

**THE ‘REAL WORLD’ APPLICATION OF POSTACTIVATION
POTENTIATION IN A PHYSICAL TRAINING AND COMPETITION
ENVIRONMENT.**

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A Thesis submitted to the Faculty of Health Science, University of the Witwatersrand,
in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2022.

Declaration

I, Nicholas Brink declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Signature of candidate:

A handwritten signature in black ink, appearing to be 'NB', followed by a period.

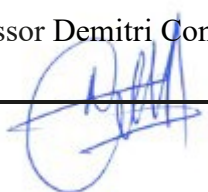
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Declaration: Student's contribution to article(s) and agreement of co-author(s)

I, Nicholas Brink, student number 9801974M, declare that this thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my thesis.

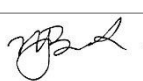
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Article 1: Brink, N.J., Constantinou, D. and Torres, G., (2021). Postactivation performance enhancement (PAPE) of sprint acceleration performance. *European Journal of Sport Science*, pp.1-7. DOI: 10.1080/17461391.2021.1955012

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Dedication

I dedicate this thesis to my wife, Sedisha and son, Zachary for their unwavering support and love and to my parents for raising me to believe in myself.

George Brink
1942 - 2009

Journal submissions and conference presentations arising from this research project.

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Abstract

Postactivation potentiation is a physiological concept that implies that a conditioning activity can enhance the outcome of a subsequent task. These tasks are normally power related activities like maximal sprinting or jumping. This study explored whether postactivation potentiation could be achieved in healthy adults using a bodyweight conditioning activity. Three original studies were conducted as part of this thesis. The researchers conducted study one and two to investigate whether a maximal intensity bodyweight task could induce postactivation potentiation in a similar subsequent task. A randomised controlled trial was conducted in each case. The researchers used study three to investigate whether a body weight conditioning activity could improve the outcome of a subsequent task. A systematic review and meta-analysis were conducted which included the results of study one and two. Study one demonstrated that relative to the baseline there was a significant improvement in the maximal linear sprint group over 10 m and 20 m at two minutes of 0.12 m.s^{-1} and 0.11 m.s^{-1} and at six minutes of 0.11 m.s^{-1} and 0.12 m.s^{-1} respectively. There was also a significant improvement in the control group between two and six minutes post-intervention at 10 m and 20 m of 0.06 m.s^{-1} and 0.08 m.s^{-1} respectively. There was no significant difference between the intervention and control group. Based upon this finding a maximal sprint acceleration may enhance the outcome of a subsequent maximal sprint acceleration. The researchers demonstrated in study two that relative to the baseline there was a significant improvement in the maximal vertical jump group in jump height (1.89 cm) and power output (114.45 W) at two minutes. There was no change in control group across the experiment and no significant difference between the control group and the intervention group. These findings suggests that two maximal vertical jumps may enhance the outcome of a subsequent maximal vertical jump after two minutes. However, these enhancements were not sustained for a further four minutes. Study three demonstrated that there was a small overall effect of 0.30 (95% CI 0.14 to 0.46, $p = 0.0003$) in favour of using a bodyweight conditioning activity to improve the outcome of a subsequent vertical jump or linear sprint. The interpretation of these outcomes indicate that while the enhancement may be small to moderate in effect, they are in favour of using bodyweight conditioning activities to enhance the outcomes of a maximal vertical jump or maximal sprint. Vertical jump and sprint ability are highly associated with performance outcomes in many sports. Bodyweight conditioning activities allows for a simple, yet effective approach

with minimal adverse consequences to achieve postactivation potentiation and an enhanced state of performance prior to participation in a ‘real world’ environment.

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List of Abbreviations

C	Control group, study one
CA	Conditioning activity
cm	Centimetre/s
CON	Control group, study two
<i>d</i>	Cohen's <i>d</i>
ES	Effect size
F	F-value
HRT	Heavy resistance training
kg	Kilogram/s
m	Metre/s
MJ	Multiple jump series group, study two
m.s ⁻¹	Metres per second
n	Number of individuals
η^2	Eta squared
RCT	Randomised control trial
RLC	Regulatory light chain
p	P-value
P	Plyometric group, study one
PAP	Postactivation potentiation
PAPE	Postactivation performance enhancement
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
S	Sprint group, study one
SD	Standard deviation

VJ	Vertical jump group, study two
W	Watt/s
~	Approximately

CHAPTER 1 – Literature Review

Introduction to Postactivation potentiation

Postactivation potentiation (PAP) is a physiological training principle which proposes that a muscle can be acutely optimised through its contractile history. This in turn affects the outcome of a subsequent task. The subsequent task is most often a power-based activity which requires high force production and a high rate of force development such as sprinting, jumping or throwing (Hodgson et al., 2005). Postactivation potentiation has been tested in a variety of sporting environments and different movement patterns with varying degrees of success (Borba et al., 2017). Traditionally, the conditioning activity for PAP was thought to require a heavy resistance isotonic preload stimulus (75-90% of one repetition maximum) to achieve a potentiated state (Hodgson et al., 2005). This required athletes to lift, push or pull heavy weights over a varying range of sets and repetitions to develop a combined effect of heightened muscle activation and consequential fatigue (figure 1). Theoretically, the fatigue dispels first, leaving the muscle in a state of acute enhancement (Rassier and Macintosh, 2000). This effect is referred to as PAP and should generate greater force production and an increase in the rate of force development in a subsequent power-based task. The primary mechanisms of PAP have been discussed in multiple studies (Hodgson et al., 2005; Tillin and Bishop, 2009). These include myosin regulatory light chains phosphorylation, changes in the pennation angle of the fascicle and higher order motor unit recruitment. As the most common theory, phosphorylation of myosin light chains produced an up-regulation in the rate of cross-bridge formation. This results in a faster rate of force development (Sale, 2002). Researchers have proposed that brief maximal voluntary contractions could produce a PAP response as this seems to be associated with an increase in peak rate of force development in a subsequent task (Blazevich and Babault, 2019).

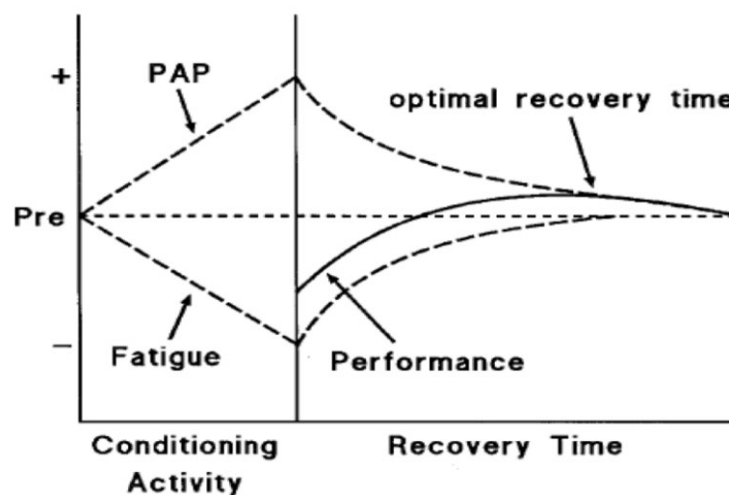


Figure 1 Relationship between postactivation potentiation and fatigue. Adapted from Sale, D. Postactivation potentiation: role in human performance (Sale, 2002).

Recent literature has discussed the association between the commonly used term, PAP, and the less well-known term; postactivation performance enhancement (PAPE) (figure 2). Over the last 20 years conventional concepts proposed that PAP is any acute enhancement lasting up to 20 minutes following a heavy resistance exercise or ballistic task (Wilson et al., 2013). It is proposed that a contraction-initiated increase in myosin regulatory light chain phosphorylation underpins the benefits observed in PAP, including an enhancement in voluntary contractile force (Vandenboom, 2011). However, correctly defined, the term PAP only refers to an enhancement of an evoked twitch response, which is relatively short lived and rapidly decreases after one minute (Vandervoort et al., 1983). In contrast, PAPE is associated with, among other things; voluntary contractions, increases in muscle temperature and several neural mechanisms unrelated to myosin regulatory light chain phosphorylation where muscle twitch has not been directly assessed (Blazeovich and Babault, 2019; Cuenca-Fernandez et al., 2017; Prieske et al., 2018). This thesis does not intend to explore these terms in detail but will use postactivation potentiation or PAP in the traditional sense, to include all muscle enhancements while PAPE will only be used to refer to an acute bout of high intensity voluntary exercise followed by an enhancement in strength, speed or power production (Blazeovich and Babault, 2019; Zimmermann et al., 2020).

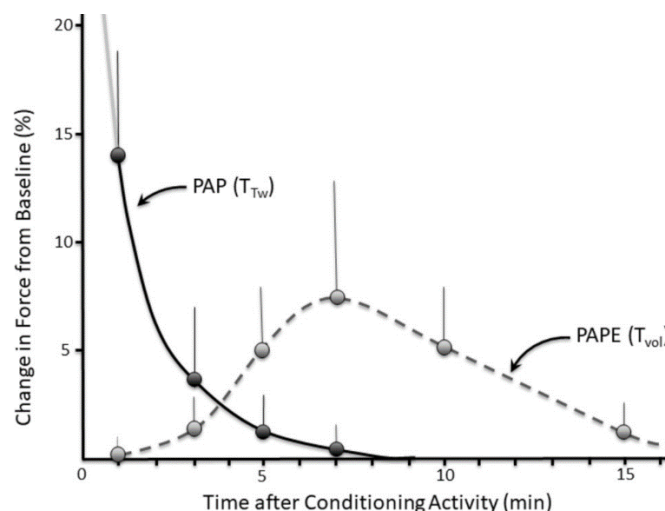


Figure 2 Relationship between postactivation potentiation and postactivation performance enhancement. Adapted from Blazeovich, A. and Babault, N. Postactivation Potentiation Versus Post-activation Performance Enhancement in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues (Blazeovich and Babault, 2019).

Based upon the Henneman size principle, type I low-force muscle fibres are recruited before the type II high-force muscle fibres during activity (Wakeling, 2009). Therefore, to achieve an optimal state of preparation for a high intensity, power-based task, an athlete needs to progress through the type I fibres first (figure 3). This can be achieved through heavy resistance training under maximal exertion (Hodgson et al., 2005) whereby the large type II muscle fibres are activated through high load, low speed activities. The challenge lies in the narrow guidelines in which the PAP principle exists. An athlete's strength and training age, the volume, intensity and recovery period of the conditioning activity, and possibly gender differences have all been reported to affect this outcome, with elite athletes showing the greatest benefits (Seitz and Haff, 2016; Wilson et al., 2013). This lack of irrefutable data makes PAP a questionable training aid rather than a definitive advantage. However, the possibility that a conditioning activity could maximise training practices long term, or acutely optimise an athlete's competitive potential, drives this research forward. Although heavy resistance training has shown positive results, the nature of heavy lifting constrains coaches and athletes to use large pieces of heavy equipment. This coupled with the fact that the PAP effect using heavy resistance training has been reported to be most effective between five to eighteen minutes (Wilson et al., 2013) makes this strategy highly impractical. The goal is to make PAP a viable training and competitive aid to be utilised under 'real world' conditions without the use of laborious gym equipment, excessive space, and unreasonable time frames. This questions the usefulness and functionality of PAP using heavy resistance training and has forced investigators to challenge the narrow parameters and whether partial or full potentiation can occur by an alternative means. In this text, 'real world' is defined as under normal physical training and competition circumstances.

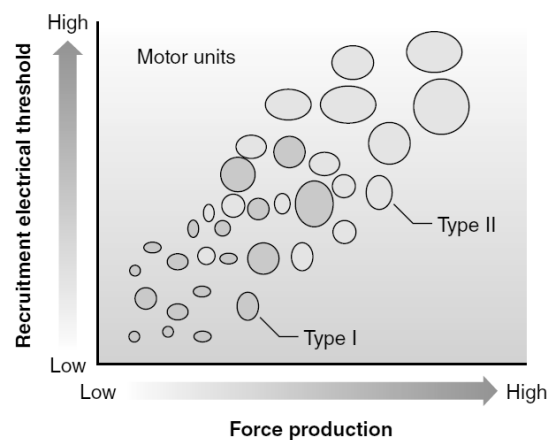


Figure 3 Graphic representation of the size principle, according to which motor units that contain Type I (slow-twitch), and Type II (fast-twitch) fibres are organised based on some “size” factor. Adapted from Duncan French, Adaptations to anaerobic training programs, Chapter 5. Haff GG, Triplett NT, editors. Essentials of strength training and conditioning 4th edition. Human kinetics; 2015 Sep 23.

The following literature review explores other methods to achieve this potentiated state. Recently researchers have investigated the effects of using ballistic type exercises as the conditioning activity to induce maximal recruitment of the type II muscle fibres (Turner et al., 2015; Sharma et al., 2018). These would include high velocity, high power activities with and without an external resistance with a vertical or horizontal bias to achieve a potentiated state. This may highlight the benefits seen when using plyometrics as a chronic or acute training stimulus (Burkett et al., 2005; Hilfiker et al., 2007). This thesis will not separate the terms ballistic and plyometric. Much of the literature reports ballistic and plyometric interchangeably. For the flow of this thesis, the term ballistic will be used unless plyometric has been specifically reported and changes the meaning of the authors intent. Ballistic exercises have shown beneficial effects in achieving PAP and would negate the need to use heavy weights, excessive space, and technically challenging exercises (Maloney et al., 2014). This review will discuss the use of ballistic exercises to induce PAP from three viewpoints. Firstly, to assess the literature on whether ballistic activities with a focus on body-weight tasks have the potential to create a PAP effect. Secondly, to look at activities that use a vertical bias conditioning activity such as jumps or plyometrics. Whether these have the potential to induce a PAP effect in a subsequent task with a vertical bias. Lastly, to look at activities that use a horizontal bias conditioning activity, such as sprinting. Whether these have the potential to induce a PAP effect in a subsequent task with a horizontal bias. Evaluating the quality of the available studies to determine the reliability and the validity of the literature will be integral in determining a need for further investigation. The authors used this literature review to examine the study methods in the available literature to determine the reliability of the results. An essential part of this study will be to provide a practical solution for coaches and athletes on whether PAP using a bodyweight conditioning activity can be used as a performance enhancement tool in a ‘real world’ environment.

Postactivation potentiation using ballistic conditioning activities.

Post-activation potentiation is a physiological concept which suggests that a conditioning activity can enhance the outcome of a subsequent power-based task (Sale, 2002). An athlete's strength and training age, the volume, intensity and recovery period of the conditioning activity, and possibly gender differences have all been reported to affect this outcome, with elite athletes showing the greatest benefits (Seitz and Haff, 2016; Wilson et al., 2013). As previously mentioned, traditionally heavy resistance training has been used as the conditioning activity using a pre-loading stimulus of between 75 – 90% of one repetition maximum prior to a similar power-based task (Hodgson et al., 2005). The aim is to enhance the outcome of this subsequent task. The proposed effect involves greater muscle recruitment of the type II fibres but also an associated fatigue response. As both effects are present simultaneously, the sum of the effects are negated. However, the fatigue effect is reported to dispel first leaving the tissue in a state of acute enhancement (Rassier and Macintosh, 2000). This enhanced effect has been reported to occur anywhere between five and eighteen minutes post conditioning activity (Wilson et al., 2013). However, using heavy resistance training prior to training and especially in competition is impractical, requiring heavy weights (Kilduff et al., 2013) and unpredictable time frames which would be difficult to implement in a 'real world' competition environment.

There is a need to investigate an alternative method to introduce PAP into the athlete's preparation which can be implemented simply with minimal detrimental effects and within a reasonable time frame. There is growing interest in the PAP effects elicited by ballistic type exercises. These are defined as using maximal intensity with the intent to move an object or body as fast as possible (Maloney et al., 2014). This can be achieved with or without an external resistance using one or multiple repetitions where maximal intensity is achieved. This can take the form of activities using a vertical or horizontal bias. The intention is to move quickly rather than the velocity of the object or body which is the driving force behind the acute neural adaptations. These include; increased motor-unit recruitment, rate of force development, and intra- and inter-muscular coordination (Turner, 2009). Whilst ballistic exercises can be undertaken using external resistance, it is the absence of an external resistance which makes this form of exercise more favourable in inducing PAP in a competition and training environment. Heavy resistance training is completely

reliant on heavy weights, space and to a degree technique. An alternative solution to achieve PAP quickly and effectively without placing an excessive reliance on facilities and equipment highlights the potential that ballistic exercises have in the application of PAP in a competition and training environment.

The Henneman size principle suggests that motor units are ramped from the smallest, type I, fatigue resistant fibres to the larger, most powerful type II fibres (Wakeling, 2009). Heavier loads activate a larger pool of the muscle tissue comprising of these type II muscle fibres. Activation of type II muscle fibres has been shown to have a larger capacity to produce a PAP response, indicating why heavier loads produce a greater PAP response in heavy resistance training (Hamada et al., 2003). As ballistic type exercises normally use less load than heavy resistance training, two theories are postulated for the benefits seen using these exercises to induce a PAP response. Firstly, due to the strong intention to move quickly, a ballistic contraction may provide a powerful, excitatory stimulus to activate all the muscle fibres extremely rapidly (Van Cutsem et al., 1998; Desmedt and Godaux, 1977). This is likely due to the lower threshold for motor unit recruitment seen during ballistic exercises compared to heavy resistance training (Van Cutsem et al., 1998; Desmedt and Godaux, 1977). The second theory proposes that selective recruitment exists as an exception to the size principle (Nardone and Schieppati, 1988; Nardone et al., 1989). By utilising high velocity, high power movements, the type I fibres can be surpassed, activating the type IIa and IIx fibres quickly. This form of recruitment may underpin the success seen in ballistic activities and PAP.

An athlete's preparation may play a role in highlighting which conditioning activities could be useful in competition. It is not uncommon for sprinters, jumpers and throwers to engage in some form of sprinting or jumping prior to competing. This is traditionally held to be the final preparation before maximal exertion. If this pre-activity phase can potentiate muscles either partially or fully, then an athlete would prioritise selecting a conditioning activity based on the specificity, and the convenience of this task. Research has demonstrated that using a conditioning activity similar to the subsequent task can enhance performances within specific populations (Smith et al., 2014). Karampatsos et al. (2013; 2017) observed that field event athletes achieved significantly greater throw distances after three vertical jumps or a

20 m sprint at maximal effort. These improvements were observed one minute post conditioning activity, indicating a reasonable time frame, post warm-up but pre-competition, in which PAP could be achieved, however these outcomes were not the athlete's personal best performances in this study. Creekmur et al., (2017) observed that a weighted vertically bias plyometric intervention could improve the outcome of a 20 and 40 yard sprint by 1.15% and 1.24% respectively. This provides further evidence that ballistic activities have the capacity to potentiate power-based tasks. The study showed that using a weighted ballistic vertical jump can produce a potentiated effect which prior to sprinting can improve the performance outcome. This method may be more applicable in a training and competition environment compared to using heavy resistance training. However, this process still requires the use of a weighted plate but does show the potential for ballistic movements to produce a PAP effect.

Smith et al. (2014) attempted to potentiate a 40 yard sprint by using a weighted sled push, a horizontally biased conditioning activity. The results indicated that the heaviest sled, 30% of the individuals body weight, produced the most enhancement in a subsequent 40-yard sprint. More interestingly was that the 'control', an unweighted sled push, produced an enhancement only marginally less than the heaviest intervention. Although the unweighted sled still provided an external resistance other than bodyweight, it could be the intent to move the sled quickly which was the association to producing a PAP effect. As the specific loading of the sled produces varied results, sled pushing may effect different kinematics compared to that of sprinting, bounding or towing (Young, 1992) which may be more specific compared to the subsequent task of a maximal 40 yard maximal sprint. This may suggest that the enhancement is not only to do with load but may also have a strong association to specificity and intensity of the task and the conditioning activity. The authors did acknowledge that this was not a true control which future studies should include.

