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Does the warm-up effect subsequent post activation performance enhancement?

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ABSTRACT

The purpose of the following study was first to identify an optimal warm-up to maximise countermovement jump (CMJ) performance, and second to investigate whether a conditioning activity (CA) of half-squats could potentiate CMJ performance above that of the optimal warm-up. Sixteen resistance trained males were recruited for the study. Participants performed six different warm-up volumes over six sessions. Warm-ups consisted of submaximal running, dynamic stretching and practice CMJs. After the warm-up, participants rested for four minutes before performing three CMJs on a force platform. The warm-up which resulted in the best CMJ relative peak power (RPP) was considered to be that individual's optimal warm-up. Participants attended another testing session where they performed their optimum warm-up followed by a pre-CMJ test. Participants then performed a CA of four half-squats with a 5RM load followed by post-CMJ tests after four- and eight-minutes recovery. No CMJ variable displayed significant improvements at either four or eight minutes recovery after the CA when compared to the pre-test. However, when everyone's optimum recovery period was considered, CMJ height significantly improved by 5.2% (p = 0.009) when compared with pre-CMJ performance. If the optimum recovery period is considered, a half-squat CA can further improve CMJ height above that of a general warm-up alone.

1. Introduction

Prior to training, athletes perform a warm-up to decrease the risk of injury and also to optimise performance (Behm, Blazevich, Kay, & McHugh, 2016). To maximise performance, it has been suggested that a general warm-up should include an aerobic component performed at an intensity of < 60% of an individual's VO2max (Bishop, 2003a), a dynamic stretching component (McMillian, Moore, Hatler, & Taylor, 2006) as well as a skill specific component, where the athlete practices the specific movement they will be performing (Young & Behm, 2003). There are many mechanisms of a general warm-up that will enhance an individual's readiness to perform effectively. These include increases in muscle temperature (Bishop, 2003b), blood flow to working muscles (McCutcheon, Geor, & Hinchcliff, 1999), range of motion (McMillian et al., 2006), baseline oxygen consumption (Bishop, 2003b) and an enhanced readiness of the neuromuscular system (Young & Behm, 2003). Athletes or coaches may also try to exploit the phenomenon of post-activation performance enhancement (PAPE) to further the benefits following a warm-up.

Post-activation performance enhancement is the phenomenon where the contractile history of a muscle acutely enhances the performance of a future voluntary contraction that is biomechanically similar after a recovery period (Blazevich & Babault, 2019; Hodgson, Docherty, & Robbins, 2005). To exploit the PAPE phenomenon, a conditioning activity (CA) is performed to enhance a subsequent movement. Typically, CA have involved heavy dynamic exercises of the lower body (for example heavy squats) in order to potentiate jumping (Boullosa, Abreu, Beltrame, & Behm, 2013; Chiu et al., 2003; Young, Jenner, & Griffiths, 1998) or sprinting performance (Seitz et al., 2016). However, more ballistic movements and plyometric activities have also been utilised as CA within the literature (Turki et al., 2011). The applications of PAPE can be used in a warm-up to acutely enhance performance for competition. Furthermore, PAPE can be used in contrast resistance training to enhance speed-strength

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variables, with the intention of producing a greater training stimulus for chronic adaptations.

Previously, the term post-activation potentiation (PAP) was used to explain the improvements in performance after a CA, however, recent literature has distinguished a difference between the terms PAP and PAPE (Blazevich & Babault, 2019; Prieske, Behrens, Chaabene, Granacher, & Maffiuletti, 2020). Post-activation potentiation involves an enhancement in an electronically evoked twitch response almost directly after the performance of a CA (Prieske et al., 2020). Alternatively, PAPE involves an enhancement in voluntary contractions (strength, power or speed) after the performance of a CA (Prieske et al., 2020). The main mechanisms of PAP include the phosphorylation of the regulatory lights chains of the myosin head (Hodgson et al., 2005; Tillin & Bishop, 2009), and changes in pennation angle of the muscles (Mahlfeld, Franke, & Awiszus, 2004). Although it is unclear, these mechanisms of PAP may influence PAPE (Blazevich & Babault, 2019). The main mechanisms of PAPE are an increase in higher order motor unit recruitment (Tillin & Bishop, 2009) and blood flow to the muscle (Blazevich & Babault, 2019). Previous research has investigated the underpinning mechanisms of PAP and PAPE (Klug, Botterman, & Stull, 1982), however, a majority of the literature assumes that any improvement in performance following a CA is due to potentiation and fails to consider the warm-up activities prior to the CA. Considering the current investigation assesses changes in voluntary contractions (jumping performance) after a CA, the term PAPE will be used from this point forward.

