**Postactivation Performance Enhancement (PAPE) using a vertical jump to improve Vertical Jump Performance.**

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**ABSTRACT**

BACKGROUND: Postactivation performance enhancement (PAPE) is a principle that suggests that an acute bout of high intensity voluntary exercise will be followed by an improvement in strength, power, and speed of a subsequent task. This study intended to demonstrate how a maximal vertical jump can enhance the outcome of a subsequent vertical jump compared to a multiple jump series and a control. METHODS: In a randomised controlled, double blind trial, adult professional soccer players (*n* = 69) undertook maximal vertical jumps at baseline and at 2 and 6 minutes post-intervention after 1 of 3 interventions; 2 repetitions of a maximal vertical jump (VJ), 40 repetitions of a multiple jump series (MJ) or a walking control (CON). RESULTS: All baseline outcomes were similar between all the groups. Relative to the baseline there was a significant improvement for VJ in jump height and power output at 2 minutes of 1.89cm and 114.45W and relative to the baseline, MJ also had a significant improvement at 2 minutes of 1.51cm and 91.60W. By 6 minutes both groups had reverted to baseline values. There was no change in CON across the experiment and no significant difference between CON and the interventions. CONCLUSIONS: These findings suggests that 2 maximal vertical jumps may enhance the outcome of a subsequent maximal vertical jump after 2 minutes and as much as a series of 40 jumps. However, these enhancements were not sustained for a further 4 minutes in either group.

Key words: PAPE; intensity; PAP; specificity; plyometric; vertical jump.

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**BACKGROUND:**

The application of the warm-up prior to sport participation is an opportunity to prepare an athlete both physically and mentally for the upcoming activity(1). Due to the high association with performance outcomes, the warm-up has always drawn interest amongst coaches, researchers, and athletes alike (2). The potential for athletes to maximise their performance outcomes by undertaking a grouping of physical tasks raises the interest in the warm-up process(3). Postactivation performance enhancement (PAPE) has been hypothesised as a medium for exceeding the performance potential attained by the warm-up alone (4). There is evidence that specific, high intensity tasks, such as a plyometric activity (2, 5, 6) at the end of a warm-up can acutely enhance an athlete’s potential which exceeds the enhancement attained by a submaximal warm-up alone (1).

Current literature has discussed the association between postactivation potentiation (PAP) and postactivation performance enhancement (PAPE) (7). Conventional models suggested that PAP is any acute enhancement lasting up to 20 minutes following heavy resistance training or a high intensity ballistic activity (8, 9). It is proposed that an initial contraction increases the myosin regulatory light chain (RLC) phosphorylation that supports the effects observed in PAP, including an enhancement in voluntary contractile force (10). Although part of this may be true, PAP only refers to an enhancement of an evoked twitch response, which is relatively short lived and rapidly decreases after ~1 minute (11). Postactivation performance enhancement is associated with among other things; voluntary contractions, increases in muscle temperature and several neural mechanisms unrelated to RLC phosphorylation where muscle twitch has not been directly assessed (12, 13). This study did not intend to explore these terms in detail, except to apply the correct terminology. In this study postactivation potentiation will refer to reported changes in muscle twitch response while, PAPE will refer to an acute bout of high intensity voluntary exercise followed by an improvement in power, speed and strength production (8, 14).

PAPE has been demonstrated to be effective in improving the acute outcome in a subsequent task, traditionally following heavy resistance training (4, 15). The evidence linking heavy resistance training and PAPE indicates a positive correlation to performance enhancement when using a conditioning activity between 75-90% of a 1 repetition max. However, the nature of heavy resistance training requires coaches to use large, heavy equipment in large spaces with supervision. In addition, sufficient time is needed to dispel the highly individualised associated fatigue which is often reported with heavy resistance training (4, 16, 17). This makes heavy resistance training difficult to implement within a training and competition environment where it remains untested except in a clinical setting. There have been investigations into the benefits of PAPE within a competition environment, but heavy resistance training has always produced large disparity between the participants outcomes (17). Although many athletes respond positively to the heavy resistance training intervention, there are often non- and negative responders(17). As a result, a cautionary warning has been issued to coaches by researches when using heavy resistance training to induce PAPE (18-20) and specific athlete testing prior to using PAPE may be indicated. The guidelines for PAPE suggest that there is a high correlation between the enhancement, and the specificity and intensity of the conditioning activity, which is a common theme associated with most warm-ups (1, 3, 21). This suggests that PAPE could be achieved while using activities similar in nature and intensity to the expected outcome.