Research also indicates that jump performance can be improved by using variations of jumping as the conditioning activity (Burkett et al., 2005; Hilfiker et al., 2007). Burkett et al. (2005) reported that a conditioning activity using maximal weighted jump exceeded the outcome of a submaximal vertical jump and a stretching intervention. Although the authors pointed to the external resistance as the primary influencing factors, the maximal intensity

of the effective intervention could also have played a role in enhancing the outcome measurement. The submaximal jump and the stretching intervention both lacked the intention to move quickly. The weighted jumps only involved the participants holding dumbbells equivalent to 10% of the body while jumping on to a box. Load may be a contributing factor but the intention to produce a maximal intensity movement seems more likely to produce PAP in the subsequent task.

Suchomel et al., (2016) suggest that the intensity and velocity of the conditioning activity need to closely mimic the levels achieved during competition or training as it was highly suggestive that this was an important component in achieving PAP. They demonstrated significant improvement in a vertical jump performance following a ballistic half squat compared to a non-ballistic half squat. As both interventions were loaded to 90% of the participants one repetition maximum and performed in either a ballistic or non-ballistic manner, it shows that weight alone is not the primary driver in PAP. This study included a control group who did not undergo the intervention. It could be concluded that the weight alone may have been detrimental to the outcome performance as both the control group and the non-ballistic group only showed trivial improvements. Lim and Kong (2013) found no PAP response following isometric knee extension and isometric squat. This indicates the associated importance attributed to the ballistic nature of the conditioning task as no benefit was found using isometric or a dynamic heavy slow resistance intervention on sprint outcomes. Seitz and Haff, (2016) found significant negative effects associated with maximal isometrics on performance outcomes. Burkett et al. (2005) also found that a maximal jump although weighted, was far superior to sub-maximal variations confirming the importance of velocity and intensity of the conditioning task in PAP.

To this researcher's knowledge, no systematic review has been done on the effects of PAP using bodyweight conditioning activities within a reasonable time frame to be useful in a competition environment. This lack of cohesion makes it difficult to create specific individualised programmes for athletes within the competition environment. For this reason, it is important to correlate the available information allowing for better understanding of this principle. This thesis investigated the effect of PAP through a systematic review and meta-analysis, linked with the hypothesised results of study one, PAP of sprint acceleration

performance and study two, PAP using a vertical jump to improve vertical jump performance. This is useful as it provides more insight into the potential effectiveness of bodyweight conditioning activities to potentiate subsequent tasks and provides coaches, trainers, and rehabilitation professionals clear options to improve training impulses and competition performances.

Postactivation potentiation using a vertical jump to potentiate a vertical jump.

There are indications that PAP can be achieved using both weighted and bodyweight ballistic tasks, which in the right circumstances can positively affect the outcome of a subsequent task (Dobbs et al., 2019; Seitz and Haff, 2016; Wilson et al., 2013). This suggests that PAP could be used as a long-term training aid and theoretically a competition enhancement within a 'real world' competition environment. Researchers advocate that ballistic type conditioning activities using bodyweight tasks to achieve PAP (Turner et al., 2015; Healy and Comyns, 2017; Smith et al., 2014) provide a practical training and competitive solution. The goal is to achieve PAP with minimal disruption to the athlete's preparations within a reasonable time frame, while achieving positive outcomes which outweigh any negative effects such as induced fatigue. This would allow athletes to specifically focus their warm-ups using minimal equipment, within reasonable space and time. Through testing and a developed protocol, athletes can maximise their ability to potentiate prior to training or competition.

Mola, Bruce-Low and Burnet, (2014) investigated the recovery time for PAP in soccer players and found that heavy resistance training had a reduced global effect compared to the control group. This study provides some interesting reflections regarding bodyweight ballistic type exercises compared to heavy resistance training. The investigators assessed two groups, the control who did not participate in the intervention and the experimental group who did a three-repetition maximum squat intervention. Both groups undertook a vertical jump measurement at baseline and a vertical jump outcome measurement post intervention. Although no significant benefit was observed in either group, what is interesting is that the control group had no positive or negative feed-forward effect from the baseline testing to the post intervention testing which were ten minutes apart. As reported by Seitz and Haff (2016), voluntary movements undertaken at maximal intensity are likely

to induce a PAPE effect. Therefore, it is likely that the baseline testing would have a PAPE response for some time after the testing finished. Although this was not addressed in this study, it may indicate that bodyweight ballistic type exercises, the PAP effect is exposed sooner with less early post intervention fatigue deficits. Despite not discussed in this study, it was hypothesised that heavier load will induce a greater PAP response but with an associated greater fatigue response. This will create a longer latent period as the fatigue takes longer to dispel before the PAP effect is exposed. As ballistic type exercises use less load it is conceivable that there would be a smaller PAP effect but similarly a smaller fatigue effect. The fatigue effect dispels quicker with ballistic type exercises, so the PAP effect is exposed sooner with less early post intervention fatigue deficits. It has been reported that heavy resistance training and ballistic type exercises produce similar outcomes, but heavy resistance training takes longer (Seitz and Haff, 2016). Seitz and Haff, (2016) reported in a systematic review that traditional heavy resistance training produced a similar effect size ($ES = 0.41$) to a ballistic type conditioning activity ($ES = 0.47$). The authors did highlight that at the time of writing only a limited number of studies had published data on ballistic type conditioning activities, whereas extensive investigation had been done on heavy resistance training. Nevertheless, it appears that although the magnitude of improvement is similar, the PAP effect is observed earlier ($<5\text{min}$) in the ballistic group compared to the heavy resistance group ($>5\text{min}$).

Tobin and Delahunt, (2014) and Sharma et al., (2018) used a similar methodology to compare a conditioning activity of a series of forty plyometric jumps on the performance of a vertical jump. Tobin and Delahunt (2014) demonstrated improvements at five time points (2.09cm – 2.87cm) post conditioning activity. There was no external resistance added to the participants. This highlights the improvements observed following a bodyweight ballistic intervention on a power-based outcome measure, a vertical jump. The outcome measurements demonstrated improvement at each time point post intervention. However as previous testing could have influenced the results, only the first outcome measurement at one minute could be directly attributed to the intervention. This provides evidence as to the early benefits observed by using a bodyweight conditioning activity to enhance the outcome in a similar power-based task. Other than the volume of jumps and equipment required like hurdles, the principle demonstrated promise as a PAP inducer for a competitive and training environment.

Sharma et al., (2018) demonstrated that multiple unweighted ballistic tasks had a greater effect on the vertical jump performance (3.87cm) compared to that of a 90% 1- rep max heavy resistance training (2.77cm) intervention at 10 minute post baseline testing. This indicates that bodyweight plyometrics may play a superior role in acutely potentiating muscle tissue. However, two potential flaws existed in this study. Firstly, the investigation conducted baseline testing within three minutes of the intervention. As this testing consisted of two maximal ballistic tasks, vertical jumps and a 20 m sprint, one or both of these activities could have had an effect on the intervention and the outcome measurements. Secondly, as the investigators considered two different baseline and outcome measurements, whichever one was conducted first would potentially influence the other measurement. This questions the validity of the study's methodology and the reliability of the results. However, both groups participated in the same protocol with only the interventions differing. This may suggest that the ballistic intervention has potential to produce a greater PAP effect compared to a heavy resistance training.

If benefits occur in vertical jumps with jump variations including drop jumps (Hilfiker et al., 2007) and depth jumps (Masamoto et al., 2003), then similar benefits are hypothesised with vertical jumps as the conditioning activity. Hilfiker et al., (2007) found that including a depth jump in a warm-up improved the outcome of a subsequent vertical jump. It is important to note that a bodyweight variation of a vertical jump can enhance the outcome of a subsequent jump without the need of an external resistance. This may indicate that specificity to the subsequent task and the intensity of the conditioning activity are key components in PAP. Coaches closely emulate the tasks and skills required in competition within the warm-up phase, both during training and competition to affect the specificity principle. There is a positive performance correlation between a sport and the warm-up processes (Russell et al., 2015). Similarly, the effectiveness of PAP is determined by how closely the conditioning activity relates to the subsequent task (Till and Cooke, 2009). Van den Tillaar, Lerberg and von Heimburg, (2019) demonstrated that specificity is an important constituent in the development of a potentiated outcome. A warm-up with activities similar to the subsequent task was used with significant benefit compared to an alternate non-specific warm-up. Burkett, Phillips and Ziuraitis, (2005) investigated the effect of intensity

and specificity of four warm-up tasks on the outcome of a vertical jump, and found a correlation between both the intensity and specificity of the conditioning activity on the subsequent task. The concept of the RAMP warm-up is well known and utilises a variety of similar exercise to potentiate athletes prior to maximal competition or training (Van den Tillaar, Lerberg and von Heimburg, 2019). Where this thesis diverges from the standard RAMP protocol is attempting providing evidence that an activity, like a vertical jump can potentiate the same subsequent activity as effectively as a range of similar conditioning tasks.

Vertical power is an important attribute to athletic performance. If athletes and coaches are presented with a method to improve vertical jump performance without the use of external resistance equipment, while using a simple approach which is easy to administer with minimal negative effects, the benefit is evident. Researchers have shown that ballistic exercises can improve power-based activities. This evidence also highlights those ballistic tasks can produce an effect quickly (<5min) and with minimal negative consequences. The intensity and the specificity of the conditioning activity are important constituents in achieving PAP. There seems to be a general agreement that exercises which are similar in nature (Van den Tillaar et al., 2019) and intensity (Suchomel et al., 2016) provide a better response especially with the vertical jump. It is these components which this study investigated, with the purpose to expand the current pool of knowledge and broaden the existing parameters, with a view to translating to ‘real world’ applications.

Postactivation potentiation using a maximal sprint to potentiate a maximal sprint.

Sprinting, especially distances up to and including one hundred metres are almost exclusively anaerobic (Duffield and Dawson, 2003), requiring high force production and rate of force development. Success or failure is measured in milliseconds, where even a partial enhancement could affect positioning, creating opportunities and success. There is a reasonable body of research; exclusively with individual athletes, to suggest that PAP could improve realistic competitive performances (Karampatsos et al., 2013; Karampatsos et al., 2017). The guidelines for PAP exist in narrow parameters with most studies suggesting individualisation of the conditioning activities to achieve the desired effect while the effects associated with team sports are as yet unavailable in competition and limited to isolated

testing scenarios in training (Tobin and Delahunt, 2014). Smith et al. (2014) attempted to potentiate athletes with loaded sled pulls over 20 m accelerations with some success, however the unloaded sled also showed significant benefits. This indicates that high intensity running without excess weight; less than 10% body weight, may achieve similar benefits observed in high intensity weighted runs with up to three times body weight.

Turner et al. (2015) demonstrated how bodyweight bounding; a similar action to high intensity running (Young, 1992), acutely enhanced 10 m and 20 m sprint performance. This study compared two interventions against a control condition. One group performed bounding while the second group performed bounding with a weighted vest at 10% of the participants' bodyweight. Both groups improved compared to the control. However, the bodyweight group showed improvement between two and four minutes while the weighted vest group only showed maximal improvement by eight minutes post intervention. Notable in this study is that a horizontal bias conditioning intervention in both weighted and bodyweight effected a positive change in a horizontal bias outcome measurement (maximal sprint). Issues pertaining to the study revolve around the application of multiple time points for outcome measurements. This effectively means that the latter results could not be directly attributed to the interventions as the participants have been exposed to earlier testing which may enhance or decrease the subsequent outcomes. Regardless, this does provide some evidence on the benefits of maximal intensity and specific conditioning activities on similar outcome measures. If athletes can achieve similar potentiated effects using simpler conditioning activities, then the benefit is evident.

Van den Tillaar, Lerberg and von Heimburg, (2019) investigated the effect of a slower warm-up involving dynamic exercises and jogging to a similar warm-up with increasing intensity sprinting. The investigators intended to investigate whether the duration of the warm-up or the intensity and specificity of the warm-up was more influential in improving the outcome of a subsequent sprint. The outcome suggested that the longer, less specific warm-up had less influence on the sprint performance when compared to the longer specific and shorter specific warm-ups. Both involved a gradual increase in the velocity of the final warm-up runs culminating in a maximal effort prior to the outcome measurement. It was also reported that the participant's perceived exertion was significantly less after the shorter specific warm-up compared to the longer specific warm-up. This is important as it highlights

the importance of developing warm-up practices which athletes are more likely to adopt and that potentially allow time to focus on other important aspects of the warm-up such as technical or tactical skills in team sports. The higher velocity warm-up showed significantly greater improvements over the timed distance.

Watterdal (2013) exposed participants to a longer warm-up of 35 minutes which consisted of five maximal sprints prior to a 60 m sprint outcome measurement and a shorter warm-up of ten minutes with a single maximal sprint. A control condition was also included. Although no significant difference was found between the groups, possibly due to the small sample size ($n=5$), the result demonstrated that most of the participants ran the quickest 60 m following the shorter warm-up. The author discusses that the longer warm-up may induce fatigue prior to the outcome measurement. However, this does provide some indication that a maximal horizontal effort as part of a warm-up may be able to induce a PAP effect in a subsequent horizontal bias task, in this case sprinting. The participants also reported their satisfaction with each of the warm-ups and there was a clear approval rating of 6.9/10 for the shorter warm-up compared to a 5.9/10 for the longer warm-up and less for the control condition. This highlights that athletes may prefer to have a warm-up that is not only effective but also simple to implement which is perceived as not interfering with the competition or training preparation.

The possibility that an athlete has the potential to compete at an elevated state of activation or to achieve a greater training stimulus drives PAP research forward. Silva et al. (2018) found that sprints at the end of a warm-up possibly improves athletic performance by 2-3% which is in line with the reported benefits of PAP using ballistic exercises (Creekmur et al., 2017). The challenge is to achieve these benefits within reasonable warm-up time frames. By using highly fatiguing or excessively long conditioning activities, the less likely athletes will incorporate these with their competition preparations. As PAP exists in narrow parameters, it is important that researchers challenge the current understanding and expand the pool of knowledge to make PAP a useful competition adjunct. PAP needs clear parameters and simple processes for athletes to achieve the benefits, while remaining in a state of focus prior to the event.

In many sports, athletic potential is related to one's ability to run fast. Where this thesis diverges for the standard warm-up protocol is providing evidence that an activity, such as a maximal sprint or vertical jump can potentiate the same subsequent activity as effectively and slightly better than a range of similar conditioning tasks. As this fall within the warm-up paradigm, it is understandable to consolidate these PAPE conditioning activities into this phase. However, as the sprint precedes the specific intent of undertaking a maximal sprint, then I would classify them as a conditioning activity. Many other factors influence an athlete's success especially in a team sport setting. However, if a certain strategy can assist in acutely affecting an athlete's performance outcomes with minimal effort, facilities, or time constraints, it seems worth considering. The evidence points to shorter, more specific, more intense warm-ups being preferred by athletes. It is also clear that doing more to induce a positive change may also be detrimental. This study intends to investigate the link between specificity and intensity with a participant's ability to produce an enhanced outcome, specifically by using a sprint to potentiate a subsequent sprint.

Conclusion

Postactivation potentiation is a principle which suggests that an athlete can acutely enhance the potential of a subsequent task by undertaking some form of conditioning activity. This review has discussed the traditional approach to producing a PAP effect using heavy resistance training and has discussed why this is impractical in a 'real world' competition environment. The review highlighted the some of the potential benefits which ballistic type exercises hold in producing a full or partial PAP response. Along with requiring less equipment, space and time it was also preferred in many cases by the athletes themselves. It is for this reason that these studies will investigate whether ballistic tasks such as a vertical jump, a sprint or another sports specific conditioning activity can potentiate a similar subsequent task and whether this is a viable and practical intervention to introduce to coaches and athletes as part of their warm-ups in a 'real world' competition and training environment.

Aims and objectives of the thesis.

This thesis aimed to provide an alternative, practical coaching solution for athletes to achieve PAP simply and quickly in a training and competition environment. Specifically, the thesis determined whether bodyweight, ballistic tasks can be used as conditioning activities to achieve PAP. Three studies were performed. Study one and study two used a randomised controlled trial methodology to investigate whether a vertical and horizontal bias bodyweight conditioning activity can affect an outcome measurement of a similar subsequent activity. This allowed for a comparison of not only the outcome measurement within the group relative to a baseline measurement but also between the groups, as a control condition was used. It was also important to determine the magnitude of the outcome. This was done firstly by introducing a third group which undertook an intervention previously investigated and shown to have a PAP benefit and secondly determined the effect size associated with both interventions compared to the control condition. The results were not only reliable as strong scientific rigour was applied but also valid. Study three used a systematic review and meta-analysis to investigate the effect of using a bodyweight conditioning activity and included the results obtained from study one and study two. This included strict inclusion criteria and followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines to evaluate these studies and other studies to synthesise and summarise the results.

Aim

To determine if bodyweight conditioning activities similar in type and intensity to the subsequent task result in a PAP response

Objectives

- To assess whether a maximal vertical jump can potentiate a subsequent vertical jump.
- To assess whether a maximal sprint effort can potentiate a subsequent sprint effort.
- To analyse the available data on PAP using bodyweight tasks through a systematic review and meta-analysis.
- To make recommendations for the application of PAP in a ‘real world’ sporting environment.

References

1. Blazevich, A.J. and Babault, N., (2019). Post-activation Potentiation (PAP) versus Post-activation Performance Enhancement (PAPE) in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, 10, p. 1359.
2. Borba, D.d.A., Ferreira-Júnior, J.B., Santos, L.A.d., Carmo, M.C.d. and Coelho, L.G.M., (2017). Effect of post-activation potentiation in Athletics: a systematic review. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 19(1), pp. 128-138.
3. Burkett, L.N., Phillips, W.T. and Ziuraitis, J., (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), pp. 673-676.
4. Creekmur, C.C., Haworth, J.L., Cox, R.H. and Walsh, M.S., (2017). Effects of plyometrics performed during warm-up on 20 and 40 m sprint performance. *J Sports Med Phys Fitness*, 57(5), pp. 550-555.
5. Cuenca-Fernandez, F., Smith, I.C., Jordan, M.J., MacIntosh, B.R., Lopez-Contreras, G., Arellano, R. and Herzog, W., (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. *Applied Physiology Nutrition and Metabolism*, 42(10), pp. 1122-1125.
6. Desmedt, J.E. and Godaux, E., (1977). Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis anterior muscle. *The Journal of physiology*, 264(3), pp. 673-693.
7. Dobbs, W.C., Toluoso, D.V., Fedewa, M.V. and Esco, M.R., (2019). Effect of Postactivation Potentiation on Explosive Vertical Jump: A Systematic Review and Meta-Analysis. *J Strength Cond Res*, 33(7), pp. 2009-2018.
8. Duffield, B. and Dawson, B., (2003). Energy system contribution in track running. *New Studies in Athletics*, 18(4), pp. 47-56.

9. Hamada, T., Sale, D., MacDougall, J. and Tarnopolsky, M., (2003). Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. *Acta physiologica scandinavica*, 178(2), pp. 165-173.
10. Healy, R. and Comyns, T.M., (2017). The Application of Postactivation Potentiation Methods to Improve Sprint Speed. *Strength and Conditioning Journal*, 39(1), pp. 1-9.
11. Hilfiker, R., Hubner, K., Lorenz, T. and Marti, B., (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research*, 21(2), pp. 550-555.
12. Hodgson, M., Docherty, D. and Robbins, D., (2005). Post-activation potentiation - Underlying physiology and implications for motor performance. *Sports Medicine*, 35(7), pp. 585-595.
13. Karampatsos, G., Terzis, G., Polychroniou, C. and Georgiadis, G., (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education & Sport*, 13(1), pp. 3-5.
14. Karampatsos, G.P., Korfiatis, P.G., Zaras, N.D., Georgiadis, G.V. and Terzis, G.D., (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), pp. 359-364.
15. Kilduff, L.P., Finn, C.V., Baker, J.S., Cook, C.J. and West, D.J., (2013). Preconditioning Strategies to Enhance Physical Performance on the Day of Competition. *International Journal of Sports Physiology & Performance*, 8(6), pp. 677-681.
16. Lim, J.J. and Kong, P.W., (2013). Effects of isometric and dynamic postactivation potentiation protocols on maximal sprint performance. *J Strength Cond Res*, 27(10), pp. 2730-2736.
17. Maloney, S.J., Turner, A.N. and Fletcher, I.M., (2014). Ballistic exercise as a pre-activation stimulus: a review of the literature and practical applications. *Sports Med*, 44(10), pp. 1347-1359.