Despite the relatively large amount of literature supporting the positive benefits of PAPE (Duthie, Young, & Aitken, 2002; McBride, Nimphius, & Erickson, 2005), numerous studies have failed to identify improvements in performance after a CA (Khamoui et al., 2009; Till & Cooke, 2009). Research has suggested that the type of CA (Fiorilli et al., 2020; Wilson et al., 2013), the recovery period allocated after a CA (Seitz et al., 2016) as well as the training history of the participants (Chiu et al., 2003; Seitz et al., 2016) could all be contributing factors to the inconsistent results. However, a variable that has yet to be investigated is the warm-up performed prior to the CA.

The typical research design utilised in the PAPE literature involves a general warm-up, pre-testing, an allocated rest period (or rest periods) and post-testing (Figure 1). In terms of the general warm-up, the procedures described within the published PAPE literature at times detail an insufficient general warm-up prior to pre-test measurements (Duthie et al., 2002; Linder et al., 2010; McBride et al., 2005; Okuno et al., 2013). For example, a participant may only perform an aerobic component of the general warm-up, with no inclusion of dynamic stretching or specific skill rehearsal (Linder et al., 2010; McBride et al., 2005; Okuno et al., 2013). Additionally, there are examples of static stretching being incorporated within the general warm-up (Duthie et al., 2002), despite the fact that prolonged static stretching may decrease subsequent performance (Behm et al., 2016).

Considering many PAPE studies have not included an appropriate warm-up prior to measuring baseline performance, these studies may not accurately reflect the performance of each individual. Therefore, positive improvements observed in explosive movements such as a jump or sprint following a CA may not be the result of PAPE, instead the improvement may be due to the CA being an extension to an inadequate warm-up prior to baseline testing. Recent research by Mina et al. (2018) has supported the notion that warm-ups prior to a CA have been insufficient within the PAPE research. Mina et al. (2018) prescribed a warm-up prior to either a free-weight back squat or a band resisted back squat CA (three repetitions with a load of 85% of 1RM) while attempting to enhance CMJ performance. When three repetitions of a free weight back squat were used as a CA, no statistically significant improvements in CMJ performance were identified leading the authors to speculate that previous PAPE literature may have only found an improvement in post-jump performance due to insufficient warm-ups being performed before the CA. Despite this, the warm-up used by Mina et al. (2018) did not include any dynamic stretching, which may have been a sub-optimal warm-up for the pre-test CMJ performance. Furthermore, the same warm-up was performed by each individual in the study, however, the optimum warm-up for jumping performance may vary between individuals.

The concept of exploiting PAPE assumes that the general warm-up prior to any pre-tests is adequate. Therefore, the CA further potentiates performance, rather than just compensating for an insufficient warm-up. There is a need for research to optimise a warm-up prior to the addition of a CA, to identify whether PAPE further improves performance.

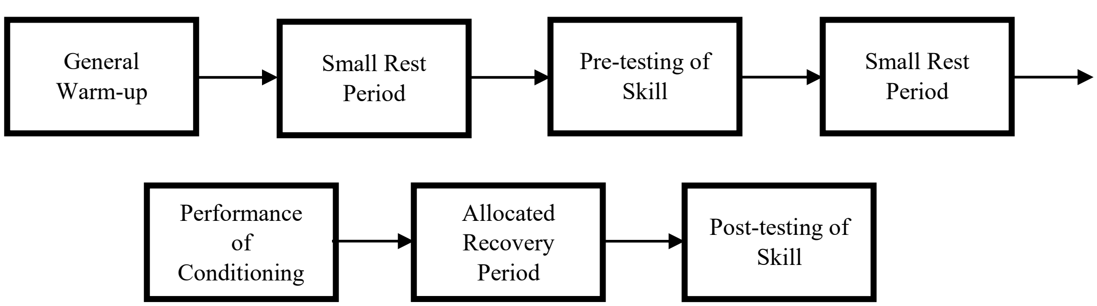

Figure 1: A representation of the "typical" procedures used within PAPE research.

