwing position at the distance of 6m was a standing assistant holding the radar (The Stalker ATS II, Version 5.0.2.1, Applied Concepts, Dallas, TX, USA) evaluating throwing speed (m/s). The best of 3 throws from each protocol was used to make statistical comparisons.

### Statistic

All statistic has been performed using STATISTICA software (TIBCO, PaloAlto, CA, USA), at alfa level 0.05. The normality was calculated by the Shapiro-Wilk test. One-way ANOVA was used to check the differences between initial throwing distance and maximum speed before the activation exercises. Two-way ANOVA for the repeated measure was used to calculate the throwing distance and maximum speed differences between pre and post-measurements (repeated factor) and between the activation exercise type (repeated pre-post measure x exercise), followed by paired sample T-test as a post hoc test. The effect of the activation exercise was calculated by Cohen's d effect size considering 0.2, 0.5, and 0.8 as small, medium, and large effect sizes, respectively.

### 3. Results

The data normality was not disrupted (Table 1, supplementary material 1) and two-way mixed absolute agreement intraclass coefficient in pre values was 0.82 at CI 0.562 – 0.941. The initial values (Table 1) between all three activation exercises during pre-test were similar in distance ($F_{2, 24} = 1.1$, $p = 0.35$) and maximum speed ($F_{2, 24} = 2.1$, $p = 0.13$).

The two-way repeated measure ANOVA showed differences in throwing distance ($F_{1, 36} = 13.5$, $p < 0.001$), whereas the post hoc test showed increased throwing distance after bent over row (Figure 3). Further differences were found in throwing speed ($F_{1, 36} = 19.9$, $p < 0.001$), where the post hoc test showed increased speed after bench press and bent over barbell row but not after push up (Figure 4).

Table 1. The effect size and data distribution of maximal ball throw distance and speed before and after conditioning activities respectively.
### 4. Discussion

Our hypothesis was based on the neuromuscular activation link between the antagonist’s muscles, which should have a similar or better enhancement effect as agonist CA. This was confirmed for throwing distance, where bent over barbell row had the largest effect size, but not for the throwing speed, with the highest effect size being found for bench press. This finding agrees with the general approach that CA exercise selection modulates the performance effect [13], and antagonist activation allows similar or better performance enhancement. On the other hand, with agonist CA the BP shows significant improvement only on throw speed but not on distance, which might be caused by disruption of the throwing technique after BP activation. The results in PU didn’t show significant improvement in throwing distance and speed, which might be correlated with low intensity of exercise which was not enough for our subjects to evoke the PAPE phenomenon.

To date, there have been limited studies examining PAPE effects on female sports performance, and most of those studies have focused on jump performance [29-35]. Regarding the upper body explosive power, researchers have focused mostly on male athletes’ performance [1,36-39], there are only a few studies targeting the effect of PAPE on female upper body performance. In the study performed by Martinez-Garcia [6] respectively 86% and 93% of female handball players improved in throwing velocity after the variable resistance intra-repetition method and after the isometric method used during bench press exercise. Similar results were obtained in shot put throwing distance which was significantly improved after bench press CA among females [20]. For rowing exercise used as CA in measurements made by Doma there were moderate to large increases in average power output (+2.5%), peak power output (+1.5%), and power output during a first stroke (+0.79%) [23]. 40 female rowers participated in the study made by Harat, where rowing on an ergometer elicit the increase in mean power after dynamic potentiating when compared to isometric potentiating and the control group [40]. Additionally, the more experienced group showed significantly better improvement than less experienced subjects for distance (+5.6 m) and mean power (+5.9 W). The push-up exercise can be successfully used as CA among female athletes to boost shot put performance, especially using isometric push-ups improves shot put throwing distance by 3.59 ± 2.7% [24]. Concerning those publications, our study confirms the knowledge that both, agonist BP and antagonist bent over row are possible appropriate CA’s for successful PAPE effect on medicine ball chest throw distance and speed performance among females after appropriate resistance training preparation. When focusing on improvement of throwing speed it seems to be better to use BP exercise as a CA (improvement 0.19m/s, Cohen’s d 0.41) although it doesn’t improve throwing distance significantly (Paired T-Test sig. 0.15). Thus, when aiming to develop further throwing distance (improvement 24cm, Cohen’s d 0.41) with a small improvement of throwing speed (improvement 0.1m/s, Cohen’s d 0.23) after CA, it is recommended to activate the antagonist by performing bent over barbell row exercise. Properly adjusted protocols for BP exercise can positively improve body explosive power.
output [41,42]. This study shows significant improvement in maximal throwing ball speed after 2 sets of 4 repetitions of BP and bent over barbell row, with respectively 60% and 80% 1RM for trained female softball players. This intensity was chosen because both stronger and weaker individuals respond to CA better when stimuli are higher [10,43]. In our athletes, the BP intensity most likely increased the recruitment of higher-order (type II) motor units [44]. However, it could be speculated that higher intensity might disrupt the throwing technique and accuracy due to the resting muscle twitch response in the agonist's muscles. Therefore, we might assume that applied BP was too intense for our subject, which was avoided in antagonist load in a bent over barbell row CA.