18. Masamoto, N., Larson, R., Gates, T. and Faigenbaum, A., (2003). Acute effects of plyometric exercise on maximum squat performance in male athletes. *The Journal of Strength & Conditioning Research*, 17(1), pp. 68-71.
19. Mola, J.N., Bruce-Low, S.S. and Burnet, S.J., (2014). Optimal recovery time for postactivation potentiation in professional soccer players. *J Strength Cond Res*, 28(6), pp. 1529-1537.
20. Nardone, A., Romano, C. and Schieppati, M., (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of physiology*, 409(1), pp. 451-471.
21. Nardone, A. and Schieppati, M., (1988). Shift of activity from slow to fast muscle during voluntary lengthening contractions of the triceps surae muscles in humans. *The Journal of physiology*, 395(1), pp. 363-381.
22. Prieske, O., Maffiuletti, N.A. and Granacher, U., (2018). Postactivation Potentiation of the Plantar Flexors Does Not Directly Translate to Jump Performance in Female Elite Young Soccer Players. *Frontiers in Physiology*, 9.
23. Rassier, D. and Macintosh, B., (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research*, 33(5), pp. 499-508.
24. Russell, M., West, D.J., Harper, L.D., Cook, C.J. and Kilduff, L.P., (2015). Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations. *Sports Medicine*, 45(3), pp. 353-364.
25. Sale, D.G., (2002). Postactivation potentiation: role in human performance. *Exercise and sport sciences reviews*, 30(3), pp. 138-143.
26. Seitz, L. and Haff, G., (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports Medicine*, 46(2), pp. 231-240.
27. Sharma, S.K., Raza, S., Moiz, J.A., Verma, S., Naqvi, I.H., Anwer, S. and Alghadir, A.H., (2018). Postactivation Potentiation Following Acute Bouts of Plyometric versus

- Heavy-Resistance Exercise in Collegiate Soccer Players. *Biomed Res Int*, 2018, p. 3719039.
28. Silva, L.M., Neiva, H.P., Marques, M.C., Izquierdo, M. and Marinho, D.A., (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, 48(10), pp. 2285-2299.
 29. Smith, C.E., Hannon, J.C., McGladrey, B., Shultz, B., Eisenman, P. and Lyons, B., (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), pp. 33-41.
 30. Suchomel, T.J., Sato, K., DeWeese, B.H., Ebben, W.P. and Stone, M.H., (2016). Potentiation effects of half-squats performed in a ballistic or nonballistic manner. *Journal of strength and conditioning research*, 30(6), pp. 1652-1660.
 31. Till, K.A. and Cooke, C., (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J Strength Cond Res*, 23(7), pp. 1960-1967.
 32. Tillin, N.A. and Bishop, D., (2009). Factors Modulating Post-Activation Potentiation and its Effect on Performance of Subsequent Explosive Activities. *Sports Medicine*, 39(2), pp. 147-166.
 33. Tobin, D.P. and Delahunt, E., (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *J Strength Cond Res*, 28(2), pp. 367-372.
 34. Turner, A.N., (2009). Training for power: Principles and practice. *Professional Strength & Conditioning*, (14), pp. 20-32.
 35. Turner, A.P., Bellhouse, S., Kilduff, L.P. and Russell, M., (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res*, 29(2), pp. 343-350.
 36. Van Cutsem, M., Duchateau, J. and Hainaut, K., (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *The Journal of physiology*, 513(1), pp. 295-305.

37. Van den Tillaar, R., Lerberg, E. and von Heimburg, E., (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*. 8(6), pp. 574-578.
38. Vandenboom, R., (2011). Modulation of skeletal muscle contraction by myosin phosphorylation. *Comprehensive Physiology*, 7(1), pp. 171-212.
39. Vandervoort, A., Quinlan, J. and McComas, A., (1983). Twitch potentiation after voluntary contraction. *Experimental neurology*, 81(1), pp. 141-152.
40. Wakeling, J.M., (2009). Patterns of motor recruitment can be determined using surface EMG. *Journal of Electromyography and Kinesiology*, 19(2), pp. 199-207.
41. Watterdal, Ø., (2013). The impact of warm up intensity and duration on sprint performance.
42. Wilson, J.M., Duncan, N.M., Marin, P.J., Brown, L.E., Loenneke, J.P., Wilson, S.M., Jo, E., Lowery, R.P. and Ugrinowitsch, C., (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), pp. 854-859.
43. Young, W., (1992). Sprint bounding and the sprint bound index. *NSCA J*, 4(6), pp. 44-44.
44. Zimmermann, H.B., MacIntosh, B.R. and Dal Pupo, J., (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology Nutrition and Metabolism*, 45(4), pp. 349-356.

**CHAPTER 2 – Study one: Brink N, Constantinou D, and Torres G (2021)
Postactivation performance enhancement (PAPE) of sprint acceleration performance,
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At the time of this thesis submission, study one was published in the European Journal of Sports Science, as an original article (Appendix 9). The original content has not been altered but figures, tables, and captions as well as referencing style have been adapted and are presented in line with the thesis format. Postactivation performance enhancement (PAPE) will be used in this study to refer to an acute bout of high intensity voluntary exercise followed by an enhancement in strength, speed or power production.

1. Original study

Title: Postactivation performance enhancement (PAPE) of sprint acceleration performance

Authors: Nicholas Brink, Demitri Constantinou, Georgia Torres

Abstract

Postactivation performance enhancement (PAPE) is a principle that an acute bout of high intensity voluntary exercise is followed by an enhancement in strength, speed, or power production. As an integral part of the warm-up, this study intended to show a direct correlation between intensity, specificity, and the outcome of a maximal task of sprint accelerations compared to a previously defined weighted plyometric intervention. In a randomised controlled, double-blind trial, adult professional footballers undertook 20 m maximal sprint accelerations at a baseline and at two and six minutes post-intervention after one of three interventions; two repetitions of 20 m sprint accelerations (S), 3x10 alternative leg weighted bounding (P) and control (C). All the baseline outcomes were similar between the groups. Relative to the baseline there was a significant improvement for S over 10 m and 20 m at two minutes of $0.12 \text{ m}\cdot\text{s}^{-1}$ and $0.11 \text{ m}\cdot\text{s}^{-1}$ and at six minutes of $0.11 \text{ m}\cdot\text{s}^{-1}$ and $0.12 \text{ m}\cdot\text{s}^{-1}$. Relative to the baseline P also had a significant improvement over 10 m and 20 m at two minutes $0.09 \text{ m}\cdot\text{s}^{-1}$ and $0.09 \text{ m}\cdot\text{s}^{-1}$ and at six minutes of $0.11 \text{ m}\cdot\text{s}^{-1}$ and $0.09 \text{ m}\cdot\text{s}^{-1}$. There was also a significant improvement in C between two and six minutes post-intervention at 10 m and 20 m of $0.06 \text{ m}\cdot\text{s}^{-1}$ and $0.08 \text{ m}\cdot\text{s}^{-1}$. There was no significant difference between the interventions and C. This finding suggests that a maximal sprint acceleration may enhance the outcome of a subsequent maximal sprint acceleration at two minutes, but the latter results could not be directly attributed to the interventions as previous testing is likely to have influenced these outcomes.

Key words: PAPE; intensity; PAP; specificity; plyometric; sprinting.

Introduction

Sprinting requires a high rate of force production that is linked to acceleration, speed, change of direction and power and relates directly to training effect and competition outcomes (Colyer et al., 2018; van den Tillaar et al., 2019). The warm-up plays an important role in enhancing or diminishing this desired effect so even small deviations; especially evident in isolated sprinting events, can influence success or failure (Gil et al., 2019). When preparing for maximal exertion, maximal sprinting is often incorporated as the apex of the warm-up sequence (Silva et al., 2018). There is evidence that high velocity, high intensity tasks at the end of a warm-up can acutely enhance an athletes' potential which exceeds the enhancement attained by a submaximal warm-up alone (van den Tillaar et al., 2019). In this study, postactivation potentiation (PAP) will refer to enhancements in muscle twitch response while postactivation performance enhancement (PAPE) will refer to an acute bout of high intensity voluntary exercise followed by an enhancement in strength, speed or power production (Blazevich and Babault, 2019; Zimmermann et al., 2020).

Postactivation performance enhancement is a physical training principle which proposes that a muscle can be acutely optimised by its contractile history, which in turn affects the outcome of a subsequent task (Hodgson et al., 2005; Lorenz, 2011). There is a plethora of evidence linking heavy resistance training (HRT) with a PAPE response using a heavy resistance isotonic preload stimulus (75-90% 1RM) to achieve this enhanced state (Hodgson et al., 2005; Matthews et al., 2004; Wilson et al., 2013). Although HRT has shown effective results, the nature of heavy lifting constrains coaches and athletes to use equipment and requires individualised time frames to dispel the associated fatigue consequence, making this strategy impractical in a training and competitive environment (Wilson et al., 2013). These effects are untested in a competition environment especially in team sports and limited to isolated testing scenarios in training (Bevan et al., 2010; Tobin and Delahunt, 2014). The guidelines for PAPE using HRT exist within narrow parameters with a high proportion of non-responders prompting cautionary recommendations from investigators to individualise the delay times after the conditioning activity (CA) to achieve the desired effect (Wilson et al., 2013). However, there seems to be a proportional association between the specificity and the intensity of the CA and PAPE which has been similarly defined in many warm-up practices (Burkett et al., 2005; Russell et al., 2015; van den Tillaar et al., 2019). This concept suggests that athletes could optimize prior to performing a maximal activity by using a CA similar in nature and intensity to the expected outcome (Suchomel et al., 2017).

There is a growing interest in the PAPE effects elicited by ballistic movements and plyometrics. By utilising high velocity, high power movements, the larger muscle fibers can theoretically be recruited extremely quickly, underpinning the success seen with plyometrics and PAPE (Maloney et al., 2014). Although much of the research associated with PAPE and plyometrics involves a weighted CA, (Piper et al., 2020) unweighted activities have also shown improvements (Turner et al., 2015). Research suggests that using an unweighted CA very similar to the final task can enhance performances within specific populations as much as a comparable weighted CA (Smith et al., 2014). Karampatsos et al. (2013; 2017) observed that field event athletes achieved significantly greater throw distances 1 minute after a 20 m sprint at maximal effort in training. Sharma et al (2018) showed that multiple unweighted plyometric tasks had a greater effect on a 20 m sprint performance compared to that of HRT, suggesting that unweighted plyometrics may play an important role in acutely enhancing muscle tissue, a concept reiterated by Creekmur et al. (2017). Smith et al. (2014) found that unloaded sled pull improved athletes 20 m sprint times as much as weighted sled pulls. This indicates that high intensity running without excess weight may have similar benefits to high intensity weighted runs. Turner et al. (2015) demonstrated how body-weighted bounding; an action similar to high intensity running (Young, 1992) acutely enhanced 10 m and 20 m sprint accelerations.

Common aspects associated with PAPE seem to include the specificity to the outcome task and the intensity of the CA. Coaches would closely emulate the tasks and skills required in competition within the warm-up phase to affect this specificity principle. There is a positive performance correlation between a sport and its warm-up processes (Russell et al., 2015). Similarly, a common theme relating to the effectiveness of PAPE, is how closely the CA relates to the outcome task (Till and Cooke, 2009). Van den Tillaar et al. (2019) found that specificity is an important constituent in the development of an enhanced outcome. A warm-up with activities similar to the subsequent task were used with significant benefit compared to an alternate non-specific warm-up. Van den Tillaar et al. (2019) also investigated the effect of a slower warm-up involving dynamic exercises and jogging to a similar warm-up with increasing intensity sprinting. The higher velocity warm-up showed significantly greater improvements over the timed distance. Silva et al. (2018) found that sprints at the end of a warm-up improves athletic performance by 2-3% which is in line with the reported benefits of PAPE using plyometrics (Creekmur et al., 2017)

This study intended to demonstrate how a CA similar in specificity and intensity to a sprint acceleration could be used to improve a subsequent sprint acceleration over 10 m and 20 m. It was hypothesised that this sprint acceleration intervention would improve a subsequent sprint acceleration as much as a previously defined weighted, plyometric PAPE intervention, and more than that of a control group.

Methods

Study design

A randomised, double-blinded controlled study design was used to compare the effects of a maximal sprint accelerations in relation to a weighted plyometric activity and a control condition on the outcome of 20 m sprint accelerations. Although a crossover design might have been better, 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).

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 squat strength [absolute squat 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 randomly and uniformly allocated to either; the sprint acceleration group (S), the plyometric group (P) or the control group (C) by an independent assessor 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. A minimum sample of 69 (effect size = 0.54, 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 sprint velocity over 20 m influenced by time x condition interaction from Turner et al (Turner et al., 2015).

Procedures

All participants had height in meters (Charder, portable height measure unit; Fizique, Johannesburg, RSA) and mass in kilograms (Charder, electric scale; Fizique, Johannesburg, RSA) measurements recorded prior to the testing. Testing occurred 48-hours after the most recent training session. Each randomised group was separated from the other groups allowing for blinding to the different interventions. A designated member of the coaching staff (UEFA A-licensed), familiar with the testing procedure was selected to administer the warm-up, intervention, pre- 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.

Participants reported to training as normal and undertook a standardised preparation football warm-up of approximately 20 minutes consisting of jogging, dynamic stretching, body preparation exercise, submaximal sprints; up to ~90%, submaximal plyometrics and six vs two, five minute rondos (small-sided possession games). The warm-up and testing occurred on a football pitch, with football boots which the participants were accustomed to using. After the warm-up, the participants progressed to the maximal baseline testing; 2 x 20 m pre-intervention sprint accelerations, with timing gates at the start, 10 m, and 20 m. This was followed by low intensity ball related games (head tennis) for 20 minutes to maintain an estimated elevated body temperature but expel any potential PAPE effects accrued during the baseline testing (Maloney et al., 2014). After 20 minutes S, P and C performed their individual interventions.

Intervention

To account for the possible PAPE and fatiguing consequences of the intervention testing, C participated in the pre-intervention testing and the post-intervention testing while omitting the intervention. A 20 minute period between the pre-intervention testing and the intervention was used to ensure that any PAPE effects incurred during the pre-intervention testing were completely dispelled prior to performing the interventions, a consequence not previously discussed in previous studies (Vandenboom, 2011; Turner et al., 2015).

The S group participants performed two maximal sprint accelerations over 20 m at 95% or above of their baseline maximum to account for specificity and intensity. The P group

participants undertook 3 sets of 10 weighted alternative leg bounds as defined by Turner et al. (2015) using 10% body mass weighted vests (Fit for Life, adjustable weighted vest; Fizique, Johannesburg, RSA). It is worth noting that the investigators used this intervention exactly as described by Turner et al. (2015), however the pre- and post-intervention protocol differed allowing for this studies objectives to be investigated. The C group participants continued to walk during the intervention period to maintain estimated elevated muscle temperature. The total time for intervention period was ~90 sec and was comparable between all participants. Following the interventions, the participants completed two maximal sprints accelerations at two and six minutes respectively post-intervention (Gołaś et al., 2016). Participants completed the four post-intervention test sprint accelerations with the aim to achieve the best outcome.

Measurements

The sprint accelerations were measured using speed gates (Fusion Sport, SmartSpeed, v.1.5.2) at 0 m, 10 m, and 20 m. The participants started 0.3 m behind the first gates (Russell et al., 2015) on their own time following a ready command. They were instructed to sprint with maximal effort past the final gate. The participants performed two maximal sprints at the pre-intervention and post-intervention tests with the goal of achieving the fastest outcome. The sprint acceleration intervention was compared to the baseline to assess for intensity as one of the highly influential factors in achieving PAPE. The S 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 data were tested for normality using the Shapiro-Wilk test. The data are presented as a mean $\pm$ standard deviation. A 3x3 mixed design analysis of variance with a within-between interaction was used to investigate the 10 and 20 m sprint accelerations. The between group factor being the groups (S, P and C) and the within subject factor being time (pre-intervention, two minutes post-intervention and six 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. Individual performances were recorded and monitored for significant differences from before and after the CA 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 $\pm$ SD values for the between and within group results are reported in table 1. The pre-intervention baseline testing also showed good test-retest reliability of (0.81) and (0.85) for 10 and 20 m, respectively. The 20 m sprint acceleration was influenced by a significant interaction between time x group, ($F_{4, 132} = 3.19$, *p* < 0.05, partial $\eta^2 = 0.09$) and time ($F_{2, 132} = 23.76$, *p* < 0.001, partial $\eta^2 = 0.27$). There was no significant difference between the groups at baseline (*p* = 0.894) and the control group did not change between the intervention. Relative to the baseline there was a significant difference for S ($F_{2, 44} = 20.14$, *p* < 0.001, partial $\eta^2 = 0.49$), at two minutes ($6.73 \text{ m}\cdot\text{s}^{-1} \pm 0.19$, *p* < 0.001) and six minutes ($6.73 \text{ m}\cdot\text{s}^{-1} \pm 0.19$, *p* < 0.001) and for P ($F_{2, 44} = 6.61$, *p* = 0.003, partial $\eta^2 = 0.23$) at two minutes ($6.73 \text{ m}\cdot\text{s}^{-1} \pm 0.15$, *p* = 0.038) and six minutes ($6.74 \text{ m}\cdot\text{s}^{-1} \pm 0.17$, *p* < 0.001) over 20 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at two minutes, there was a significant mean difference between two minutes post-intervention and six minutes post-intervention ($6.71 \text{ m}\cdot\text{s}^{-1} \pm 0.17$, *p* = 0.003). There was no significant difference between the groups at any time point. However, S and P were 1.47% and 1.44% faster than C at two minutes, respectively.

Table 1. Sprint velocity over 20 m mean $\pm$ SD values.

	Groups	Pre-intervention baseline	Post-intervention two minutes	Post-intervention six minutes
20 m sprint velocity ($\text{m}\cdot\text{s}^{-1}$)	Sprint	6.62 ± 0.15	$6.73 \pm 0.19^*$	$6.73 \pm 0.19^*$
	Plyometric	6.63 ± 0.13	$6.73 \pm 0.15^*$	$6.74 \pm 0.17^*$

	Control	6.64 ± 0.15	6.63 ± 0.16	6.71 ± 0.17†
p-value (ES)	Sprint	1.00 (0.13)	>0.05 (0.57)	1.00 (0.11)
ES assessment	compared to control	Trivial	Moderate	Trivial
p-value (ES)	Plyometric	1.00 (0.07)	>0.05 (0.64)	1.00 (0.17)
ES assessment	compared to control	Trivial	Moderate	Trivial

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

The mean ± SD values for the between and within group results are reported in table 2. The 10 m sprint acceleration was influenced by a significant interaction between time and group, ($F_{4, 132} = 2.53$, $p < 0.05$, partial $\eta^2 = 0.07$) and time ($F_{2, 132} = 22.07$, $p < 0.001$, partial $\eta^2 = 0.25$). There was no significant difference between the groups at baseline ($p = 0.776$) and the control group did not change between the intervention. Relative to the baseline there was a significant difference for S ($F_{2, 44} = 16.40$, $p < 0.001$, partial $\eta^2 = 0.43$), at two minutes ($5.82 \text{ m}\cdot\text{s}^{-1} \pm 0.17$, $p = 0.001$) and six minutes ($5.80 \text{ m}\cdot\text{s}^{-1} \pm 0.18$, $p < 0.001$) and P ($F_{2, 44} = 6.02$, $p = 0.005$, partial $\eta^2 = 0.22$) at two minutes ($5.81 \text{ m}\cdot\text{s}^{-1} \pm 0.15$, $p < 0.05$) and six minutes ($5.81 \text{ m}\cdot\text{s}^{-1} \pm 0.16$, $p < 0.05$) over 10 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at time point two minutes, there was a significant mean difference between two minutes post-intervention and six minutes post-intervention ($5.80 \text{ m}\cdot\text{s}^{-1} \pm 0.16$, $p < 0.05$). There was no significant difference between the groups at any time point. However, S and P were 1.44% and 1.22% faster than C at two minutes, respectively.

Table 2. Sprint velocity over 10 m mean ± SD values.