Therefore, the present study aims to firstly identify an individual warm-up which maximises pre-test jumping performance. Once the optimum warm-up was established, the study aimed to identify whether a heavy back-squat CA can further improve CMJ performance by eliciting an acute performance enhancement.

2. Methods

The following study used a within-subjects repeated measures design to establish which general warm-up protocol was the most effective for each individual participant and assess the effectiveness of adding a CA to this warm-up on post-CMJ performance. After two familiarisation sessions, participants took part in six experimental procedures with varying warm-up volumes. Each of these sessions were performed 2-5 days apart. Each participant completed the sessions at consistent times of the day to control for any diurnal variations in performance and were instructed to maintain regular eating and sleeping habits throughout data collection. Participants were not allowed to consume caffeine on the day prior to any testing session and were not to perform any strenuous lower-body exercise within 48 hours. These sessions were performed in a random order to prevent any order-effect influencing results.

After completing the six experimental warm-up sessions, participants performed another testing session that involved their optimum warm-up followed by a CA of four half-squats with a 5RM load. This session was to assess if the CA could further enhance post-CMJ performance beyond that of the general warm-up alone.

Sixteen recreationally trained males with a minimum of one-year resistance training experience completed the present study (Mean ± SD age = 21.4 ± 1.9 years, height = 179.9 ± 6.1 cm, body mass = 81.7 ± 8.1 kg, Smith machine 5RM half-squat = 166.5 ± 36.7 kg). Two participants withdrew from the study due to injuries that occurred outside of testing sessions and were not included in any data analyses. Participants were over the age 18, free of injury or illness and able to half-squat at least 1.5 times their body weight for one repetition as previous literature has related participant strength as a requirement for a positive potentiating effect (Seitz et al., 2016). Before the commencement of the study, the procedures and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the University's Human Research Ethics Committee (A13-151).

The participants attended two familiarisation sessions. The first session was to measure the 90° knee angle to meet the required depth for the half-squat and to determine the 5RM half-squat load for each participant. Once the participants were in the appropriate half-squat position, a marker was placed on the side of the Smith machine so that each participant's half-squat height was consistent throughout the entire study. A grid was set up on the ground so that each participant's foot position could be recorded and kept consistent throughout the study.