In this study, female softball players significantly improved their maximal throwing speed and distance after bent over barbell rowing. This exercise evokes large muscle activation symmetrically from the upper to lower back [45], which are antagonists for the muscle responsible for throwing performance. Possible mechanisms underlie neural responses after the activation of the antagonist, which is observed in increased electromyography activity of agonist muscles [17].

Some athletes might not respond to the post-activation potentiation enhancement due to fatigue or too high an intensity of the exercise. Our study suggests that this phenomenon might be avoided by the activation of the antagonist's muscles. This might be especially beneficial if the volume or intensity of CA might decrease the PAPE effect. The agonist CA certainly has a positive PAPE effect but does not have to be the best way to elicit PAPE. The agonist exercises can be most effective to increase general power outcome (such as throwing speed) but are not necessary for improving performance output (such as throwing distance).

A potential study limitation is that only medicine ball chest throws were used to assess the effect of CA on upper body explosive performance. This method is often used for examination training effects [6,44], as it allows constrained use of body segments[44]. On the other hand, the throwing position causes more stability and, therefore, less variability in throwing attempts [27,45]. Moreover, the results might be affected by throwing ball weight and throwing technique [46]. Subsequently, there is a question for further research, what antagonist exercise intensity and volume are best for the highest PAPE effect. Another limitation is the intensity of push-ups which might differ among participants and missing physiological mechanisms examination which could explain obtained results. Additionally, throwing distance measuring accuracy was dependent on assistant evaluation which might be a subjective opinion and therefore might lead to minor differences.

5. Conclusion

We conclude that upper body throwing performance is higher after antagonist exercise than agonist CA and both agonist and antagonist CA increases power. In the resistance training practice, we recommend the interchange of agonist and antagonist PAPE stimulation at push-up bodyweight or BP and bent over raw submaximal (80% of 1RM) intensity to succeed PAPE on upper limbs.

Abbreviations

CA – conditioning activity
PAPE – post-activation potentiation enhancement
BP – Bench press
1RM – one repetition maximum
PU – push up
ROW - bent-over barbell row

Declarations
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Competing interest Anna Pisz, Dusan Blazek, Radim Jebavy, Petr Stastny, Michal Wilk, Michal Krzysztofik, and Dominik Kolinger declare they have no competing and conflicts of interest relevant to the content of this article.

Ethical approval Approval number: 120/2019 by the ethical committee at Faculty of Physical Education and Sport at Charles University.

Author's Contributions AP, DB, RJ, PS, MK designed the study protocol and conceptualisation of manuscript. AP, DB, RJ, performed the familiarization and study measurements. DK, DB, PS, MW analysed the data and interpreted them into manuscript. DK, RJ, DB, PS, MW, AP, MK write the manuscript.

Consent to participate The participants gave informed written consent to the study

Consent for publication is Not applicable.

Availability of data and material all data are available in the supplementary material 1, the data tabe.

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**Figures**
Figure 1

Flow chart of experimental protocol and sessions.

Figure 2

Pictures of conditioning activity and ball throwing positions. A = bent over row, B = push up, C = ball throw.
Figure 3

Individual throwing performance among softball players by maximum throwing distance (cm). Boxplots are expressed in median and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively.

Figure 4

Individual throwing performance among softball players by maximum maximum throwing speed (m/s). Boxplots are expressed in median and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively.

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial1.xlsx