	Groups	Pre-intervention baseline	Post-intervention two minutes	Post-intervention six minutes
10 m sprint velocity (m·s⁻¹)	Sprint	5.70 ± 0.15	5.82 ± 0.17*	5.80 ± 0.18*
	Plyometric	5.72 ± 0.11	5.81 ± 0.15*	5.81 ± 0.16*
	Control	5.72 ± 0.15	5.74 ± 0.14	5.80 ± 0.16†

p-value (ES)	Sprint	1.00 (0.13)	>0.05 (0.51)	1.00 (0.17)
ES assessment	compared to control	Trivial	Moderate	Trivial
p-value (ES)	Plyometric	1.00 (0.09)	>0.05 (0.48)	1.00 (0.06)
ES assessment	compared to control	Trivial	Small	Trivial

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

Eighteen (78%) and 19 (83%) of the 23 participants in S did their fastest 10 m sprint acceleration at two and six minutes respectively, while 20 (87%) of the participants did their fastest 20 m sprint acceleration at two and six minutes compared to their baseline sprint acceleration. All 23 participants within this group achieved > 95% of the baseline velocity during the intervention over both the 10 m and 20 m. There was no significant difference between the baseline velocity and the intervention velocity in S over 10 m ($p = 0.23$) or 20 m ($p = 0.22$)

Discussion

The outcome of this study supports the hypothesis that a maximal sprint acceleration intervention may improve the outcome of a subsequent maximal sprint acceleration. When compared to a previously tested PAPE effect (Turner et al., 2015); using a weighted plyometric intervention, the sprint acceleration group showed improvements in sprint velocity within a similar range over two and six minutes post-intervention. Furthermore, following a standardised football warm-up, some improvements were observed following a maximal sprint acceleration intervention compared to no intervention. Although this between group outcome was not significant, a medium effect size of $d = 0.57$ and 0.51 for 20 m and 10 m was found at two minutes between group S and group C indicating a moderate difference in magnitude. Group C demonstrated a significant improvement during the post-intervention testing between two and six minutes. Additionally, groups S and P significantly improved their within group times relative to their baselines. This shows that a maximal sprint acceleration intervention may improve the outcome of a subsequent maximal sprint acceleration.

A sprint acceleration intervention can improve a subsequent sprint acceleration within two minutes and these improvements can be maintained for at least six minutes. However, these improvements at six minutes cannot be directly attributed to the intervention effect and may be influenced by the initial post-intervention testing evident in group C. This is an important consideration when preparing athletes for competition or training. Many studies have discussed the implication of the enhancement/fatigue factor with previous studies having shown a delay in this improvement especially after using a heavy CA (Hodgson et al., 2005; Matthews et al., 2004; Wilson et al., 2013). This is likely due to an initial heightened fatigue effect which is less evident when ballistic or plyometric CA's were used (Sharma et al., 2018). This suggests that a heavier CA induces more fatigue and thus requires longer recovery until PAPE is reached. Studies assessing heavier CA's; >75% 1RM, compared to plyometric CA's have shown similar outcomes with marked differences in time between CA and maximal improvements (Maloney et al., 2014). Along with the cumbersome nature of using weights it is challenging to find out when the fatigue has dispelled and an athlete has achieved an enhanced state, linked to the individualisation of the PAPE effect. Most studies that use body weight or plyometric tasks compared to heavier CA's show quicker recovery times post CA while in this study, neither S nor P showed diminished performance post-intervention (Maloney et al., 2014; Seitz and Haff, 2016). This has been demonstrated in previous studies where interventions like body weight activities; sprints, jumps and plyometric activities show quick improvements with minimal early fatiguing effects, while more weighted the interventions, the longer the period between diminished performance to the enhancement (Seitz and Haff, 2016; Wilson et al., 2013).

Blazevich and Babault, (2019) suggest that using a submaximal warm-up results in the CA producing a more extreme PAPE effect while a maximal or complete warm-up prior to the CA tend to produce more varied outcomes. Large parts of the literature indicate that the warm-up processes for PAPE studies are submaximal (Smith et al., 2014; Sharma et al., 2018; Tobin and Delahunt, 2014), effectively allowing the testing and intervention to produce an exaggerated PAPE effect. Part of this study revealed that a standardised football warm-up is not sufficient to fully enhance athletes as indicated by their pre-intervention baseline sprint velocities compared to the post-intervention sprint velocities. It was only the

addition of the maximal intervention which allowed the participants to exceed the baseline level evident in the S and P. Group C who did not receive either intervention and were allowed ~25 minutes to dispel any PAPE effects incurred during the pre-intervention testing had no significant change from the baseline to two minutes post-intervention. This study attempted to reduce any effect that baseline testing may have had on the subsequent results. The length of PAPE is reported in different studies as lasting anything up to 20 minutes post-intervention (Blazevich and Babault, 2019). This investigation attempted to reduce any PAPE effects from the pre-intervention baseline testing by allowing each group 20 minutes to dispel any fatigue and or enhanced effects incurred during the baseline testing. This coupled with the C group not participating in the intervention demonstrated that the intervention was directly attributed to the subsequent improvements observed in the S and P groups at two minutes.

What was not initially considered was what effect the subsequent post-intervention testing would have on the next post-intervention test. The C group had a significant change post-intervention from two minutes post-intervention to six minutes post-intervention. This improvement was attributed to the testing impulse at two minutes as their previous impulse was ~25 minutes previously allowing for sufficient time to dispel any PAPE effects which was highlighted in the pre-intervention baseline test and post-intervention test at two minutes, showing no significant difference. This indicates a maximal sprint acceleration at two minutes during post-intervention testing was sufficient in nature to achieve a PAPE state. This also suggests that the maintained enhancement for S and P between two minutes and six minutes post-intervention cannot be directly attributed to the intervention either and that the results during the second post-intervention testing were affected by the initial post-intervention testing. This shows that in this study the results at six minutes post-intervention cannot be directly attributed to the effect of the intervention and were also affected by the sprint acceleration at two minutes post-intervention. This makes previous findings questionable where multiple post-intervention tests are undertaken and suggests caution when reviewing literature where significant change is reported with multiple post-intervention testing scenarios administered. Future consideration needs to be given to the effect testing protocols have on subsequent testing protocols when investigating PAPE.

This study demonstrated that the majority (>75% over 10 m and >80% over 20 m) of the participants in S improved their velocity at the two and six minutes post-intervention compared to their pre-intervention baseline outcome. In contrast P showed an improvement in >65% of the participants over the same distances and time points. An unexpected outcome of this study was that approximately 75% of the participants in the C group showed significant improvements over both the 10 m and 20 m, between the two and six minutes post-intervention tests. This may suggest that within this population and this environment, more participants overall will elicit improvements doing a sprint acceleration rather than a weighted bounding intervention, up to six minutes post-intervention. This supports the claim that specificity and intensity may be highly influential in producing an early PAPE response in more participants within a group. Achieving this PAPE response may help to mitigate the individual response effect as even if some individuals are non-responders or partial responders the odds of this are reduced.

Conclusion

The findings of this study have important implications for coaches looking to take advantage of the PAPE conundrum. This study proposes that a sprint acceleration; specifically, two sets of 20 m maximal intensity runs, may induce a PAPE response in a subsequent maximal 10 m and 20 m maximal sprint acceleration at two minutes. The improvements observed from a sprint acceleration CA are of a similar magnitude to a weighted plyometric CA with a horizontal bias. Comparable to other plyometric CA's utilizing body weight, sprint accelerations seem to exhibit immediate enhancements without the associated fatigue effects commonly observed with PAPE and HRT. Future consideration needs to be given to the effect testing protocols have on subsequent testing protocols when investigating PAPE. This format of inducing a PAPE response promotes a practical warm-up solution for athletes and coaches seeking to achieve performance enhancement without using laborious equipment, determining individual response times, or eliciting a dominant initial fatigue consequence. In conclusion the implementation of a CA or preload stimulus similar in nature and intensity to the subsequent task may be effective in delivering an enhancement to competitive athletes and teams.

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Conflicts of interest

The authors declare no conflict of interest.

References

1. Bevan, H.R., Cunningham, D.J., Tooley, E.P., Owen, N.J., Cook, C.J. and Kilduff, L.P., (2010). Influence of postactivation potentiation on sprinting performance in professional rugby players. *J Strength Cond Res*, 24(3), pp. 701-705.
2. Blazeovich, A.J. and Babault, N., (2019). Post-activation Potentiation (PAP) versus Post-activation Performance Enhancement (PAPE) in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, 10, p. 1359.
3. Burkett, L.N., Phillips, W.T. and Ziuraitis, J., (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), pp. 673-676.
4. Colyer, S.L., Nagahara, R., Takai, Y. and Salo, A.I., (2018). Kinetic factors differentiating mid-to-late sprint acceleration performance in sprinters and soccer players. *ISBS Proceedings Archive*, 36(1), p. 674.
5. Creekmur, C.C., Haworth, J.L., Cox, R.H. and Walsh, M.S., (2017). Effects of plyometrics performed during warm-up on 20 and 40 m sprint performance. *J Sports Med Phys Fitness*, 57(5), pp. 550-555.
6. Gil, M.H., Neiva, H.P., Garrido, N.D., Aidar, F.J., Cirilo-Sousa, M.S., Marques, M.C. and Marinho, D.A., (2019). The Effect of Ballistic Exercise as Pre-Activation for 100 m Sprints. *International Journal of Environmental Research and Public Health*, 16(10).
7. Gołaś, A., Maszczyk, A., Zajac, A., Mikołajec, K. and Stastny, P., (2016). Optimizing post activation potentiation for explosive activities in competitive sports. *J Hum Kinet*, 52, pp. 95-106.

8. Hodgson, M., Docherty, D. and Robbins, D., (2005). Post-activation potentiation - Underlying physiology and implications for motor performance. *Sports Medicine*, 35(7), pp. 585-595.
9. Karampatsos, G., Terzis, G., Polychroniou, C. and Georgiadis, G., (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education & Sport*, 13(1), pp. 3-5.
10. Karampatsos, G.P., Korfiatis, P.G., Zaras, N.D., Georgiadis, G.V. and Terzis, G.D., (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), pp. 359-364.
11. Lorenz, D., (2011). Postactivation potentiation: An introduction. *International journal of sports physical therapy*, 6(3), p. 234.
12. Maloney, S.J., Turner, A.N. and Fletcher, I.M., (2014). Ballistic exercise as a pre-activation stimulus: a review of the literature and practical applications. *Sports Med*, 44(10), pp. 1347-1359.
13. Matthews, M.J., Matthews, H.P. and Snook, B., (2004). The acute effects of a resistance training warmup on sprint performance. *Research in Sports Medicine*, 12(2), pp. 151-159.
14. Piper, A.D., Joubert, D.P., Jones, E.J. and Whitehead, M.T., (2020). Comparison of Post-Activation Potentiating Stimuli on Jump and Sprint Performance. *International Journal of Exercise Science*, 13(4), pp. 539-553.
15. Russell, M., West, D.J., Harper, L.D., Cook, C.J. and Kilduff, L.P., (2015). Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations. *Sports Medicine*, 45(3), pp. 353-364.
16. Seitz, L.B. and Haff, G.G., (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports Med*, 46(2), pp. 231-240.
17. Sharma, S.K., Raza, S., Moiz, J.A., Verma, S., Naqvi, I.H., Anwer, S. and Alghadir, A.H., (2018). Postactivation Potentiation Following Acute Bouts of Plyometric versus

- Heavy-Resistance Exercise in Collegiate Soccer Players. *Biomed Res Int*, 2018, p. 3719039.
18. Silva, L.M., Neiva, H.P., Marques, M.C., Izquierdo, M. and Marinho, D.A., (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, 48(10), pp. 2285-2299.
 19. Smith, C.E., Hannon, J.C., McGladrey, B., Shultz, B., Eisenman, P. and Lyons, B., (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), pp. 33-41.
 20. Suchomel, T.J., Comfort, P. and Lake, J.P., (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength & Conditioning Journal*, 39(1), pp. 10-20.
 21. Till, K.A. and Cooke, C., (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J Strength Cond Res*, 23(7), pp. 1960-1967.
 22. Tobin, D.P. and Delahunt, E., (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *J Strength Cond Res*, 28(2), pp. 367-372.
 23. Turner, A.P., Bellhouse, S., Kilduff, L.P. and Russell, M., (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res*, 29(2), pp. 343-350.
 24. van den Tillaar, R., Lerberg, E. and von Heimburg, E., (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*, 8(6), pp. 574-578.
 25. Vandenboom, R., (2011). Modulation of skeletal muscle contraction by myosin phosphorylation. *Comprehensive Physiology*, 7(1), pp. 171-212.
 26. Wilson, J.M., Duncan, N.M., Marin, P.J., Brown, L.E., Loenneke, J.P., Wilson, S.M., Jo, E., Lowery, R.P. and Ugrinowitsch, C., (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), pp. 854-859.

27. Young, W., (1992). Sprint bounding and the sprint bound index. *NSCA J*, 4(6), pp. 44-44.
28. Zimmermann, H.B., MacIntosh, B.R. and Dal Pupo, J., (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology Nutrition and Metabolism*, 45(4), pp. 349-356.

CHAPTER 3 – Study two: Brink N, Constantinou D, and Torres G (2021) Postactivation Performance Enhancement (PAPE) using a vertical jump to improve vertical jump performance, *Journal of Sports Medicine and Physical Fitness*. DOI: 10.23736/S0022-4707.22.12899-9 (accepted)

At the time of this thesis submission, study two has been accepted at the *Journal of Sports Medicine and Physical Fitness*, as an original article. The original content has not been altered. For the purposes of this thesis figures, tables, and captions as well as referencing style have been adapted in line with the format of this thesis. Postactivation performance enhancement (PAPE) will be used in this study to refer to an acute bout of high intensity voluntary exercise followed by an enhancement in strength, speed or power production.

2. Original study

Title: Postactivation Performance Enhancement (PAPE) using a vertical jump to improve vertical jump performance.

Authors: Nicholas Brink, Demitri Constantinou, Georgia Torres

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 two and six minutes post-intervention after one of three interventions; two 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 two minutes of 1.89 cm and 114.45 W and relative to the baseline, MJ also had a significant improvement at two minutes of 1.51 cm and 91.60 W. By six 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 two maximal vertical jumps may enhance the outcome of a subsequent maximal vertical jump after two minutes and as much as a series of 40 jumps. However, these enhancements were not sustained for a further four 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 (van den Tillaar et al., 2019). The warm-up has always drawn interest amongst coaches, researchers, and athletes alike due to the high association with performance outcomes (Silva et al., 2018). The potential for athletes to maximise their performance outcomes by undertaking a grouping of physical tasks raises the interest in the warm-up process (Russell et al., 2015). Postactivation performance enhancement (PAPE) has been hypothesised as a medium for exceeding the performance potential attained by the warm-up alone (Hodgson et al., 2005). There is evidence that specific, high intensity tasks, such as a plyometric activity (Karampatsos et al., 2017; Karampatsos et al., 2013; Silva et al., 2018) 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 (van den Tillaar et al., 2019).

Current literature has discussed the association between postactivation potentiation (PAP) and postactivation performance enhancement (PAPE) (Smith and MacIntosh, 2021). Conventional models suggested that PAP is any acute enhancement lasting up to 20 minutes following heavy resistance training or a high intensity ballistic activity (Blazevich and Babault, 2019; Maloney et al., 2014). 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 (Vandenboom, 2011). 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 (Vandervoort et al., 1983). 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 (Cuenca-Fernandez et al., 2017; Prieske et al., 2020). 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 (Blazevich and Babault, 2019; Zimmermann et al., 2020).

PAPE has been shown to be effective in improving the acute outcome in a subsequent task, traditionally following heavy resistance training (Lorenz, 2011; Hodgson et al., 2005). 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 one repetition maximum. 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 (Matthews et al., 2004; Wilson et al., 2013; Hodgson et al., 2005). 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 (Wilson et al., 2013). Although many athletes respond positively to the heavy resistance training intervention, there are often non- and negative responders (Wilson et al., 2013). As a result, a cautionary warning has been issued to coaches by researchers when using heavy resistance training to induce PAPE (Bevan et al., 2010; Tobin and Delahunt, 2014; Till and Cooke, 2009) and that specific athlete testing may be indicated prior to using PAPE. 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 (Burkett et al., 2005; Russell et al., 2015; van den Tillaar et al., 2019). 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 (Maloney et al., 2014). 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 (Smith et al., 2014; Turner et al., 2015; Healy and Comyns, 2017). Thus, plyometrics may provide a practical training and competitive enhancement solution.

Body weight plyometric tasks have shown similar or exceed the outcomes of the weighted and heavy resistance training conditioning activities (Sharma et al., 2018; Turner et al., 2015). Mola et al. (2014) 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. (2018) 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. (2014) used similar methodology to compare a conditioning activity of a series of forty plyometric jumps on the performance of a vertical jump. The study 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 (Hilfiker et al., 2007) and depth jumps (Masamoto et al., 2003), 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 (van den Tillaar et al., 2019) and intensity (Suchomel et al., 2016) 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 (Gorostiaga et al., 2009). 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 (Tobin and Delahunt, 2014) and more than that of a control condition 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 (R x 64 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.

(2014). 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. The staff member 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 (Barengo et al., 2014) consisting of jogging, dynamic stretching, body preparation exercise, submaximal sprints; up to ~90%, submaximal plyometrics and six vs two, five 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, two 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 (Maloney et al., 2014). After 20 minutes VJ, MJ and CON performed their individual interventions (Figure 1).

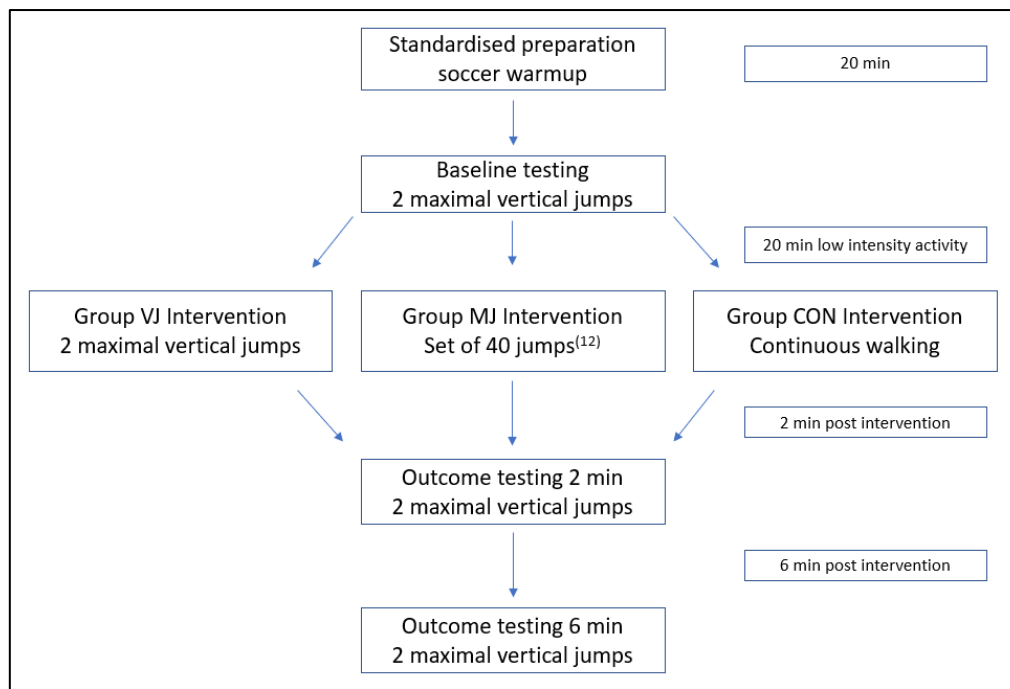


Figure 1. Test protocol for the control and experimental trials.

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 (Rassier and Macintosh, 2000; Seitz and Haff, 2016). This should indicate that any changes post-intervention will be directly attributed to the intervention.