Plyometrics have demonstrated potential as an alternative to heavy resistance training as a conditioning activity to elicit a PAPE response. By using high velocity, high power movements, the type II muscle fibers can theoretically be recruited extremely quickly, supporting the success seen with plyometrics as the conditioning activity and PAPE (9). There are certainly indications that PAPE can be achieved using both weighted and body weight plyometric tasks; quickly and without the long-time frames to dispel the associated fatigue commonly seen when using heavy resistance training (22-24). Thus, plyometrics provide a practical training and competitive enhancement solution. In many cases the body weight plyometric tasks have shown similar or exceed the outcomes of the weighted and heavy resistance training conditioning activities (23, 25). Mola et al. (26) investigated the recovery time for PAPE in soccer players and found that heavy resistance training had a reduced global effect compared to the control group who used a vertical jump indicating that a ballistic intervention was comparable to the heavy resistance training. This was reiterated by Sharma et al.(25) who compared a multiple plyometric task intervention to heavy resistance training and found a significant benefit for both over multiple outcome measures and time points including a VJ which exceeded the outcome of the heavy resistance training. Tobin et al. (19) used similar methodology to compare a conditioning activity of a series of forty plyometric jumps on the performance of a vertical jump. They demonstrated improvements at three time points post-intervention and other than the volume of jumps and equipment required, the principle demonstrated potential as a conditioning activity for a competitive environment. If benefits occur in a vertical jump with jump variations including drop jumps (27) and depth jumps (28), then similar benefits are hypothesised with the vertical jump as a conditioning activity. The intensity and the specificity of the conditioning activity are important constituents in achieving PAPE. There seems to be a general agreement that exercises which are similar in nature (1) and intensity (29) provide a better response particularly to the vertical jump. Vertical jump performance has also shown a high correlation to actions commonly observed in soccer such as short sprints(30). The goal is to achieve PAPE with minimal disruption to the athlete’s preparations within a reasonable time frame, while achieving positive effects which outweigh any negative effects. This would allow athletes to specifically focus their warm-up with minimal equipment, within reasonable space and time.

This study intended to demonstrate how a maximal vertical jump could be used to improve the outcome of a subsequent vertical jump. It was hypothesised that this vertical jump intervention would improve a subsequent vertical jump as much as a previously defined PAPE intervention (19) and more than that of a control condititon and the baseline outcome.

**METHODS:**

**Study design**

A randomised, double blinded controlled study design was used to compare the effects of two maximal vertical jump in relation to a multiple jump series and a control condition on the outcome of a maximal vertical jump. A crossover design might have been better, using a randomised and counterbalanced order over three different and non-consecutive days. However, testing professional athletes can be a challenging undertaking due to their hectic training and match schedule allowing for a small window of opportunity. For this reason, a single testing session was selected. Ethics approval for the study was granted by the University of the Witwatersrand’s Human Research Ethics Committee (Medical) (approval number M190623) and was conducted in accordance with the principles set forth in the Helsinki Declaration.

**Participants and sampling**

Male, professional soccer players were invited to participate in this study from the first and reserve squad linked to a team in South Africa’s Premier Soccer League (age: 24 ± 5 years; mass: 69.2 ± 9.8 kg; height: 1.74 ± 0.06 m; relative strength [absolute strength/body mass]: 1.85 ± 0.19). The participants were invited on the basis that they were match fit and in full training participation. Seventy-two participants consented to participate in the study, with three participants excluded based on being unfit to train. The remaining (n=69) participants were uniformly and randomly allocated to each group by an independent assessor with no association to the participants prior to testing. All the participants were listed in alphabetical order by surname and assigned a number from 1 to 69. R statistical software (Rx64 3.5.2) randomly allocated each number to group A, B or C with an even distribution. Each group was then randomly allocated to the vertical jump group (VJ), the multiple jump series group (MJ) or the control group (CON) to prevent selection bias. All the participants were informed about the study parameters but were blinded to the study’s objectives to prevent bias and signed a consent document to acknowledge this. The data were kept anonymous and confidential, using codes and a password. As a regular part of training and testing, these participants were familiar with all aspects of the testing procedures required as part of this study. A minimum sample of 18 (effect size = 1.2, power = 0.95 and significance level = 0.05), was determined from a sample size calculation using G∗Power software (version 3.1.9.2; Heinrich-Heine-Universität Dusseldorf, Germany), effect size specification as in Cohen (1988) and the vertical jump height influenced by time interaction by Tobin et al.(19). The study used all athletes available (n = 69) as it allowed for easy implementation of the study.