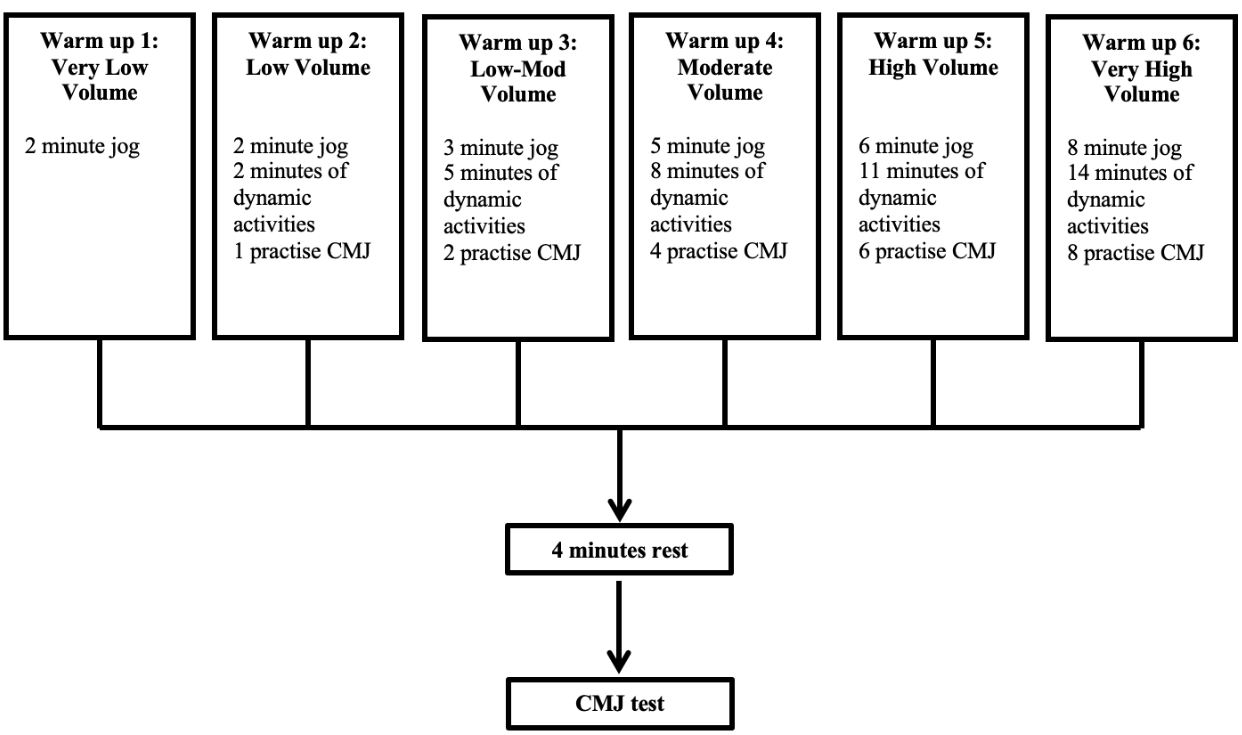

Figure 2: Representation of the procedures used within the six warm-up conditions.

Prior to determining the participant's 5RM, three warm-up sets of eight repetitions at 50%, five repetitions at 70%, and three repetitions at 90% of their self-predicted 5RM were completed with two-minutes of rest between sets. Following completion of the warm-up sets, the participant attempted five repetitions at 100% of their self-predicted 5RM load. If successful, four minutes of rest was provided and the load was increased by 5kg. If a participant failed to complete five repetitions at a particular load, their last successful lift was considered their 5RM. The second session was focused on practicing the CMJ and the warm-up protocol. Participants practised the submaximal jogging and dynamic stretches used within the warm-up before they practised the CMJ on the Ballistic Measurement System (BMS) (400 Series Force Plate-Fitness Technology, Adelaide, Australia) with the linear position transducer (LPT) (PT5A-Fitness Technology, Adelaide, Australia). Participants held a light aluminium bar across their shoulders (LPT attached) during the CMJ to prevent the use of an arm-swing and were instructed to perform the CMJ at a self-selected speed and depth before jumping for maximal height.

Participants performed seven experimental conditions, the first six involved warm-ups that differed in the total workload (ranging from "very low" to "very high") (Figure 2).

Participants began each session by performing the specific warm-up allocated for the appropriate session. The warm-up sessions included an aerobic component (jogging), dynamic stretches and activities of the lower body (Table 1) as well as practise CMJs.

After completing the allocated warm-up procedure, participants rested (seated in a chair) for four minutes before performing three CMJs. The CMJ variables assessed were jump height, relative peak power (RPP) and peak force.

In the seventh experimental condition, to specifically examine PAPE compared to simple warm-up effects, a CA of four half-squats at a 5RM load was added to each individual's optimal warm-up routine determined from the previous conditions. The optimum warm-up was the condition that produced the greatest RPP during a single CMJ. At the start of this experimental condition, the participant performed their optimum warm-up followed by four minutes of recovery. Three CMJs were then performed as a baseline-measure, followed by two minutes recovery prior to three warm-up sets of half squats (1st warm-up set: 8 repetitions at 50% 5RM, 2nd warm-up set: 5 at 70% 5RM, 3rd warm-up set: 3 repetitions at 90% 5RM). After the final warm-up set, participants rested in a seated position for four minutes prior to performing four half-squats at a 5RM load as their CA. Following the CA, participants recovered in a seated position prior to performing CMJs four and eight minutes post-CA. The recovery period of eight minutes is within the guidelines of the meta-analysis performed by Wilson et al. (2013), who suggested that rest periods after a CA should be between seven and ten minutes for individuals with one year's training experience. Previous research has identified a potentiating response with a smaller recovery (Lowery et al., 2012), hence four minutes recovery was also selected to assess if any individuals displayed a potentiating effect with a decreased recovery time.

Considering past research has suggested that the optimum recovery time after a CA is individualised (Chaouachi et al., 2011), the recovery period that created the highest CMJ height for each individual was recorded as post-best.