The VJ group participants performed two 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 two sets of ten ankle hops, three sets of five hurdle hops at 70 cm, and five drop jumps from a height of 50 cm, a total of 40 jumps as defined by Tobin et al. (2014). It is worth noting that the investigators used this intervention exactly as described by Tobin et al. (Tobin and Delahunt, 2014). 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 two maximal vertical jumps at two and six minutes respectively post-intervention (Gołaś et al., 2016). Participants completed the four 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 (Turner et al., 2015; Tobin and Delahunt, 2014).

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 (Sayers et al., 1999) $\text{peak anaerobic power (Watts)} = 60.7 \cdot \text{jump height (cm)} + 45.3 \cdot \text{body mass (kg)} - 2055$ 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 $\pm$ 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, two minutes post-intervention and six 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 $\pm$ SD values for the between and within group vertical jump height 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 $\eta^2 = 0.15$) and time ($F_{2, 132} = 11.51$, $p < 0.001$, partial $\eta^2 = 0.15$). 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 $\eta^2 = 0.39$), at two minutes ($53.54 \text{ cm} \pm 4.48$, $p < 0.001$) and for MJ ($F_{2, 44} = 10.39$, $p < 0.001$, partial $\eta^2 = 0.32$) at two minutes ($53.49 \text{ cm} \pm 4.15$, $p = 0.001$) 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 two minutes respectively.

Table 1. Vertical jump height mean $\pm$ SD values.

	Groups	Pre-intervention	Post-intervention	Post-intervention
		baseline	two minutes	six minutes
Vertical jump height (cm)	Vertical Jump	51.64 ± 3.72	$53.54 \pm 4.48^{*\dagger}$	52.23 ± 4.00
	Multiple jump	51.98 ± 4.48	$53.49 \pm 4.15^{*\dagger}$	52.02 ± 3.84
	Control	52.04 ± 4.76	51.67 ± 4.94	52.07 ± 5.50

p-value (ES)	Vertical jump	1.00 (0.09)	>0.05 (0.40)	1.00 (0.03)
ES assessment	compared to control	Trivial	Small	Trivial
p-value (ES)	Multiple jump	1.00 (0.01)	>0.05 (0.39)	1.00 (0.01)
ES assessment	compared to control	Trivial	Small	Trivial

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

The mean $\pm$ SD values for the between and within group peak power results are reported in table 2. The vertical jump peak power output influenced by a significant interaction between time x group, ($F_{4, 132} = 6.02$, $p = 0.001$, partial $\eta^2 = 0.16$) and time ($F_{2, 132} = 11.52$, $p < 0.001$, partial $\eta^2 = 0.14$). 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 ($F_{2, 44} = 14.21$, $p < 0.001$, partial $\eta^2 = 0.41$), at two minutes ($4366.21 \text{ W} \pm 603.76$, $p < 0.001$) and for MJ ($F_{2, 44} = 10.41$, $p < 0.001$, partial $\eta^2 = 0.33$) at two minutes ($4312.72 \text{ W} \pm 539.62$, $p = 0.001$) 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 two minutes respectively.

Table 2. Peak power output mean $\pm$ SD values.

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

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

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 two 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 two 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 two minutes however these enhancements are not maintained four 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 (Hodgson et al., 2005; Matthews et al., 2004; Wilson et al., 2013). This heightened fatigue effect from heavy resistance training, which is less evident when ballistic or plyometric conditioning activities are used (Turner et al., 2015), 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 (Sharma et al., 2018). 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 (Seitz and Haff, 2016; Turner et al., 2015).

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 two minutes post intervention, in this case vertical height and peak power output. It is also evident 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 a vertical bias within the warm-up to fully enhance the athlete's potential prior to participation (Blazevich and Babault, 2019). 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 (Smith et al., 2014; Tobin and Delahunt, 2014; Sharma et al., 2018), 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 (Blazevich and Babault, 2019). Future research should investigate the effect of a maximal intensity warm-up compared to a submaximal intensity warm-up on the effects of PAPE.

The length of PAPE has been reported in different studies as lasting up to 20 minutes post-intervention (Maloney et al., 2014). 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 (Blazevich and Babault, 2019) 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. (2014), 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 two minutes post-intervention as the outcome had returned to baseline by six minutes. This is a conflicting outcome but on examination Tobin et al. (2014) retested post-intervention at one, three, and five minutes; every two minutes. Each maximal test may have influenced the subsequent test thus maintaining the PAPE effect. Our testing occurred at two and six minutes with two minutes post-intervention sufficient to elicit a PAPE effect. The data from this study suggests that the four minutes between the post-intervention at two minutes and the post-intervention at six minutes was too long to maintain this PAPE effect. Both groups returned to the baseline level in line with the control group by six 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 two minute time point and would likely still be present had the post-intervention testing been conducted again at four minutes post-intervention due to the testing impulse at two minutes (Tobin and Delahunt, 2014). But the less weight added to the conditioning activity, the quicker but shorter the PAPE response (Smith et al., 2014; Turner et al., 2015). 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 two maximal intensity vertical jumps, induce a PAPE response in a subsequent maximal vertical jump at two minutes post-intervention but not at six 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.

References

1. Barengo, N.C., Meneses-Echávez, J.F., Ramírez-Vélez, R., Cohen, D.D., Tovar, G. and Bautista, J.E.C., (2014). The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *International journal of environmental research and public health*, 11(11), pp. 11986-12000.

2. Bevan, H.R., Cunningham, D.J., Tooley, E.P., Owen, N.J., Cook, C.J. and Kilduff, L.P., (2010). Influence of postactivation potentiation on sprinting performance in professional rugby players. *J Strength Cond Res*, 24(3), pp. 701-705.
3. Blazevich, A.J. and Babault, N., (2019). Post-activation Potentiation (PAP) versus Post-activation Performance Enhancement (PAPE) in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, 10, p. 1359.
4. Burkett, L.N., Phillips, W.T. and Ziuraitis, J., (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), pp. 673-676.
5. Cuenca-Fernandez, F., Smith, I.C., Jordan, M.J., MacIntosh, B.R., Lopez-Contreras, G., Arellano, R. and Herzog, W., (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. *Applied Physiology Nutrition and Metabolism*, 42(10), pp. 1122-1125.
6. Gorostiaga, E.M., Llodio, I., Ibáñez, J., Granados, C., Navarro, I., Ruesta, M., Bonnabau, H. and Izquierdo, M., (2009). Differences in physical fitness among indoor and outdoor elite male soccer players. *European journal of applied physiology*, 106(4), pp. 483-491.
7. Gołaś, A., Maszczyk, A., Zajac, A., Mikołajec, K. and Stastny, P., (2016). Optimizing post activation potentiation for explosive activities in competitive sports. *J Hum Kinet*, 52, pp. 95-106.
8. Healy, R. and Comyns, T.M., (2017). The Application of Postactivation Potentiation Methods to Improve Sprint Speed. *Strength and Conditioning Journal*, 39(1), pp. 1-9.
9. Hilfiker, R., Hübner, K., Lorenz, T. and Marti, B., (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research*, 21(2), p. 550.
10. Hodgson, M., Docherty, D. and Robbins, D., (2005). Post-activation potentiation - Underlying physiology and implications for motor performance. *Sports Medicine*, 35(7), pp. 585-595.
11. Karampatsos, G., Terzis, G., Polychroniou, C. and Georgiadis, G., (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education & Sport*, 13(1), pp. 3-5.

12. Karampatsos, G.P., Korfiatis, P.G., Zaras, N.D., Georgiadis, G.V. and Terzis, G.D., (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), pp. 359-364.
13. Lorenz, D., (2011). Postactivation potentiation: An introduction. *International journal of sports physical therapy*, 6(3), p. 234.
14. Maloney, S.J., Turner, A.N. and Fletcher, I.M., (2014). Ballistic exercise as a pre-activation stimulus: A review of the literature and practical applications. *Sports medicine*, 44(10), pp. 1347-1359.
15. Masamoto, N., Larson, R., Gates, T. and Faigenbaum, A., (2003). Acute effects of plyometric exercise on maximum squat performance in male athletes. *The Journal of Strength & Conditioning Research*, 17(1), pp. 68-71.
16. Matthews, M.J., Matthews, H.P. and Snook, B., (2004). The acute effects of a resistance training warmup on sprint performance. *Research in Sports Medicine*, 12(2), pp. 151-159.
17. Mola, J.N., Bruce-Low, S.S. and Burnet, S.J., (2014). Optimal recovery time for postactivation potentiation in professional soccer players. *The Journal of Strength & Conditioning Research*, 28(6), pp. 1529-1537.
18. Prieske, O., Behrens, M., Chaabene, H., Granacher, U. and Maffiuletti, N.A., (2020). Time to differentiate postactivation “potentiation” from “performance enhancement” in the strength and conditioning community. *Sports Medicine*, 50, pp. 1559-1565.
19. Rassier, D. and Macintosh, B., (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research*, 33(5), pp. 499-508.
20. Russell, M., West, D.J., Harper, L.D., Cook, C.J. and Kilduff, L.P., (2015). Half-time strategies to enhance second-half performance in team-sports players: a review and recommendations. *Sports Medicine*, 45(3), pp. 353-364.
21. Sayers, S., Harackiewicz, D., Harman, E., Frykman, P. and Rosenstein, M., (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise*, 31(4), pp. 572-577.

22. Seitz, L. and Haff, G., (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports Medicine*, 46(2), pp. 231-240.
23. Sharma, S.K., Raza, S., Moiz, J.A., Verma, S., Naqvi, I.H., Anwer, S. and Alghadir, A.H., (2018). Postactivation potentiation following acute bouts of plyometric versus heavy-resistance exercise in collegiate soccer players. *BioMed research international*, 2018.
24. Silva, L.M., Neiva, H.P., Marques, M.C., Izquierdo, M. and Marinho, D.A., (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, 48(10), pp. 2285-2299.
25. Smith, C.E., Hannon, J.C., McGladrey, B., Shultz, B., Eisenman, P. and Lyons, B., (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), pp. 33-41.
26. Smith, I.C. and MacIntosh, B.R., (2021). A Comment on “A New Taxonomy for Postactivation Potentiation in Sport”. *International Journal of Sports Physiology and Performance*, 16(2), pp. 163-163.
27. Suchomel, T.J., Sato, K., DeWeese, B.H., Ebben, W.P. and Stone, M.H., (2016). Potentiation effects of half-squats performed in a ballistic or nonballistic manner. *Journal of strength and conditioning research*, 30(6), pp. 1652-1660.
28. Till, K.A. and Cooke, C., (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *The Journal of Strength & Conditioning Research*, 23(7), pp. 1960-1967.
29. Tobin, D.P. and Delahunt, E., (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *J Strength Cond Res*, 28(2), pp. 367-372.
30. Turner, A.P., Bellhouse, S., Kilduff, L.P. and Russell, M., (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res*, 29(2), pp. 343-350.
31. van den Tillaar, R., Lerberg, E. and von Heimburg, E., (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*, 8(6), pp. 574-578.

32. Vandenberg, R., (2011). Modulation of skeletal muscle contraction by myosin phosphorylation. *Comprehensive Physiology*, 7(1), pp. 171-212.
33. Vandervoort, A., Quinlan, J. and McComas, A., (1983). Twitch potentiation after voluntary contraction. *Experimental neurology*, 81(1), pp. 141-152.
34. Wilson, J.M., Duncan, N.M., Marin, P.J., Brown, L.E., Loenneke, J.P., Wilson, S.M., Jo, E., Lowery, R.P. and Ugrinowitsch, C., (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), pp. 854-859.
35. Zimmermann, H.B., MacIntosh, B.R. and Dal Pupo, J., (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology Nutrition and Metabolism*, 45(4), pp. 349-356.

CHAPTER 4 – Study three: Brink N, Constantinou D, and Torres G (submitted in 2021) Postactivation potentiation in healthy adults using a bodyweight conditioning activity: a systematic review and meta-analysis., *Journal of Strength and Conditioning Research*. (under review)

At the time of this thesis submission, study three was under review at the *Journal of Strength and Conditioning Research*, as a systematic review and meta-analysis. The original content has not been altered. For the purposes of this thesis figures, tables, and captions as well as referencing style have been adapted in line with the format of this thesis.

1. Systematic review and meta-analysis

Title: Postactivation potentiation in healthy adults using a bodyweight conditioning activity: a systematic review and meta-analysis.

Authors: Nicholas Brink, Demitri Constantinou, Georgia Torres

Abstract

Objective: To review the available evidence on whether a bodyweight conditioning activity results in a postactivation potentiation effect.

Design: Systematic review and meta-analysis.

Data sources: PubMed (National Library of Medicine), Web of Science (Clarivate Analytics), Google Scholar, SPORTDiscuss (EBSCO), Embase (Elsevier) and Thesis Global.

Eligibility criteria for selecting studies: Participants were healthy, active adults who performed either a vertical jump or a linear sprint outcome measurement. All studies were randomised control trials where the effects of a bodyweight conditioning activity were compared to a control condition. The control group followed the same course as the experimental group excluding the intervention with the intervention and outcome measurement carried out in the same session. The intervention was completed prior to the initiation of the outcome measure testing.

Results: Nineteen studies fulfilled the eligibility criteria and were included. There was a small overall effect of 0.30 (95% CI 0.14 to 0.46, $p = 0.0003$) in favour of using a bodyweight conditioning activity to improve the outcome of a subsequent vertical jump or linear sprint. Secondary analysis indicated that there was no difference between the vertical jump and sprint sub-group, the < five minutes, or five minutes and greater between intervention and outcome measurement sub-group or whether an intervention with the same movements or different movements was used before the outcome task sub-group.

Conclusion: Using bodyweight conditioning activities prior to performing a maximal vertical jump or sprint may provide a small benefit in performance outcome.

Systematic review registration number: PROSPERO CRD42020152006

Keywords: Postactivation potentiation; warm-up; plyometrics; jump; sprint.

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Introduction

Interventions employing postactivation potentiation (PAP) is a physical training principle which proposes that a muscle can be acutely optimised by its contractile history, which in turn affects the outcome of a subsequent task. This potentiated task is commonly associated with power-based activities which require high force production and a high rate of force development like sprinting and jumping (Hodgson et al., 2005). Postactivation potentiation has been tested in a multitude of sporting environments and different movement patterns with varying degrees of success (Borba et al., 2017). Typically, the conditioning activity for PAP was thought to require a heavy resistance, isotonic preload stimulus (75-90% 1RM) to achieve this potentiated state (Hodgson et al., 2005). This required athletes to lift, push or pull heavy weights over a varying range of sets and repetitions to develop a combined effect of heightened muscle activity and consequential fatigue. Theoretically, the fatigue dispelled first, leaving the muscle in a state of acute enhancement (Rassier and Macintosh, 2000).

There is a growing interest in the PAP effects elicited by ballistic conditioning activities including plyometrics (Maloney et al., 2014). The Henneman size principle suggests that motor units are activated from the smallest, type I, fatigue resistant fibres to the larger, most powerful type IIx fibres. Selective recruitment is an exception to this principle (Nardone and Schieppati, 1988; Nardone et al., 1989). By utilising high velocity, high power movements, the smaller fibres can be surpassed, activating exclusively the larger type IIa and IIx fibers extremely quickly. This form of recruitment may underpin the success seen in ballistic conditioning activities and PAP. Seitz and Haff, (2016) demonstrated that plyometric interventions had a greater effect on the outcome measurement compared to traditional high intensity tasks, suggesting that plyometrics may play a superior role in acutely potentiating muscle tissue, a concept reiterated by Creekmur et al. and Sharma et al. (2017; 2018). However Seitz et al. (2016) also notes that studies investigating plyometrics are limited. Further studies have since been published and as ballistic conditioning activities including plyometrics have shown potential to induce a superior PAP response, additional investigation is warranted.

There is a positive performance association between a sport and the specificity of the warm-up processes (Russell et al., 2015). Similarly, a common theme exists relating to the effectiveness of PAP - how closely the conditioning activity relates to the potentiated task impacts the transfer of the training effect (Till and Cooke, 2009). Van den Tillaar et al. (2019)

demonstrated that specificity is an important constituent in the development of a potentiated outcome. A warm-up with activities similar to the potentiated task were used with significant benefit compared to an alternate non-specific warm-up. Suchomel et al. (2016) propose that the intensity and velocity of the conditioning activity needs to closely mimic the levels achieved during competition or training as it is highly suggestive that this is an important component in achieving a PAP effect. It is not uncommon for sprinters and jumpers to engage in some form of sprinting or jumping prior to competitive involvement. Research has provided an indication that using a conditioning activity very similar to the potentiated task can enhance performances within specific populations (Smith et al., 2014). In a practical example Karampatsos et al. (2017; 2013) observed that field event athletes achieved significantly greater throw distances after three vertical jumps or a 20 m sprint at maximal effort. Research also suggests that jump performance improves by using different variations of jumping as the conditioning activity (Burkett et al., 2005; Hilfiker et al., 2007).

An initial search of PROSPERO, PubMed, JBI Evidence Synthesis, Google scholar, Web of Knowledge and SPORTDiscus was undertaken in June 2020, revealing that no comprehensive systematic review had been done on this subject. This systematic review intended to investigate whether PAP can be achieved using a bodyweight conditioning activity in a healthy adult population. It aimed to provide insight for coaches, rehabilitation specialists, and medical practitioners into the effect of bodyweight conditioning activities to potentiate subsequent tasks which could improve rehabilitation outcomes, training impulses and competition performances.

Methods

Search strategy and study selection

The proposed systematic review was formatted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement checklist in table 4 (Moher et al., 2009). The title of the review was registered in PROSPERO, registration number CRD42020152006. A full search strategy was developed for PubMed; National Library of Medicine (table 1) using text words within the titles and abstracts of relevant articles and the index terms used to describe the articles. The search strategy, including the identified keywords and index terms, and was adapted for each information source. The reference list for each study selected for critical appraisal was screened for additional studies. An electronic literature search was conducted via PubMed (National Library of

Medicine), Web of Science (Clarivate Analytics), Google Scholar, SPORTDiscuss (EBSCO) and Embase (Elsevier). The search strategies incorporated natural language and PubMed's controlled vocabulary: Medical Subject Headings (MeSH). Unpublished studies included Thesis Global, and contacting authors. Following on from the search strategy, all found citations were compiled and uploaded into EndNote X9/2019 (Clarivate Analytics, PA, USA) and the duplicates removed. Two independent reviewers screened the titles and abstracts for assessment against the inclusion criteria for the review. Possible relevant studies were recovered in full and their citation details captured. Two independent reviewers assessed the full text of the selected studies in detail against the inclusion criteria. Full text studies that did not meet the inclusion criteria were recorded and reasons reported in the systematic review. At each stage of the review, disagreements were resolved through discussion. The search results were reported in full in the final systematic review and presented in a (PRISMA) flow diagram in figure 1 (Moher et al., 2009).

Eligibility criteria

This systematic review examined studies that included a healthy, active adult population where their level of participation, type of activity and training experience had been reported. This review assessed original research focusing on any bodyweight conditioning activity which attempted to elicit PAP or to achieve a potentiated effect during a subsequent task. Types of conditioning activities included, but were not limited to, variations of the vertical jump, variations of the horizontal jump and linear sprints over different distances. The intervention needed to be completed prior to the initiation of the outcome measurement. The volume and intensity of the intervention as well as the duration between the intervention and the outcome measurement was captured when the studies were assessed. The reviewers evaluated studies that included a control condition which was treated identically to the experimental group excluding the intervention. Both the control group and experimental groups used a reliable measurable performance outcome. This review assessed studies with the primary outcome measures being a measurable change in the score between the control group and the experimental group. Only a single outcome measurement was included per study. When multiple outcomes were measured during the same session, only the first measurement was recorded. Where available, secondary outcome measures like type, volume and intensity of the potentiated task were captured. This systematic review considered randomised controlled trials (RCT), crossover and parallel studies which were published and unpublished. These investigated the PAP effects of a bodyweight

conditioning activity on a subsequent task. Only studies published over the last 20 years were included in this systematic review due to the recent modern scientific developments within this topic and the lack of availability of studies prior to this (Dobbs et al., 2019). Studies which did not provide enough information to extract an effect size and were not published in English were excluded.