**Procedures**

All the participants had their height in metres (Charder, portable height measure unit; Fizique, Johannesburg, RSA) and mass in kilograms (Charder, electric scale; Fizique, Johannesburg, RSA) measurements recorded prior to the testing as part of a standard weekly practice. The testing occurred during the second half of pre-season, 48-hours after the most recent training session. Each randomised group was separated from the other groups allowing for blinding to the different interventions. The groups were divided into smaller groups to allow for accurate timing between the intervention and the pre-intervention and post-intervention testing. A designated member of the coaching staff (UEFA A-licensed), familiar with the testing protocol and responsible for the warm-up preparations for the team was selected to administer the warm-up, intervention, pre-intervention, and post-intervention testing. He was instructed by the primary investigator on the procedures but not informed of the objectives of the study allowing for blinding to prevent bias.

The participants reported to training in their allocated groups and undertook a standardised soccer warm-up of approximately 20 minutes(31) consisting of jogging, dynamic stretching, body preparation exercise, submaximal sprints; up to ~90%, submaximal plyometrics and 6 vs 2, 5-minute rondos (small-sided possession games). The warm-up occurred on a soccer pitch, using soccer boots. The testing occurred on a hard, stable surface alongside the soccer pitch in training shoes which the participants were accustomed to using. After the warm-up, the participants progressed to the baseline testing, 2 maximal vertical jumps. To maintain an estimated elevated body temperature, the participants partook in low intensity activities with a soccer ball (head tennis). This was to allow any PAPE effects accrued during the baseline testing to be dispelled prior to undertaking the interventions(9). After 20 minutes VJ, MJ and CON performed their individual interventions (Figure 1).

**Intervention**

To account for the possible PAPE and fatiguing consequences of the intervention testing, a control group participated in the warm-up, the pre-intervention testing and the post-intervention testing while omitting the intervention. The CON group participants continued to walk during the intervention period to maintain estimated elevated muscle temperature. A 20 minute period between the baseline testing and the intervention was used for all the groups to ensure that any PAPE effects incurred during the baseline testing was completely dispelled prior to performing the interventions to avoid any feed-forward of the PAPE effects, a consequence not previously discussed in previous studies (32, 33). This should indicate that any changes post-intervention will be directly attributed to the intervention.

The VJ group participants performed 2 maximal vertical jumps at 95% or above of their baseline maximum height and peak power output to account for specificity and intensity. The MJ group participants undertook 2 sets of 10 ankle hops, 3 sets of 5 hurdle hops at 70 cm, and 5 drop jumps from a height of 50 cm, a total of 40 jumps as defined by Tobin et al. (19). It is worth noting that the investigators used this intervention exactly as described by Tobin et al. (19), however the pre-intervention and post-intervention protocol differed allowing for this studies objectives to be investigated by preventing a PAPE feed-forward effect from the pre-intervention testing. The timer was started at the end of the last repetition on the last set. The total time for intervention period was ~90 sec and was comparable between all participants. Following the interventions, the participants completed 2 maximal vertical jumps at 2 and 6 minutes respectively post-intervention (34). Participants completed the 4 post-intervention test vertical jumps with the aim to achieve the best outcome. This was considered as the most likely time range, while using a body weight conditioning activity, post warm-up but pre-competition to produce a beneficial effect prior to performance (19, 23).