All CMJs were performed on a portable force plate in conjunction with an LPT. Both the force plate and LPT were calibrated prior to every session. The sampling frequency for both the force plate and LPT was set at 500Hz and the data was filtered using a fourth order Butterworth method with a cut-off frequency of 9Hz. The LPT was attached to the end of an aluminium bar (0.4kgs in weight) that was held on the participant's shoulders. Test-retest reliability of each CMJ variable was determined by Intraclass correlation (ICC) and coefficient of variation percentages (CV%).

Table 1: The dynamic stretches and the amount of repetitions used in each warm-up condition.

Dynamic Exercise	**Volume Level**				
	Low	Low-Moderate	Moderate	High	Very High
Gluteal Stretch Walk	2	6	10	14	18
Quadriceps Grab Walk	2	6	10	14	18
Bouncing on Spot (double leg)	4	16	28	40	52
Heel to Gluteal Run	2	8	14	20	26
Walking Lunges	1	3	6	9	12

Note: The number of exercises in the table are to be performed on each side of the body. The Very Low warm-up condition consisted of two minutes of jogging only.

Relative peak power was selected as the CMJ variable to determine the optimum warm-up. This was decided as enhanced power output is a targeted training outcome for many athletes and coaches therefore, changes in CMJ RPP could lead to practical applications for training both acute and chronic PAPE responses.

Means and standard deviations (SD) were calculated for all CMJ variables from each warm-up condition as well as pre- and post-CMJ variables in the session with the CA. Prior to analysis, a Shapiro-Wilk test was used to assess the distribution of the data, with all variables being normally distributed. To determine whether any significant differences in CMJ performance existed between warm-up conditions, a repeated measures Analysis of Variance (ANOVA) was performed. To establish if the inclusion of the CA had a potentiating effect on CMJ performance, a second ANOVA was performed to determine if significant differences existed at 4 or 8 minutes post CA. Two rest periods were used to determine the optimal rest period as the time course for PAPE may vary for each individual (Chaouachi et al., 2011). Therefore, the recovery period that produced the greatest jump height was considered "post-best" and a paired t-test was conducted to analyse differences between pre to post-best for all CMJ variables. Effect sizes were used to quantify the magnitude of differences between the pre to post-changes within the CA protocols. The effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00) (Hopkins, Marshall, Batterham, & Hanin, 2009).

3. Results

The results from the repeated measures ANOVA on the different warm-up volumes as well as the mean and SD for CMJ variables are displayed in Table 2. Warm-up condition 4 (WU4) (moderate volume) had the highest mean for CMJ RPP (59.07 ± 7.76W) as well as jump height (0.507 ± 0.079m) whilst warm-up condition 6 (very high) had the highest CMJ peak force (2004.9 ± 365.3N). For the CA condition, mean and SD for all pre-, 4-min post, 8-min post and post-best CMJ variables are displayed in Table 3. No significant changes were displayed for any CMJ variables when pre-CMJ variables were compared to either 4-min or 8-min post. When each individual's best recovery period was considered (post-best), CMJ height significantly increased when compared with the pre-jump scores (p = 0.019). No other significant differences were identified for any other variables of the CMJ.

Table 2: Intraclass Correlation (ICC) and Coefficient of Variation Percentage (CV%) for Counter Movement Jump (CMJ) variables to assess test-retest reliability.

	RPP	**Jump height**	**Peak force**
ICC	0.963	0.980	0.813
CV%	2.2%	2.2%	3.0%

Note: RPP = Relative peak power.

4. Discussion

The primary purpose of this study was to determine if an individualised warm-up volume could enhance CMJ performance. An additional aim was to determine if including a CA to the optimal warm-up, could potentiate subsequent CMJ performance. Considering the vast inconsistencies within the PAPE literature, it is imperative that a sufficient warm-up is performed before any pre-testing variables are assessed. Performing a sufficient warm-up, any significant increase in post-test variables following the CA, can more accurately be assumed to be due to Performance enhancement, rather than the general effects of a warm-up. This is the first study that assesses the effect of adding a heavy dynamic CA to an individual's optimum warm-up.