Assessment of methodological quality and risk of bias

Two independent reviewers critically appraised the eligible studies for methodological quality in the review using standardised critical appraisal instruments according to the Cochrane risk of bias tool (Higgins et al., 2019). Disagreements were resolved through discussion. A value of low, high, or unknown risk of bias was provided for five domains of bias: selection bias, performance bias, detection bias, attrition bias, and reporting bias.

Data extraction

Data was extracted from studies included in the review by two independent reviewers. Specific details extracted included population groups, interventions, outcomes measurements, and study methods significant to the review objective with any disagreements resolved through discussion. Authors were contacted to request missing or additional data for clarification.

Data synthesis

The findings from the studies included were assessed, and a meta-analysis was carried out using Review Manager (RevMan) V.5.3 (Copenhagen, Denmark: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Effect sizes were expressed as a standardised mean difference, their 95% confidence intervals were calculated and presented as a forest plot. The standard chi squared and I^2 tests were used to test heterogeneity. Statistical analyses was performed using a fixed effects model as the heterogeneity between studies was low (Tufanaru et al., 2015). Sub-group analyses was conducted to compare the impact of different aspects of the systematic review. Publication bias was presented for visual analysis through funnel plots.

Results

Identification of studies

Following the initial database search, 1168 individual links were retrieved. After duplicates were removed, titles and abstracts screened, and full texts assessed for eligibility, nineteen studies were identified for qualitative and quantitative analysis.

Characteristics of the included studies

The nineteen studies identified for analysis have been summarised in table 2. All studies used a randomised controlled crossover ($n = 17$) or parallel ($n = 2$) design. The studies included 303 (male: $n = 278$; female: $n = 25$), physically active (recreational: $n = 5$; competitive: $n = 14$) individuals (21.3 ± 2.6 years) from Europe ($n=14$), South America ($n = 2$), Africa ($n = 2$), and North America ($n = 1$). All the studies included a controlled condition that was the same as the experimental condition excluding the intervention. In each study the intervention was a bodyweight conditioning activity and was concluded prior to the initiation of the outcome measurement. All the outcome measurements were either a vertical jump or a linear sprint (table 3).

Methodological quality and risk of bias

The authors' judgement of risk of bias has been summarised in figure 2 and reported for each study in figure 3. Selection, reporting, and attrition bias was low across all the studies with performance and detection bias being very high. The risk of publication bias was not detected on visual examination of the funnel plot (figure 4).

Meta-analysis

From the nineteen studies, 606 individual events were analysed using standardised mean difference. The pooled results showed a small effect of 0.30 (95% CI 0.14 to 0.46, $p = 0.0003$) in favour of using a bodyweight conditioning activity compared to the control condition. The heterogeneity was small between the studies ($I^2=1\%$) (figure 3). Sub-group analysis indicated that there were no significant differences when comparing a vertical jump 0.30 (95% CI 0.05 to 0.53) or linear sprint 0.29 (95% CI 0.07 to 0.51) outcome task ($p = 1.00$), the time between the intervention and the outcome measurement being less than five

minutes 0.33 (95% CI 0.10 to 0.57) or five minutes and greater 0.25 (95% CI 0.03 to 0.47) ($p = 0.60$), and using a similar intervention 0.35 (95% CI 0.14 to 0.56) or different intervention 0.19 (95% CI -0.11 to 0.49) to the outcome task ($p = 0.40$).

Discussion

This systematic review and meta-analysis included 303 participants and 606 individual events which compared the effect of a bodyweight conditioning activity against a control condition on the outcome of a vertical jump or linear sprint. The pooled results suggested a significant, though small magnitude of change occurred in favour of the experimental group indicating that a bodyweight conditioning activity may improve the outcome in both these subsequent tasks.

When analysing the results of a systematic review it is important to compare the outcomes to similar studies. Seitz and Haff, (2016) reported in a systematic review and meta-analysis that investigated the outcome of jumps and sprints an effect size of 0.31 and 0.50, respectively while Wilson et al. (2013) reported a similar pooled effect size of 0.38 for the outcome of 'power tasks' which likely included vertical jumps but was not clearly defined. Dobbs et al. (2019) found a trivial effect of 0.08 on the outcome of vertical jumps following a variety of conditioning activities however, they pooled multiple intra-study results questioning this study's methodology. Only Seitz and Haff, (2016) looked at a plyometric conditioning activity in a sub-group analysis indicating an effect size of 0.47 and although this was equivalent to a high and moderate intensity conditioning activity, the authors report limited studies available investigating plyometrics as a conditioning activity. None of these systematic reviews included characteristics or training protocols of the included studies creating challenges analysing the different effects. Nevertheless, it seems likely that the effect of power-based conditioning activities does have a small to moderate effect on a power-based outcome measurement. This is reiterated in this current study where a small but significant effect was found when using a power-based conditioning activity to potentiate a power-based outcome measurement.

Researchers looked at previous systematic reviews and meta-analyses at the outcome of power related tasks namely, jumps, sprints, change of direction, and ballistic conditioning activities including plyometrics outcomes while investigating a variety of different interventions with a strong focus on resistance tasks (Seitz and Haff, 2016; Dobbs et al., 2019; Wilson et al., 2013). All of these studies used a test-retest design and neglected to include any form of within study bias assessment other than publication bias (Seitz and Haff, 2016). Our study differed in its methodological approach by using very strict inclusion criteria. Each study needed to have a controlled condition which undertook the same processes as the experimental group excluding the intervention. This was vital in mitigating any risk of the baseline testing interfering with the intervention and the outcome measurement. Only recently have studies questioned the methodology of what effect and to what extent the previous testing may have on the interventions or the subsequent outcomes (Blazevich and Babault, 2019; Prieske et al.; Cuenca-Fernandez et al., 2017). In numerous studies authors have interspaced the intervention in between the outcome measurements (Bergmann et al., 2013; Bogdanis et al., 2017; Kummel et al., 2016). Although this may be a specific study objective, it also potentially skews the results as the later outcome measurements are also affected by previous outcome testing prior to the intervention, which could be highlighted as fatigue or enhancement. Therefore, each intervention was required to be performed and concluded prior to the initiation of the outcome measurement. This was to ensure that the effect was due to the intervention and could not be attributed to earlier outcome testing influencing the later outcome testing. Many of the studies investigated the effects of multiple different tasks as the outcome measurement (Abade et al., 2017; De Sousa Fortes et al., 2018; Fashioni et al., 2019; Howe et al., 2017) and while multiple attempts at the same task were included, these authors felt that specificity was an integral aspect in measurement of a PAP response. Where multiple different outcomes were measured, only the first measurement was considered due to the potential positive or negative feed-forward effect that one outcome measurement may have on the following measurement. Studies were excluded where the order of the outcome testing could not be determined. Where the outcome was measured over multiple time points only the first time point after the intervention was included (Turner et al., 2015). This was to avoid any feed-forward effects from the initial outcome testing to the latter outcome testing.

The effect of a bodyweight conditioning activity on either a vertical bias (global frame) outcome measurement ($ES = 0.30$) or on a horizontal bias (global frame) outcome measurement ($ES = 0.29$) was almost identical. This does suggest that the outcome of a maximal power-based task regardless of type of action can be improved using a bodyweight conditioning activity. Although this effect is small, it is significant in both cases which has been reiterated in other studies (Sharma et al., 2018; Abade et al., 2017; De Sousa Fortes et al., 2018; Lima et al., 2011) which have all reported trivial to moderate effect sizes when comparing different power-based outcome tasks following a bodyweight conditioning activity. This would suggest athletes undertaking a bodyweight conditioning activity with either a vertical or horizontal bias would provide similar benefits in the enhancement of a subsequent power-based task. The effect of time between the bodyweight conditioning activity and the outcome measure was similar with less than five minutes ($ES = 0.33$) showing a slightly greater magnitude of change compared to more than five minutes ($ES = 0.25$) though in both cases the effect size was significant. This contrasts with other studies where the researchers have indicated that ballistic conditioning activities including plyometric activities tended to show quicker enhancements after the intervention compared to other weighted conditioning activities (Seitz and Haff, 2016; Tobin and Delahunt, 2014). This information is slightly misleading as although most of the studies included in this meta-analysis investigated an individual time-point, three studies tested multiple time-points post intervention. As a specific study objective, only the initial outcome testing data were included to prevent any feed-forward through previous outcome testing. This may skew the outcome marginally but at least between five minutes and 10 minutes post intervention a small significant effect was still evident. Our study highlighted that specificity is an influential element in a PAP outcome. Studies which compared a vertical movement or horizontal movement to a similar outcome measurement had an $ES = 0.35$ while using an intervention different to the outcome measurement had an $ES = 0.19$ and although not significantly different from each other the similar sub-group had a significant benefit compared to the control group while the different sub-group did not. This has been reiterated in previous studies investigating the effects of PAP, athlete preparation and warm-up optimisation (van den Tillaar et al., 2019; Burkett et al., 2005; Russell et al., 2015).

Study biases and limitations

A moderate selection bias was present as all studies reported randomisation of subjects and random allocation of group order but limited details of how this was implemented. In these studies, performance and detection bias was high and blinding the participants and the assessors would have reduced these biases however, this can be challenging in a crossover study. Three studies reported blinding of the participants and the assessor, and two studies reported blinding during the outcome measurements (Hilfiker et al., 2007; Brink et al., 2020; Brink et al., 2021). The outcome may not transfer directly to elite athletes, as the physically active adult population was not selected based on strength or activity experience, both of which have been reported to impact the outcome of a PAP response (Seitz and Haff, 2016; Wilson et al., 2013).

This study did not differentiate between the type of movement, including multiple variations of the vertical jump and linear horizontal movements, and volume of the bodyweight conditioning activities that were administered. If the intervention had a vertical or horizontal bias without change in direction, the study was included if it met the other inclusion criteria. This was to maintain the focus on whether a bodyweight conditioning activity could induce a PAP regardless of the type of activity used. Another limitation was that only the initial time-point post intervention was included. As certain studies included multiple time-points and in some cases the significant effect was reported after the initial outcome measurement, the authors felt strongly that feed-forward may have either a positive or negative effect on the later outcome measurement. Where studies continued to employ the intervention while testing the outcome, the authors only included the initial outcome measurement. This was also an attempt to control the feed-forward fatigue or enhancement effect potentially created by the outcome testing and repeated intervention administration. Only nineteen eligible studies were identified for inclusion in the meta-analysis.

Practical applications

There is substantial evidence that using a bodyweight ballistic or power-based conditioning activity has a small but significant benefit on the outcome of a power-based task. As these bodyweight tasks do not require any equipment or complex instruction and the enhancement effects have been reported as quickly as one minute post intervention, there seems little reason why athletes, coaches and rehabilitation specialist would not include both a maximal

vertical jump or maximal linear sprints in athlete preparation for training or competition. As a recommendation, the final preparation phase should include three maximal vertical jumps and three maximal linear sprints of at least 20 m up to five minutes before participation.

Conclusion

This systematic review and meta-analysis demonstrated that a PAP response can be induced by a bodyweight conditioning activity prior to undertaking a subsequent task. There was no significant difference between doing a vertical jump or a linear sprint as an outcome measure or doing the outcome measurement less than five minutes or more than five minutes after the intervention. There was no difference whether the outcome was the same or different to the conditioning activity although it was moderately more beneficial to use a vertical bias conditioning activity to potentiate a vertical power-based activity and similarly for horizontal condition activities and linear sprints. Due to the simplistic nature of using a bodyweight intervention, coaches and athletes are encouraged to employ these before undertaking maximal vertical jumps or linear sprints.

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Conflicts of interest

The authors declare no conflict of interest.

References

1. Abade, E., Sampaio, J., Goncalves, B., Baptista, J., Alves, A. and Viana, J., (2017). Effects of different re-warm up activities in football players' performance. *Plos One*, 12(6).
2. Bergmann, J., Kramer, A. and Gruber, M., (2013). Repetitive hops induce postactivation potentiation in triceps surae as well as an increase in the jump height of subsequent maximal drop jumps. *PLoS One*, 8(10), p. e77705.

3. Blazevich, A.J. and Babault, N., (2019). Post-activation Potentiation (PAP) versus Post-activation Performance Enhancement (PAPE) in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, 10, p. 1359.
4. Bogdanis, G.C., Tsoukos, A. and Veligekas, P., (2017). Improvement of Long-Jump Performance During Competition Using a Plyometric Exercise. *Int J Sports Physiol Perform*, 12(2), pp. 235-240.
5. Borba, D.d.A., Ferreira-Júnior, J.B., Santos, L.A.d., Carmo, M.C.d. and Coelho, L.G.M., (2017). Effect of post-activation potentiation in Athletics: a systematic review. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 19(1), pp. 128-138.
6. Brink, N., Constantinou, D. and Torres, G., (2020). Postactivation performance enhancement (PAPE) of sprint acceleration performance. Unpublished.
7. Brink, N., Constantinou, D. and Torres, G., (2021). Postactivation performance enhancement (PAPE) of vertical jump performance. Unpublished.
8. Burkett, L.N., Phillips, W.T. and Ziuraitis, J., (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), pp. 673-676.
9. Byrne, P.J., Kenny, J. and O' Rourke, B., (2014). Acute Potentiating Effect of Depth Jumps on Sprint Performance. *Journal of Strength and Conditioning Research*, 28(3), pp. 610-615.
10. Creekmur, C. C., Haworth, J. L., Cox, R. H. & Walsh, M. S. (2017). Effects of plyometrics performed during warm-up on 20 and 40 m sprint performance. *J Sports Med Phys Fitness*, 57(5), pp 550-555.
11. Cuenca-Fernandez, F., Smith, I.C., Jordan, M.J., MacIntosh, B.R., Lopez-Contreras, G., Arellano, R. and Herzog, W., (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. *Applied Physiology Nutrition and Metabolism*, 42(10), pp. 1122-1125.
12. De Sousa Fortes, L., Paes, P.P., Mortatti, A.L., Perez, A.J., Cyrino, E.S., De Lima-Júnior, D.R.A.A. and Moreira, A., (2018). Effect of different warm-up strategies on

- countermovement jump and sprint performance in basketball players. *Isokinetics and Exercise Science*, 26(3), pp. 219-225.
13. de Villarreal, E.S.S., Gonzalez-Badillo, J.J. and Izquierdo, M., (2007). Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *European Journal of Applied Physiology*, 100(4), pp. 393-401.
 14. Dobbs, W.C., Toluoso, D.V., Fedewa, M.V. and Esco, M.R., (2019). Effect of Postactivation Potentiation on Explosive Vertical Jump: A Systematic Review and Meta-Analysis. *J Strength Cond Res*, 33(7), pp. 2009-2018.
 15. Esformes, J.I., Cameron, N. and Bampouras, T.M., (2010). Postactivation potentiation following different modes of exercise. *Journal of Strength and Conditioning Research*, 24(7), pp. 1911-1916.
 16. Fashioni, E., Langley, B. and Page, R.M., (2019). The effectiveness of a practical half-time re-warm-up strategy on performance and the physical response to soccer-specific activity. *Journal of Sports Sciences*, 38(2), pp. 140-149.
 17. Gil, M.H., Neiva, H.P., Alves, A.R., Sousa, A.C., Duarte-Mendes, P., Marques, M.C. and Marinho, D.A., (2020). Does the inclusion of ballistic exercises during warm-up enhance short distance running performance? *The Journal of sports medicine and physical fitness*, 60(4), pp. 501-509.
 18. Gil, M.H., Neiva, H.P., Garrido, N.D., Aidar, F.J., Cirilo-Sousa, M.S., Marques, M.C. and Marinho, D.A., (2019). The Effect of Ballistic Exercise as Pre-Activation for 100 m Sprints. *International Journal of Environmental Research and Public Health*, 16(10).
 19. Higgins, J.P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M.J. and Welch, V.A., (2019). *Cochrane handbook for systematic reviews of interventions*. John Wiley & Sons.
 20. Hilfiker, R., Hübner, K., Lorenz, T. and Marti, B., (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research*, 21(2), p. 550.
 21. Hodgson, M., Docherty, D. and Robbins, D., (2005). Post-activation potentiation. *Sports medicine*, 35(7), pp. 585-595.

22. Howe, L., Coward, M. and Price, P., (2017). The postactivation potentiation effect of either plyometrics or speed, agility and quickness exercises on linear sprint performance.
23. Karampatsos, G., Terzis, G., Polychroniou, C. and Georgiadis, G., (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education and Sport*, 13(1), p. 3.
24. Karampatsos, G.P., Korfiatis, P.G., Zaras, N.D., Georgiadis, G.V. and Terzis, G.D., (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), pp. 359-364.
25. Kummel, J., Bergmann, J., Prieske, O., Kramer, A., Granacher, U. and Gruber, M., (2016). Effects of conditioning hops on drop jump and sprint performance: a randomized crossover pilot study in elite athletes. *Bmc Sports Science Medicine and Rehabilitation*, 8.
26. Lima, J.C.B., Marin, D.P., Barquilha, G., Da Silva, L.O., Puggina, E.F., Pithon-Curi, T.C. and Hirabara, S.M., (2011). Acute effects of drop jump potentiation protocol on sprint and counter movement vertical jump performance. *Human Movement*, 12(4), pp. 324-330.
27. Margaritopoulos, S., Theodorou, A., Methenitis, S., Zaras, N., Donti, O. and Tsolakis, C., (2015). The effect of plyometric exercises on repeated strength and power performance in elite karate athletes. *Journal of Physical Education & Sport*, 15(2), pp. 310-318.
28. Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. and Group, P., (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*, 62(10), pp. 1006-1012.
29. Nardone, A., Romano, C. and Schieppati, M., (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of physiology*, 409(1), pp. 451-471.
30. Nardone, A. and Schieppati, M., (1988). Shift of activity from slow to fast muscle during voluntary lengthening contractions of the triceps surae muscles in humans. *The Journal of physiology*, 395(1), pp. 363-381.

31. Prieske, O., Behrens, M., Maffiuletti, N.A., Koopmann, T., Faber, I., Schorer, J., Sarto, F., Impellizzeri, F., Franchi, M. and Chaabene, H., 1. Time to Differentiate Postactivation “Potentiation” from “Performance Enhancement” in the Strength and Conditioning Community.
32. Rassier, D. and Macintosh, B., (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research*, 33(5), pp. 499-508.
33. Russell, M., West, D.J., Harper, L.D., Cook, C.J. and Kilduff, L.P., (2015). Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations. *Sports Medicine*, 45(3), pp. 353-364.
34. Seitz, L.B. and Haff, G.G., (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports Med*, 46(2), pp. 231-240.
35. Sharma, S.K., Raza, S., Moiz, J.A., Verma, S., Naqvi, I.H., Anwer, S. and Alghadir, A.H., (2018). Postactivation potentiation following acute bouts of plyometric versus heavy-resistance exercise in collegiate soccer players. *BioMed research international*, 2018.
36. Sims, L., (2016). Isometric mid-thigh pull vs. plyometric post activation potentiation and their effects on maximum velocity in athletic males. Cardiff Metropolitan University.
37. Smith, C.E., Hannon, J.C., McGladrey, B., Shultz, B., Eisenman, P. and Lyons, B., (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), pp. 36-44.
38. Stieg, J.L., Faulkinbury, K.J., Tran, T.T., Brown, L.E., Coburn, J.W. and Judelson, D.A., (2011). Acute effects of depth jump volume on vertical jump performance in collegiate women soccer players. *Kinesiology*, 43(1), pp. 25-30.
39. Suchomel, T.J., Sato, K., DeWeese, B.H., Ebben, W.P. and Stone, M.H., (2016). Potentiation effects of half-squats performed in a ballistic or nonballistic manner. *Journal of strength and conditioning research*, 30(6), pp. 1652-1660.

40. Till, K.A. and Cooke, C., (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *The Journal of Strength & Conditioning Research*, 23(7), pp. 1960-1967.
41. Tobin, D.P. and Delahunt, E., (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *The Journal of Strength & Conditioning Research*, 28(2), pp. 367-372.
42. Tufanaru, C., Munn, Z., Stephenson, M. and Aromataris, E., (2015). Fixed or random effects meta-analysis? Common methodological issues in systematic reviews of effectiveness. *Int J Evid Based Healthc*, 13(3), pp. 196-207.
43. Turner, A.P., Bellhouse, S., Kilduff, L.P. and Russell, M., (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res*, 29(2), pp. 343-350.
44. van den Tillaar, R., Lerberg, E. and von Heimburg, E., (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*, 8(6), pp. 574-578.
45. Watterdal, Ø., (2013). The impact of warm up intensity and duration on sprint performance.
46. Wilson, J.M., Duncan, N.M., Marin, P.J., Brown, L.E., Loenneke, J.P., Wilson, S.M., Jo, E., Lowery, R.P. and Ugrinowitsch, C., (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), pp. 854-859.