**Measurements**

The vertical jump height and peak power output was recorded using a jump mat (Fusion Sport, Jump Mat, v.1.5.2). Peak power output was determined using Sayers equation (35) peak anerobic power (Watts) = 60.7 · jump height (cm) + 45.3 · body mass (kg) – 2055 and expressed as peak power output. Participants started following a ready command on their own time. They were instructed to jump with maximal effort as high as possible and received verbal encouragement. The participants performed two maximal vertical jumps at the pre-intervention and post-intervention tests with the goal of achieving the best outcome. The vertical jump intervention was compared to the baseline to assess for intensity as one of the highly influential factors in achieving PAPE. The VJ group participants who did not achieve 95% or above of the baseline testing during the intervention testing were recorded and compared to the within group participants who achieve 95% or above compared to the pre-intervention testing.

**Statistical analysis**

Statistical analysis was performed using SPSS software (Version 26; SPSS, Inc, Chicago, IL, USA). The assumption of normality was tested using the Shapiro-Wilk test. The data are presented as a mean ± standard deviation. A 3x3 mixed design ANOVA with a within-between interaction was used to investigate the height and peak power output of the vertical jumps. The between subject factor was group (VJ, MJ and CON) and the within subject factor was time (pre-intervention, 2 minutes post-intervention and 6 minutes post-intervention). Mauchly’s test was consulted and Greenhouse-Geisser correction was applied if sphericity was violated. Significant main events observed in the within subject factor for each time point was compared to the baseline and were investigated further with a Bonferroni pairwise comparison. Where significant p values were identified for the interaction effect (time x group), posthoc testing used Cohen’s *d* for each pairwise comparison. The magnitude of effect size was evaluated and considered trivial (<0.2), small (0.2–0.50), moderate (0.50–0.80), and large (>0.80) as proposed by Cohen. Where significant p values were identified for the between group factor, the effect was analysed by simple main effects. Individual performances were recorded and monitored for significant differences from before and after the conditioning activity as well as the percentage of individuals who displayed change. A paired t test was used to compare the baseline and the sprint intervention. The level of significance was set at p < 0.05.

**RESULTS:**

The mean and SD values for the between and within group results are reported in table 1. The pre-intervention baseline testing showed good ICC test-retest reliability of (0.92) and (0.94) for vertical jump height and peak power output, respectively. The vertical jump height was influenced by a significant interaction between time x group, (*F*4, 132 = 5.98, p < 0.001, partial η2 = 0.15) and time (*F*2, 132 = 11.51, p < 0.001, partial η2 = 0.15). There was no significant difference between the groups at baseline (p = 0.947) and the control group did not change across all time points. Relative to the baseline there was a significant difference for VJ (*F*2, 44 = 14.19, p < 0.001, partial η2 = 0.39), at 2 minutes (53.54 cm ± 4.48, p < 0.001) and for MJ (*F*2, 44 = 10.39, ρ < 0.001, partial η2 = 0.32) at 2 minutes (53.49 cm ± 4.15, p = 0.001) for vertical jump height. The between group effects showed no significant difference between the intervention groups and the control group at any time point. However, VJ and MJ were 3.47% and 3.38% higher than CON at 2 minutes respectively.

The mean and SD values for the between and within group results are reported in table 2. The vertical jump peak power output influenced by a significant interaction between time x group, (*F*4, 132 = 6.02, ρ = 0.001, partial η2 = 0.16) and time (*F*2, 132 = 11.52, ρ < 0.001, partial η2 = 0.14). There was no significant difference between the groups at baseline (p = 0.798) and the control group did not change across all time points. Relative to the baseline there was a significant difference for VJ (*F*2, 44 = 14.21, ρ < 0.001, partial η2 = 0.41), at 2 minutes (4366.21 W ± 603.76, p < 0.001) and for MJ (*F*2, 44 = 10.41, p < 0.001, partial η2 = 0.33) at 2 minutes (4312.72 W ± 539.62, p = 0.001) for vertical jump peak power output. The between group effects showed no significant difference between the intervention groups and the control group at any time point. However, VJ and MJ were 4% and 2.80% greater than CON at 2 minutes respectively.