The results of this investigation showed that WU2, 4 and 5 lead to significantly greater CMJ RPP compared with WU1 (Table 3). Considering three of the five warm-up volumes show a significant enhancement in at least one CMJ variable compared with the very low warm-up volume (WU1), it can be suggested that this warm-up did not adequately prepare participants for CMJ performance. The only difference between the very low and low volume warm-ups was that the low volume warm-up included two minutes of dynamic activities and one practise CMJ. Considering the low WU volume exhibited significantly heightened CMJ RPP than the very low volume, it supports the suggestions from Young and Behm (2003) that a warm-up needs to consist of an aerobic, dynamic stretching and skill rehearsal component.

WU4 produced significantly greater CMJ height than WU 3 and 6 (Table 3). The decreases in CMJ height after the very high warm-up volume suggests that this volume may be too high to enhance CMJ performance. Despite this, three of the sixteen

Table 3: Descriptive statistics for each CMJ variable after the six different warm-up conditions. A statistically significant change is represented by values in bold with * meaning a significant change from WU1, † a significant change from WU3 and ⁰ a significant change from WU6 (p < 0.05).

	Very Low WU (1)	**Low WU (2)**	**Low-mod WU (3)**	**Moderate WU (4)**	**High WU (5)**	**Very High WU (6)**
RPP (W.kg^{-1})	55.49 ± 5.52	**57.49 ± 6.15***	57.20 ± 7.97	**59.07 ± 7.76*†**	**58.27 ± 8.21***	56.57 ± 7.41
JH (m)	0.491 ± 0.064	0.500 ± 0.061	0.485 ± 0.087	**0.507 ± 0.079†⁰**	0.493 ± 0.076	0.480 ± 0.068
PF (N)	1996.9 ± 271.6	1963.0 ± 306.1	1993.9 ± 294.3	1985.6 ± 304.3	1983.5 ± 308.3	2004.9 ± 365.3

Note: WU = Warm-up, RPP = Relative peak power, JH = Jump height, PF = Peak force.

participants produced their best RPP following WU6, suggesting this was their optimal warm-up. Additionally, the greatest mean for a majority of the variables obtained from the CMJ was observed following the moderate volume warm-up. An explanation for the individuality in the optimum warm-ups could be the different fitness qualities amongst the population (e.g., aerobic capacity), however, apart from 5RM half-squat strength, these were not assessed in this investigation. Furthermore, an individual's optimum WU volume may vary from day to day depending on other confounding variables that could not be controlled within this study (e.g., physical activity completed at work/ during each day).

From these findings, it further suggests that past PAPE literature has not employed adequate warm-ups which could negatively affect pre-CMJ performance (Linder et al., 2010; McBride et al., 2005; Tobin & Delahunt, 2014). McBride et al. (2005) and Linder et al. (2010) both only used four and five minutes of cycling at 70 Watts respectively to warm-up prior to a sprint. Even though both studies concluded that improvements in sprint performance were due to PAPE, questions must be raised about such an assumption as the CA could have improved performance due to general mechanisms of a warm-up as opposed to performance enhancement. Furthermore, Tobin and Delahunt (2014) concluded that a CA of 40 plyometric jumps potentiated CMJ height and peak force across all post testing time points. Despite this finding, it must be questioned whether pre-CMJ performance was optimised, as no aerobic component was included within this warm-up.

When the CA of four half-squats at a 5RM load was added to the optimum warm-up, the repeated measures ANOVA showed no significant improvements in any CMJ variables after four, and eight, minutes of recovery. CMJ jump height displayed a 2.9% improvement after four minutes recovery, and a 3.1% increase at eight minutes (Table 4), however, neither change was statistically significant, and this was considered a "trivial" effect. Lowery et al. (2012) had participants (parallel squat strength = 1.7 ± 0.2 times body weight) perform a similar CA to the present investigation (four half-squat at a load of 70% of the participants 1RM) and identified significant increases in both jump height and peak power after four minutes rest. Furthermore, Mitchell and Sale (2011) used five repetitions of the half-squat at a 5RM load (participant mean 5RM = 144.5 ± 19.4 kg) to significantly increase CMJ jump height by 2.9% after four minutes recovery. Despite the insignificant change in jump height after the CA in the present study, the percentage increase in jump height after four minutes recovery was actually the same as the significant 2.9% increase identified in the investigation by Mitchell and Sale (2011).