Appendix

Table 1: Search strategy: Search of Medline PubMed

Search	Query	Records retrieved
#1	"postactivation"[Text Word] OR "post-activation"[Text Word]	984
#2	"warmup"[Text Word] OR "warm-up"[Title/Abstract] OR "warm-up"[Text Word]	2853
#3	"jump*"[Text Word] OR "sprint*"[Text Word]	33654
#4	"plyo*"[Text Word]	873
#5	Search: # 2 OR # 3 OR # 4	36209
#6	Search: # 1 AND # 5	215
#7	Search: # 6 Filters: English	214
#8	Search: # 7 Filters: Humans	141

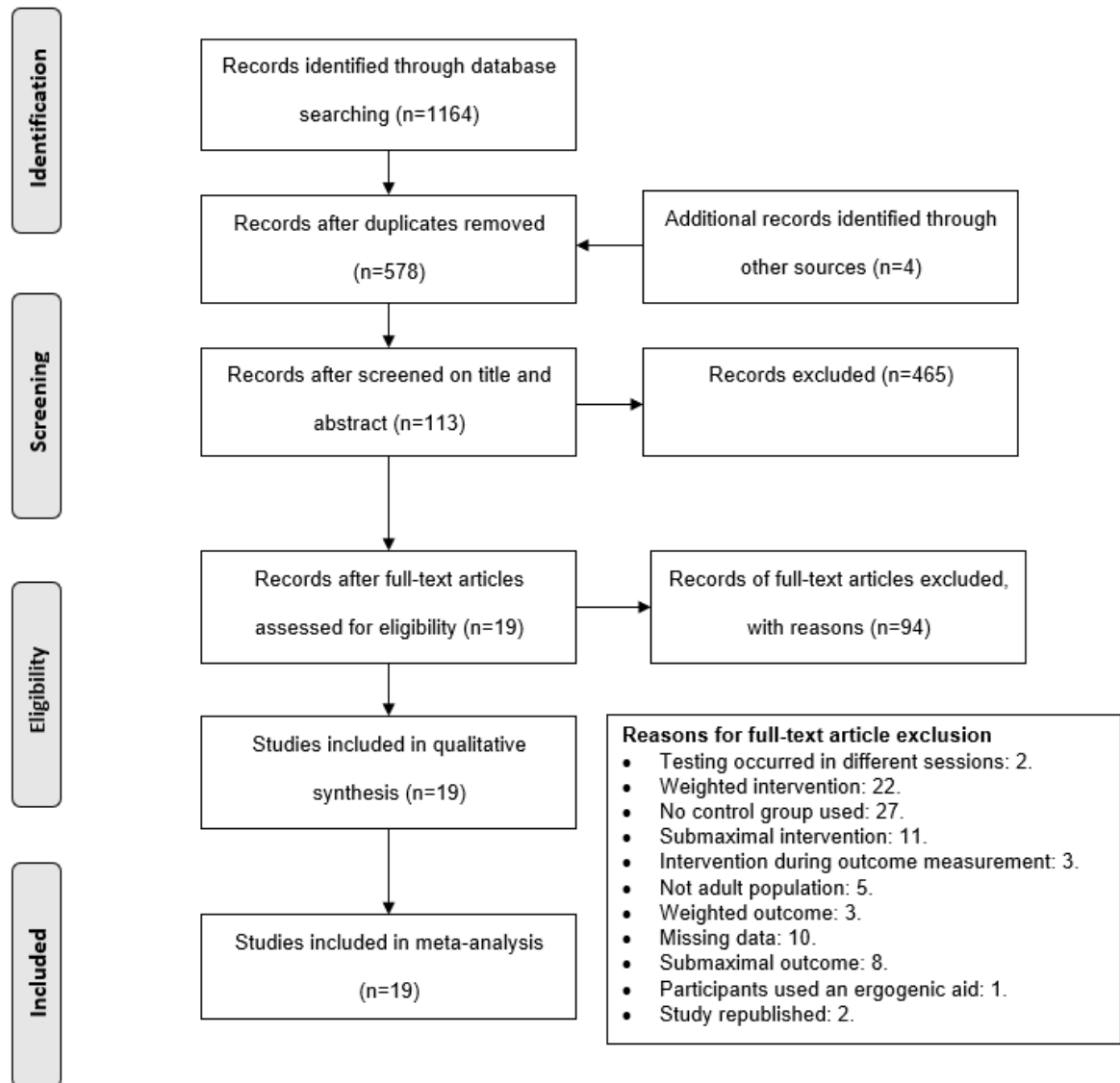


Figure 1: Flow chart of study selection for the analysis on whether a bodyweight conditioning activity can acutely improve the outcome of a subsequent task through postactivation potentiation.

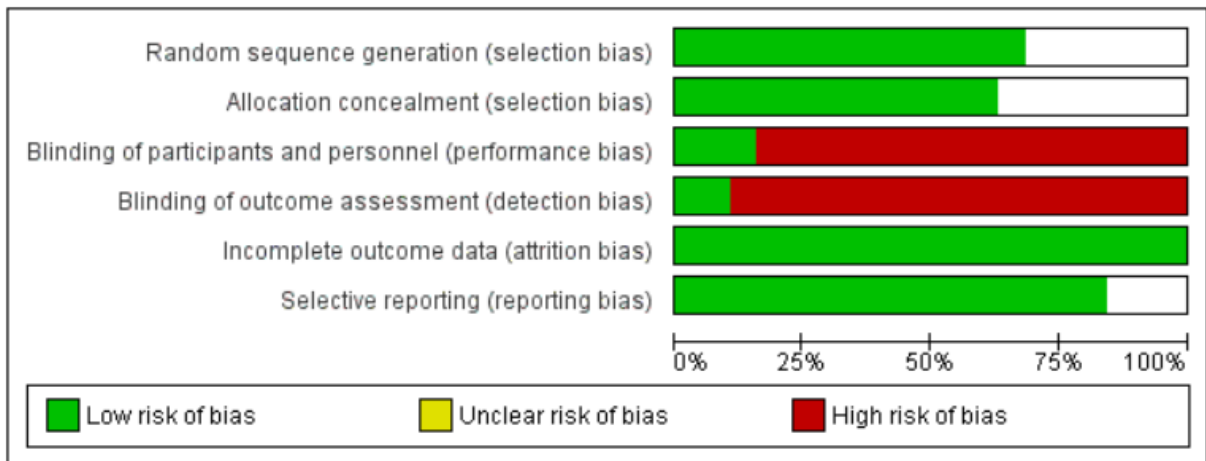


Figure 2: Risk of bias summary. The authors' judgements about each risk of bias item are presented as percentages across all included studies.

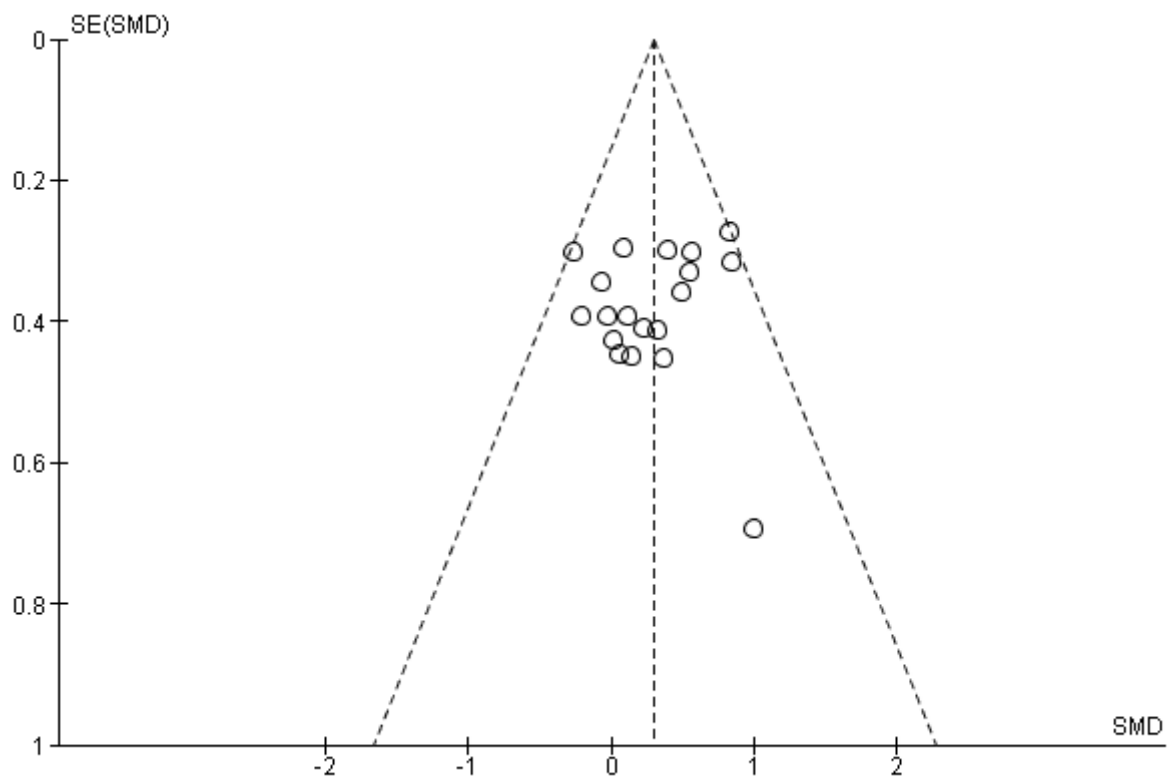


Figure 4: Funnel plot for assessing publication bias in studies measuring a bodyweight conditioning activity against a control.

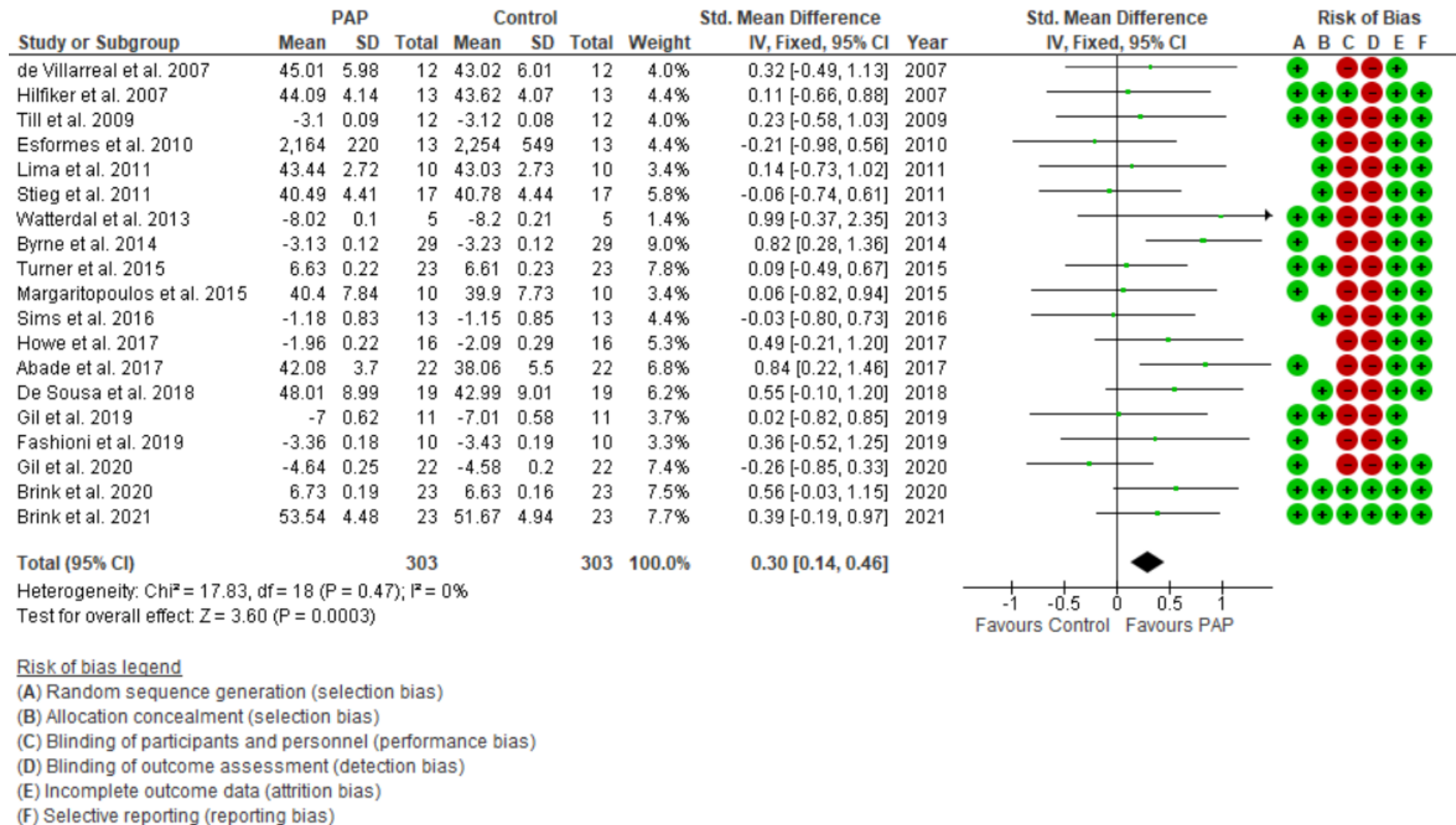


Figure 3: Primary analysis of studies measuring a bodyweight conditioning activity against a control.

Table 2: Characteristics of the included studies

Study	Location	Sex	Age	Study designs	Level of competition	Sport	Warm up
Abade et al.(2017)	Portugal	M22	18 ± 1	RCT crossover	Competitive	Soccer	Maximal
Brink et al.(2021)	South Africa	M23	24 ± 5	RCT parallel	Competitive	Soccer	Submaximal
Brink et al.(2020)	South Africa	M23	24 ± 5	RCT parallel	Competitive	Soccer	Submaximal
Byrne et al.(2014)	Ireland	M29	20 ± 4	RCT crossover	Competitive	Variety	Submaximal
De Sousa et al.(2018)	Brazil	M19	24 ± 1	RCT crossover	Competitive	Basketball	Submaximal
de Villarreal et al.(2007)	Spain	M12	23 ± 3	RCT crossover	Competitive	Volleyball	Submaximal
Esformes et al.(2010)	Wales	M13	22 ± 3	RCT crossover	Competitive	Variety	Submaximal
Fashioni et al.(2019)	UK	M10	23 ± 4	RCT crossover	Recreational	Soccer	Submaximal
Gil et al.(2020)	Portugal	M22	19 ± 2	RCT crossover	Recreational	PA	Submaximal
Gil et al.(2019)	Portugal	M11	25 ± 6	RCT crossover	Recreational	PA	Submaximal
Hilfiker et al.(2007)	Switzerland	M13	22 ± 4	RCT crossover	Competitive	Snow sport	Submaximal
Howe et al.(2017)	UK	M13 F3	19 ± 2	RCT crossover	Recreational	PA	Submaximal
Lima et al.(2011)	Brazil	M10	21 ± 3	RCT crossover	Competitive	Sprinting	Submaximal
Margaritopoulos et al.(2015)	Greece	M5 F5	19 ± 1	RCT crossover	Competitive	Karate	Submaximal
Sims et al.(2016)	UK	M13	19 ± 1	RCT crossover	Recreational	PA	Submaximal
Stieg et al.(2011)	USA	F17	19 ± 1	RCT crossover	Competitive	Soccer	Submaximal
Till et al.(2009)	UK	M12	18 ± 1	RCT crossover	Competitive	Soccer	Submaximal
Turner et al.(2015)	UK	M23	21 ± 1	RCT crossover	Recreational	PA	Maximal
Watterdal et al.(2013)	Sweden	M5	24 ± 2	RCT crossover	Competitive	MD running	Submaximal

RCT, randomised controlled trial; M, male; F, female; PA, physically active; MD, middle distance

Table 3: The intervention and outcome protocols of the included studies

Study	Intervention	Outcome measurement	Time between intervention and outcome measurement
Abade et al.(2017)	Maximal Vertical and horizontal movement - 4 sets of 5 jumps over 40 cm barriers followed by agility ladder 10 steps	Vertical jump height - 2 maximal attempts	6 min
Brink et al.(2021)	Maximal vertical jumps - 2 maximal VJ (2 min)	Vertical jump height – 2 maximal attempts	2 min
Brink et al.(2020)	Maximal sprint - 2 maximal 20 m sprint (2 min)	Linear sprint – 2 maximal attempts (20 m)	2 min
Byrne et al.(2014)	Maximal vertical movement - 3 maximal depth jumps	Linear sprint – 1 maximal attempt (20 m)	1 min
De Sousa et al.(2018)	Maximal vertical jump - 6 sets of 6 VJ 10s between reps 2 min between sets	Vertical jump height - 1 maximal attempt	5 min
de Villarreal et al.(2007)	Maximal vertical jump - 3 x 5 drop jumps	Vertical jump height - 1 maximal attempt	5 min
Esformes et al.(2010)	Maximal horizontal & vertical jumps - performed 6 alternate bounds, 6 right speed hops, 6 left speed hops, 6 vertical bounds	Vertical jump power output (W) – 3 maximal attempts	5 min
Fashioni et al.(2019)	Maximal sprints & vertical jumps - 2 straight sprinting, 2 tuck jumps into sprints, 2 reaction sprints	Linear sprint – 1 maximal attempt (20 m)	5 min
Gil et al.(2020)	Maximal vertical jumps - 2x5 depth jumps (70 cm)	Linear sprint – 1 maximal attempt (30 m)	10 min
Gil et al.(2019)	Maximal vertical jumps - 2x5 depth jumps (70 cm)	Linear sprint – 1 maximal attempt (50 m)	5 min
Hilfiker et al.(2007)	Modified vertical jumps - 5 modified drop jumps (60cm)	Vertical jump height – 3 maximal attempts	1 min
Howe et al.(2017)	Maximal vertical & horizontal jumps - Hurdle hops x6, Lateral hurdle hops x10, VJ x 5, depth jump x10 (20 cm), Broad jump x 5	Linear sprint – 3 maximal attempts (10 m)	4 min
Lima et al.(2011)	Maximal vertical jumps - 2x5 depth jumps (75 cm)	Vertical jump height – 1 maximal attempt	5 min
Margaritopoulos et al.(2015)	Maximal vertical jumps - 3x5 tuck jumps (30 sec)	Vertical jump height – 1 maximal attempt	5 min

Sims et al.(2016)	Maximal vertical jumps- 3x20 pogo jumps	Linear sprint – 3 maximal attempts (10 m: 30-40 m)	8 min
Stieg et al.(2011)	Maximal vertical jumps - 6 depth jumps	Vertical jump height – 3 maximal attempts	10 min
Till et al.(2009)	Maximal vertical jumps - 5 Tuck jumps	Linear sprint – 3 maximal attempts (20 m)	4 min
Turner et al.(2015)	Maximal horizontal jumps - 3 x 10 alt leg bounds	Linear sprint velocity – 1 maximal attempt (20 m)	2 min
Watterdal et al.(2013)	Maximal horizontal sprint - 1 x 50 m sprint	Linear sprint - 1 maximal attempt (60 m)	10 min

VJ, vertical jump.