**DISCUSSION:**

This study provides support for our hypothesis that a maximal vertical jump intervention may improve the outcome of a subsequent maximal vertical jump. When compared to a previous reported multiple jump intervention the maximal vertical jump showed enhancements within a similar range after 2 minutes post-intervention. Although not significant, following a standardised soccer warm-up, a maximal vertical jump intervention showed improvements compared to the CON. A small effect size of *d* = 0.40 and 0.32 was found for height and peak power output at 2 minutes. This indicated that there was a small difference in magnitude between the VJ and CON groups. A crossover design may have alleviated this significance issue but was not possible within this population group. Group CON showed no significant change during the testing while both VJ and MJ significantly improved their within condition height and peak power output compared to their baselines. This shows that a maximal vertical jump can improve the outcome of a subsequent maximal vertical jump.

A vertical jump intervention can enhance a subsequent vertical jump within 2 minutes however these enhancements are not maintained 4 minutes later. This is a consideration when preparing athletes for competition or training as many other studies have highlighted the effect of the enhancement/fatigue factor for the delay in this improvement especially after using heavy resistance training as the conditioning activity (4, 16, 17). This heightened fatigue effect from heavy resistance training, which is less evident when ballistic or plyometric conditioning activities are used (23), suggests that heavy resistance training induces more fatigue and thus requires longer recovery until PAPE is reached. Heavy resistance training and plyometric conditioning activities have shown similar PAPE outcomes but with marked differences in time between the conditioning activity and maximal improvements (25). Along with the cumbersome nature of using heavy weights it also becomes a challenge to determine when the associated fatigue has dispelled, and the athlete has achieved their individual enhanced state. Most studies that use body weight or plyometric tasks compared to HRT show quicker recovery times post conditioning activity with neither VJ nor MJ showed diminished performance post-intervention in this study. This has been shown in previous studies where body weight activities (sprints, jumps and plyometric activities) used as the intervention generally display quicker improvements with minimal early fatiguing effects, while more weight added to the intervention, the longer the period between diminished performance to the enhancement (23, 33).

The significant improvements resulting from the within group pre-intervention to the post-intervention outcomes suggests that a maximal vertical jump will result in an improvement in a subsequent maximal vertical jump up to 2 minutes post intervention, in this case vertical height and peak power output. It is also evidence that there was no significant difference between group VJ and MJ at any time. The soccer specific warm-up alone was not sufficient to impact the results of the pre-intervention testing or the post-intervention testing as CON showed no significant improvement after the intervention. This highlights the importance of performing maximal intensity components, with either a vertical and/or a horizontal bias within the warm-up to fully enhance the athlete’s potential prior to participation (8). As this was the standardised warm-up used by this team prior to training and competition and no element fully achieved maximal intensity, it provided support for the hypothesis that maximal intensity is an important contributor in achieving a state of optimal enhancement. This has often been observed in previous studies investigating PAPE where the warm-up prior to baseline is often submaximal (19, 22, 25),and thus provokes a greater PAPE response due to a maximal intensity intervention. Alternatively, if part of the warm-up includes an element of maximal intensity then the PAPE effect is assumed to be less evident (8). Future research should investigate the effect of a maximal intensity warm-up compared to a submaximal intensity warm-up on the effects or PAPE.

The length of PAPE has been reported in different studies as lasting up to 20 minutes post-intervention (9). This investigation attempted to control the feed-forward of the PAPE effects incurred from the pre-intervention baseline testing by allowing each group 20 minutes to dispel any fatigue and/or enhancements. This coupled with group CON not participating in the intervention and displaying no significant change post-intervention in vertical jump height or peak power output showed that the intervention was directly attributed to the subsequent improvements observed in VJ and MJ. As the intensity of the warm-up is proportional to the outcome of the subsequent task, the inclusion of PAPE tasks which are similar in nature and intensity to the final task within the warm-up are fundamental in optimising athletes prior to participation. What was highlighted in this and other studies (8) is that a submaximal warm-up is not sufficient to prepare athletes to produce maximal outputs. Evident in this study is that this submaximal warm-up did not achieve the output figures during the pre-intervention baseline testing observed in the post-intervention testing in the groups which undertook the maximal interventions. In a similar study by Tobin et al. (19) the vertical jump improvements carried through each time point up until five minutes post-intervention, where as in this study the effect lasted up until 2 minutes post-intervention as the outcome had returned to baseline by 6 minutes. This is a conflicting outcome but on examination Tobin et al. (19) retested post-intervention at one, three, and five minutes; every 2 minutes. Each maximal test may have influenced the subsequent test thus maintaining the PAPE effect. Our testing occurred at 2 and 6 minutes with 2 minutes post-intervention sufficient to elicit a PAPE effect. The data from this study suggests that the 4 minutes between the post-intervention at 2 minutes and the post-intervention at 6 minutes was too long to maintain this PAPE effect. Both groups returned to the baseline level in line with the control group by 6 minutes. It was postulated that the nature of a body weight maximal vertical jump is sufficient to induce an initial PAPE effect as indicated at the 2 minute time point and would likely still be present had the post-intervention testing been conducted again at 4 minutes post-intervention due to the testing impulse at 2 minutes (19). But the less weight added to the conditioning activity, the quicker but shorter the PAPE response (22, 23). Future studies should investigate the plausibility that multiple post-intervention testing may influence the later post-intervention outcomes.