Previous research by Wilson et al. (2013) suggested that both the optimal rest period and CA intensity would be different between individuals. From this suggestion, a comparison between pre- and post-best recovery CMJ performance was also conducted. Post-best jump height (5.2%) showed a statistically significant but small effect after the CA was added to the individuals' optimum warm-up. Such improvements in jump height are similar to that of Young, Jenner and Griffiths (1998) and Mitchell and Sale (2011), even though they found these increases in performance at specific recovery periods. Considering a significant acute enhancement in jump height performance occurred after the performance of the CA, and an optimal WU was executed prior to any pre-CMJ testing, the increase in jump height was most likely due to performance enhancement rather than just a top-up to a general warm-up.

Table 4: Comparison between pre-CMJ variables and each recovery period (4-min, 8-min and post-best) after the performance of the CA. Statistical significance is represented by values in bold with * ($p < 0.05$).

	RPP	**Jump height**	**Peak Force**
Pre	60.17 ± 7.16	0.504 ± 0.089	2027.5 ± 276.6
Post-4 min	59.56 ± 6.70	0.519 ± 0.073	2003.0 ± 235.3
% diff pre to post-4min	-1.0	2.9	-1.2
P value	1.000	0.598	1.000
ES (95% CI)	-0.09 (-0.78 – 0.61)	0.18 (-0.51 – 0.87)	-0.10 (-0.78 – 0.61)
Post-8 min	58.37 ± 7.36	0.520 ± 0.079	2024.9 ± 283.0
% diff pre to post-8min	-3.0	3.1	-0.1
P value	0.194	0.216	1.000
ES (95% CI)	-0.25 (-0.94 – 0.45)	0.19 (-0.51 – 0.88)	-0.01 (-0.70 – 0.68)
Post-best	60.00 ± 6.80	0.530 ± 0.074	2055.1 ± 268.6
% diff pre to post-best	-0.3	5.2	1.4
P value	0.838	**0.009***	0.289
ES (95% CI)	-0.02 (-0.72 – 0.67)	0.32 (-0.-0.39 – 1.01)	0.10 (-0.59 – 0.79)

Note: RPP = Relative peak power, ES = Effect size, CI = Confidence interval

Although improvements in post-best jump height were observed, no other CMJ variable displayed significant changes from pre- to post-best, and all changes apart from jump height were "trivial". The intensity of the CA may have been a contributing factor to these CMJ variables not displaying significant improvements. Much of the previous literature used either five repetitions at a 5RM load (Boullosa et al., 2013; Young et al., 1998) or three repetitions at a 3RM load (Kilduff et al., 2007) as a CA. The present investigation used four repetitions at a 5RM load due to the recommendations from Wilson et al. (2013), suggesting that recreationally trained participants should not perform CA that are too fatiguing. It was decided that the four repetitions would be appropriate for the sample of the present study; however, potentially a CA with an extra repetition or a greater load (three at a 3RM) could have elicited greater improvements in post-CMJ performance.

The strength of participants may have been another factor that attributed to limited evidence of PAPE at specific recovery intervals (4 or 8 minutes). Chiu et al. (2003) suggested that participants should be able to squat 1.5 times their body weight whilst Seitz, Villarreal and Haff (2014) recommended relative squat strength should exceed twice that of body weight. The participants in the present study had a relative strength in the half-squat of 2.4kg per 1kg of body weight. Although this exceeds both the strength recommendations of the previously mentioned literature, it must be noted that the squats were only half-squats (90º knee angle) and were performed in a Smith machine. From the research conducted by Chiu et al. (2003) and Seitz, Villarreal and Haff (2014), participants performed parallel squats. This increase in squatting depth would have decreased the total amount lifted during their RM testing. Although participants were asked to not participate in strenuous lower-body activity 48 hours prior to testing sessions, the differing activities participants may have performed in their general day before a session is a further limitation to the study.

Due to the significant increases in jump height after the performance of the CA (with each individual's optimal recovery period considered), a similar warm-up and CA protocol could be used in specific sports settings to take advantage of the acute enhancement of jump height. Provided sufficient equipment was available and the recovery interval could be controlled, athletes could perform a similar warm-up and CA of four half-squat at a 5RM load to potentiate jumping performance similar to that of the CMJ. Coaches and athletes would need to identify each individual's optimum warm-up and recovery time after the CA to take full advantage of the PAPE phenomenon.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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