**CONCLUSION:**

This study provides important recommendations for coaches looking to benefit from the application of PAPE using simple yet effective tasks within a competition and training environment. The study proposes that 2 maximal intensity vertical jumps, induce a PAPE response in a subsequent maximal vertical jump at 2 minutes post-intervention but not at 6 minutes post-intervention. These enhancements are similar to those observed from a previously defined body weight PAPE intervention of forty jumps and more than a control condition and baseline trial. This effect is immediate with no evident reduction in performance. This provides a practical solution for coaches looking to utilise the PAPE effect within training and competition but also highlights the importance of undertaking a maximal warm-up. In conclusion the implementation of a conditioning activity similar in nature and intensity to the subsequent task may be effective in delivering an enhancement to athletes.

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**Conflicts of interest**

The authors declare no conflict of interest.

**Authors Contributions**

All authors contributed equally to the development and production of the study.

All authors read and approved the final version of the manuscript.

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**APPENDIX:**

**Tables**

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| Table 1. Vertical jump height mean and SD values. | | | | |
|  | **Groups** | **Pre-intervention baseline** | **Post-intervention**  **2 minutes** | **Post-intervention**  **6 minutes** |
| Vertical jump  height (cm) | Vertical Jump  Multiple jump  Control | 51.64 ± 3.72  51.98 ± 4.48  52.04 ± 4.76 | 53.54 ± 4.48\*†  53.49 ± 4.15\*†  51.67 ± 4.94 | 52.23 ± 4.00  52.02 ± 3.84  52.07 ± 5.50 |
| p-value (ES)  ES assessment | Vertical jump compared to control | 1.00 (0.09)  Trivial | >0.05 (0.40)  Small | 1.00 (0.03)  Trivial |
| p-value (ES)  ES assessment | Multiple jump compared to control | 1.00 (0.01)  Trivial | >0.05 (0.39)  Small | 1.00 (0.01)  Trivial |

\* Significantly different from pre-intervention baseline. † Significantly different from post-intervention time point 6 minutes. ES = Effect size, p-value = significant level. No significant between group differences observed.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table 2. Peak power output mean and SD values. | | | | |
|  | **Groups** | **Pre-intervention baseline** | **Post-intervention 2 minutes** | **Post-intervention 6 minutes** |
| Peak power output (W) | Vertical Jump  Multiple jump  Control | 4251.76 ± 558.59  4221.13 ± 520.02  4214.22 ± 450.40 | 4366.21 ± 603.76\*†  4312.72 ± 539.62\*†  4191.67 ± 461.29 | 4286.67 ± 566.89  4223.67 ± 491.36  4216.01 ± 520.69 |
| p-value (ES)  ES assessment | Vertical jump compared to control | 1.00 (0.07)  Trivial | >0.05 (0.32)  Small | 1.00 (0.13)  Trivial |
| p-value (ES)  ES assessment | Multiple jump compared to control | 1.00 (0.01)  Trivial | >0.05 (0.24)  Small | 1.00 (0.02)  Trivial |

\* Significantly different from pre-intervention baseline. † Significantly different from post-intervention time point 6 minutes. ES = Effect size, p-value = significant level. No significant between group differences observed.

Diagram

Description automatically generated

Figure 1. Test protocol for the control and experimental trials.