Table 4: PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	√
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	√
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	√
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	√
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	√
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	√
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	√
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	√

Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	√
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	√
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	√
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	√
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	√
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	√

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	√

Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	√
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	√
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	√
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	√
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	√
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	√
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	√
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	√
DISCUSSION			

Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	√
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	√
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	√
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	√

Chapter 5 – Discussion

Introduction

This thesis intended to provide a practical solution for coaches, athletes, and rehabilitation specialists on how to use PAP in a ‘real world’ training and competition environment. The potential benefits associated with PAP in an isolated clinical environment have been well documented both with heavy resistance training and ballistic exercises (Maloney et al., 2014; Seitz and Haff, 2016). However, difficulties around the practical implementation of PAP in training and competition has stifled its inclusion in standard warm-up practices (Maloney et al., 2014). Issues revolve around the use of heavy equipment, space constraints, complex exercises, highly individualised responses, and excessively long warm-up strategies (Wilson et al., 2013; Van den Tillaar et al., 2019). If PAP does induce benefit in a subsequent power-based task, how can we ensure that athletes and coaches would implement these tasks as part of their warm-up practices? The benefits need to be explicit; the exercises need to be simple and reduce the risk of detracting from the preparation and the performance.

In first chapter, the author discussed the current research regarding the use of PAP as an application to enhance athletic performance. The focus was to review the available literature to determine whether PAP was a viable method to produce improvements in an athlete’s performance (Hodgson et al., 2005). The traditional application of PAP using heavy resistance training presented potential limitations for implementation in a training and competition environment (Kilduff et al., 2013). There were also concerns regarding the large disparity between the individuals who produced improved performances and those who show no improvement or detrimental outcomes (Wilson et al., 2013). The main limitation regarding this method revolved around the large fatigue effect post conditioning activity and the conflicting recommendations regarding the ideal time between the conditioning activity and the subsequent power-based task (Maloney et al., 2014). Another constraint was the need for heavy training equipment, space, and reasonable training technique to achieve the desired effects (Turner et al., 2015; Sharma et al., 2018). A more practical and reliable means of inducing a PAP response was needed to reduce the risk of a potential reduction in performance while making it a viable adjunct to an athlete’s warm-up. Ballistic exercises were reviewed as an alternative to heavy resistance training. There was evidence that ballistic exercises had the potential to induce a PAP response (Suchomel et al., 2016; Tobin and Delahunt, 2014; Turner et al., 2015). These exercises were often long, drawn-out

activities, requiring external resistance or technically complex routines (Creekmur et al., 2017; Tobin and Delahunt, 2014). The objective was to explore whether there was sufficient evidence to advocate the use of ballistic exercises which used no external resistance, were quick to implement and simple enough to avoid detracting from other components of the warm-up process while producing a substantial improvement in performance or training impulse.

Also highlighted in the literature review was the questionable quality of the evidence (Tobin and Delahunt, 2014; Turner et al., 2015). In many cases the methodology was flawed, poorly organised and confusing (Sharma et al., 2018). There was a need to produce results which followed strict academic rigour. Despite much of the evidence being in favour of using ballistic exercises to induce PAP, the research often neglected the effect of the baseline testing and how this would impact on the intervention and the outcome measurements (Sharma et al., 2018; Tobin and Delahunt, 2014; Piper, 2019). As discussed, PAP has been reported to last anywhere from immediately to up to 20 minutes post intervention (Wilson et al., 2013). As the baseline testing often consisted of a power-based task, a jump or sprint, it is conceivable that this could affect future outcomes both positively and negatively. As an important consideration both study one and study two implemented the intervention 20 minutes post baseline testing. This allowed any benefits or deficits incurred by the participant during the baseline test to dispel prior to the groups participating in the intervention. As PAP is a feed-forward effect, it is vital that any outcome measurement tested is exclusively attributed to the intervention and not influenced by prior testing effects. Both study one and study two produced improvements following the intervention and in both cases the control condition remained the same as the baseline. This indicates that two maximal vertical jumps may improve the outcome of a subsequent vertical jump and two 20 m maximal sprints can improve the outcome of a subsequent sprint two minutes after each intervention.

Another concern in many previous studies was the testing of multiple outcomes measurements (Sharma et al., 2018; Piper, 2019). In many cases a vertical bias (jump) and a horizontal bias (sprint) test would be undertaken together at the baseline testing and as an outcome measurement. As PAP acutely effects the subsequent task, either positively or negatively, the initial exercise would certainly have an effect of the subsequent exercise. It was initially thought to conduct both studies together, but careful consideration rejected this

notion as the result would inevitably be flawed. As such study one and study two were conducted on the same day but a week apart. The result indicated that two maximal vertical jumps can improve the height and power output of a subsequent vertical jump relative to its baseline and compared to a control group. Similarly, two maximal sprints can improve the velocity of a subsequent sprint relative to its baseline and compared to a control condition.

During the protocol development the implication of multiple outcome measurement testing was not considered. This was a common application in previous research to indicate how long post intervention the effect of PAP lasts (Turner et al., 2015; Tobin and Delahunt, 2014; Piper, 2019). This approach was pertinent in investigating how long the effect of the intervention would last. Since both studies were conducted prior to the data analysis it was only on assessment of the data that this flaw was discovered. As the initial outcome measurement was two minutes post intervention it was reasonable to assume that in both studies, the PAP effect was present for at least two minutes post intervention. In study two, the vertical jump indicated an improvement in the intervention group at two minutes but not in the control group. By six minutes post intervention all the groups had returned to their baseline values. In study one, the sprint intervention group improved two minutes post intervention while the control condition remained at the baseline level. After the two minute outcome measurement, the sprint intervention group remained elevated, but the control group improved their velocity by the six minute outcome measurement. This indicated that outcome measurement testing influenced the outcome in the control group. As this outcome measurement was the same as the intervention, it is conceivable to conclude that two maximal sprints can influence the outcome of a subsequent sprint and this benefit is present for at least four minutes post intervention. What cannot be concluded is that any change in the effect post initial outcome measure in the intervention group can be directly attributed to undertaking the intervention. This questions the reliability of many previous studies which have concluded that PAP effects were present for a specified time where in fact the result may have been distorted by consistent outcome testing.

PAP using a vertically bias conditioning activity.

Vertical power is an important component in many athletes' physical characteristics. Even in sprinting, vertical displacement plays an important role in speed generation. It has been well documented that vertically bias strengthening exercises have a proportional benefit to an athlete's linear speed (Cronin and Hansen, 2005; Cormie et al., 2010). Vertical jump

outcome has been reported as an indirect measure of speed potential (Conlon et al., 2013; Cronin and Hansen, 2005). There is significant evidence that chronic development of vertical bias strengthening and ballistic exercises create a positive training impulse for the development of linear speed (Cormie et al., 2011). It is therefore reasonable to assume that being able to jump higher would be a benefit in many sports which require vertical displacement to achieve a desired outcome.

As it was assumed that an acute improvement in vertical displacement would immediately benefit athletes in competition and chronically enhance their training impulse, it was decided to investigate the potential to induce this benefit with a 'real world' environment consideration. This may be prior to a race on a track, on a pitch prior to the commencement of a team sport game, at half time or at the training ground. The requirement was that the intervention needed to be technically simple, required no external resistance, and was quick to administer.

Ballistic exercises have shown benefits in inducing a PAP response (Maloney et al., 2014) while variations of the vertical jump have shown an improvement in subsequent jump performance (Hilfiker et al., 2007; Burkett et al., 2005). The aim was to induce a PAP response in a vertical jump by using a vertical jump as the conditioning activity. Intensity and specificity have been reported as an integral component in producing a PAP response (van den Tillaar et al., 2019; Suchomel et al., 2016). Assuming the conditioning activity was done at maximal intensity, this would allow for a technically simple exercise to be used quickly and allowed for an enhancement at the next power-based task. Notably, using a bodyweight ballistic exercise with a vertical bias does produce an enhanced PAP response, but this response was short. Other authors have reported the enhancement lasting up to five minutes post intervention but this was likely only due to repeated vertical jump testing which maintained the heightened response (Tobin and Delahunt, 2014). Study two of this thesis showed that the benefits of conducting two maximal vertical jumps to improve a subsequent vertical jump lasts approximately two minutes. This was evident as all the groups had returned to a baseline level by six minutes post intervention and there was no change recorded in the control group at any time point.

An important implication for athletes not incorporating PAP inducing tasks into their warm-ups was that the literature often reported that the benefits were highly individualised

especially when using heavy resistance training and/or an external resistance (Wilson et al., 2013; Turner et al., 2015). This caused variable outcomes regarding the expected benefits as well as the time until PAP was achieved. This approach in study two found that the benefit occurred quickly; within two minutes, and these benefits occurred in over 80% of the participants at their initial outcome measurement. This is important, as coaches and athletes are more likely to adopt an intervention where a beneficial outcome will occur. Athletes have reported in multiple studies that they preferred a shorter but higher intensity warm-up (van den Tillaar et al., 2019; Watterdal, 2013). The aim should be to structure the warm-up in a way to maximise the benefit while allowing the athlete to focus their intentions on the fundamental aspects of the warm-up prior to training or competition. The results from study two indicated that two maximal vertical jumps could potentiate a subsequent maximal vertical jump within two minutes post intervention. This intervention was easy to implement, required no equipment and was technically simple to do. Most of the participants (80%) improved with minimal modification to the athlete's preparation.

Study three of the thesis was a systematic review and meta-analysis. The systematic review was included as the third study, following the two RCT's. The data from the RCT's were included in the systematic review along with other studies which met the criteria for inclusion. The systematic review found a small yet significant effect size for using a bodyweight conditioning activity to potentiate a vertical jump, when compared to the control condition. A sub-group analysis indicated a greater effect size when using a vertically bias conditioning activity to potentiate a subsequent vertical jump and this was substantially superior to using a horizontally bias conditioning activity to potentiate a vertical jump. If an athlete only intended to enhance a vertical jump, then employing maximal vertical jumps would suffice. However, as most sports require both vertical and horizontal displacement, using a combination of vertical and horizontal bias activities would be more appropriate. In many cases coaches may implement a training task which aims to develop an athlete's vertical displacement. As part of the preparation for this session, vertical jumps could be used to potentiate athletes prior to undertaking this task, thus maximising the benefits of this training impulse. The outcome of this systematic review suggests that maximal bodyweight vertical jumps employed prior to training or competition is a viable method to induce a PAP response in athletes employing a vertically bias activity. This enhancement was reported to be present for up to two minutes post intervention and although the benefit was small, it was significant. This provides athletes and coaches an efficient and effective approach to

improve an athlete's potential quickly and could be easily implemented in competition or training in a 'real world' environment.

PAP using a horizontally bias conditioning activity.

Speed is one of the most valuable attributes athletes possess. In certain sports, speed is the sole determinate for success and in many others it is considered pivotal in performance outcomes (Colyer et al., 2018). This is determined by two factors. How fast the body accelerated and the maximal speed achieved. Ultimately, if athletes want to run faster, they need to improve their speed and conversely if athletes want to improve their speed they need to learn to run faster (Haugen, 2017). As a chronic impulse, the speed training effect can be enhanced using multiple external stimuli to improve speed, including downhill running, resistance bands, towing and treadmills (Leyva et al., 2017; Haugen et al., 2019). An intrinsic method for improving an athlete's ability to run faster could also augment this process to develop speed. As PAP has demonstrated improvements in the outcome of sprints following a maximal conditioning activity, it is plausible to apply this principle to develop a chronic improvement in speed during training. It would also stand to reason that athletes may utilise this technique to enhance the capacity for running faster in a competition environment.

For athletes to consider the implementation of different techniques into their warm-ups, they need to be certain that this will not detract from the current warm-up practice. In many cases a warm-up is set over a defined time and extra time detracts from other important tasks undertaken during this process (Van den Tillaar et al., 2019; Watterdal, 2013). It is also critical to use activities which are simple and don't require high levels of technical proficiency as the more complicated or challenging the less likely athletes will incorporate those into their current preparations. While using external resistance in the form of heavy resistance training and external loads has been shown to produce a PAP effect, it is unlikely most coaches and athletes will include something which requires more space, time and equipment to implement. Some reports have indicated that athletes prefer simpler and shorter warm-ups (Watterdal, 2013; Silva et al., 2018). The basis for this study was to explore the potential that sprinting could be improved by sprinting. Much of the literature has investigated sprinting velocity using heavy resistance training, pushing or pulling actions and vertical ballistic activities (Smith et al., 2014; Sharma et al., 2018; Creekmur et

al., 2017). There was significantly less evidence that using a horizontal bias conditioning activity can potentiate a subsequent sprint, (Turner et al., 2015). As described in the literature review a ballistic activity is any maximal task with the intent to move an object or body quickly (Maloney et al., 2014; Turner, 2009). Although many sources define this as a form of jump or plyometric this could include actions of bounding or sprinting with or without an external resistance. As the goal was to develop a simple method to achieve a full or partial PAP effect and using a task which included the principles of intensity and specificity, it was determined to investigate whether a maximal sprint could potentiate a subsequent sprint performance.

The goal was to investigate sprint performance relative to a baseline and control condition. It was important to determine whether a sprint could be enhanced by two maximal sprints, yet not influenced by other factors including the baseline testing or other outcome measurements. As PAP is a feed-forward mechanism, it was important to control as many of these factors as possible during testing. Initially it appeared that the sprint intervention had the potential to produce a PAP effect for at least six minutes. However, closer examination revealed that the control condition was also elevated at six minutes in line with the intervention groups. The control condition did not participate in the intervention and their previous maximal effort was during the baseline testing, over 20 minutes earlier. This was more than sufficient time to dispel any PAP effects which could have influenced later testing outcomes. As the outcome measure measurements and intervention were the same (two maximal sprints), it was concluded that the outcome measurement influenced the results of the latter testing at six minutes. Therefore, any changes following the initial outcome measurement cannot be directly attributed to the intervention alone. This is a concern reiterated by Blazeovich and Babault, (2019) that multiple testing outcome measurements have the potential to influence latter outcome measurements. This was important to recognise as a flaw in this study but also in previous literature. Previous studies may claim the feed-forward effect of PAP as exaggerated in time and effect due to the multiple outcome measures undertaken (Tobin and Delahunt, 2014; Turner et al., 2015; Piper, 2019). As the intervention and the outcome measurement were the same, two maximal sprints, it does suggest that a PAP effect from two maximal sprints can last as long as four minutes post intervention.

The results of study one suggested that a maximal sprint can be potentiated by two maximal sprints. Concerns highlighted in other literature was the possibility that a PAP effect is highly individualised, leading to challenge in achieving an overall improvement without the potential of some athletes incurring a detrimental outcome (Wilson et al., 2013). Ballistic exercises which use less external resistance tended to produce less fatigue as well as a shorter time until enhancement (Turner et al., 2015). It was observed in this population that over 80% of the participants achieved an enhancement at two minutes. This would suggest that this method of inducing PAP was not only simple and quick but efficient in producing a beneficial outcome in most of the participants. Notably, if the training or competition task consists of both vertical and horizontal bias tasks then using both a maximal vertical jump and a maximal sprint would be appropriate. If the training impulse is purely aimed to improve speed, then using a maximal sprint intervention is likely to provide the desired enhancement. It was determined that two maximal sprints had the potential to improve the outcome of a subsequent maximal sprint within two minutes and up to four minutes post conditioning activity.

The results of the systematic review (study 3) indicated that a bodyweight conditioning activity had a small but significant effect in improving a maximal sprint outcome. There was an indication that the effect size increased in a sub-group analysis when the conditioning activity is the same as the outcome measurement. Although using a vertical bias conditioning activity was not significantly different compared to using a horizontal bias conditioning activity as the outcome measurement. Using a bodyweight maximal sprint conditioning activity to potentiate a subsequent sprint performance was not only effective but efficient in producing an enhanced effect relative to the baseline and a control condition.

PAP using bodyweight conditioning activities to improve performance.

An objective of this research was to determine whether a bodyweight conditioning activity could be used in a 'real world' environment with 'real world' applications. To achieve this, it was not only important to quantify the outcome of a bodyweight task to potentiate a subsequent task but also to compare that outcome to recent similar research. As PAP is influenced by previous interventions due to its feed-forward effect, it was vital to first establish whether an isolated bodyweight conditioning activity could cause a PAP effect while carefully controlling the preceding testing. This was achieved in the two randomised controlled trials by commencing the testing 20 minutes before the isolated intervention. As

the testing was maximal in nature, it was conceivable that the testing could influence the intervention and thus influence the subsequent outcome measurements. This has not been previously described in the literature.

As all the groups participated in the initial warm-up and baseline testing, then waited 20 minutes before undertaking the intervention, it was postulated that all preceding effects associated with the baseline testing would have dissipated. All the groups would maintain an estimated elevated body temperature by partaking in low intensity ball related tasks described as head tennis. This was to mimic the initial warm-up and was effective as the baseline testing and the intervention tests in the vertical jump and sprint group were the same with no significant difference. This was important to observe as it firstly ensured that the baseline testing had not influenced the intervention and that the warm-up before the baseline testing and the low intensity ball related tasks were indeed comparable to the initial warm-up. This allowed the investigators to conclude that the intervention in this case was the most likely contributor to any changes observed at the initial outcome measurement.

In both randomised controlled trials, a change in the outcome measurement occurred relative to the baseline and compared to the control condition. It is worth noting that despite the within group change being significant, the between group change was not. In both studies the effect size compared to the control condition indicated a small to moderate magnitude of change. What was also indicated was that compared to a previously defined intervention, Tobin and Delahunt, (2014) and Turner et al. (2015) both the two maximal vertical jumps and the two maximal sprints were comparable at the initial outcome measurement. What was not initially considered and possibly should have been, was what effect previous testing would have on subsequent testing. In study two using the vertical jump, there was no effect evident at the second time point at six minutes. The authors assumed that the effect of the intervention had resolved back to baseline by that point. However, this was incorrect as in study one, the maximal sprint control demonstrated no change between the intervention and the initial outcome measurement but elevated to the intervention group level by the second outcome measurement. This was serendipitous as it revealed that all studies which conduct multiple outcome measurement have in fact influenced the subsequent results as evident in both previously defined interventions used in these randomised controlled trials (Turner et al., 2015; Tobin and Delahunt, 2014).

Following the indication that both a body weight vertical jump and maximal sprint could influence the outcome at two minutes, it was decided to collate this data with similar data pertaining to body weight activities and the effect it had on a subsequent power-based task. A systematic review and meta-analysis was used to systematically collate the available data for review and statistically analyse the possible influence of PAP. This provided evidence for the validity of study one and study two as they were compared to other similar studies, as both were included in the systematic review. It was evident that bodyweight tasks had some variability in the nature of the task used as well as the units applied. For this reason, a standardised mean difference was used to compare multiple different variables which were all bodyweight in nature. It was very important to attempt to standardise the inclusion criteria. Following on from the realisation that multiple outcome measurements have had a feed-forward effect on latter outcome measurements, it was decided to only include the first outcome measurement. Although this may be controversial, as much of the research within the field of PAP and PAPE has been conducted and presented using multiple testing outcome measurements. The only solution was to include research which conducted one outcome measurement or if multiple measurements were conducted to only consider the initial measurement.

Another issue relating to much of the previous research was the inclusion of multiple different tasks as the outcome measurement. In a similar approach each task will indicatively affect the outcome of the next task. To control this effect only one task was selected and if multiple tasks were undertaken only the initial task was included. The results indicated that using a body weight intervention did have a small effect in improving the outcome of a subsequent power-based task. This was in line with the randomised controlled trials of study one and study two. There was only minimal difference between using a bodyweight condition to potentiate a vertical power-based task compared to a horizontal power-based task. This was again confirmed in the randomised controlled trials as both indicated a similar effect size. The meta-analysis did highlight that bodyweight activities produced a similar outcome if the outcome measurement was tested prior to five minutes or five minutes after the intervention. This may be true but requires some postulation. In study two, it was evident that the vertical jump conditioning activity was unable to produce an enhanced effect more than four minutes post intervention. It was clear that this effect returned to baseline somewhere between two and four minutes. Further research would need to determine exactly how long the effect is capable of lasting. The sprint outcome in study one, was still elevated

four minutes post intervention so there appears to be evidence that some interventions have the potential to produce an enhancement up to and beyond five minutes.

Specificity was demonstrated in the sub-group analysis as part of the meta-analysis as there was a greater effect in favour of using the same conditioning activity as the subsequent task. This outcome, though not significantly different compared to the using a different conditioning activity, was significantly greater than the control condition. Using a different conditioning activity compared to the outcome measurement was not significantly different compared to the control condition. As the objective of this study was to evaluate the potential that a bodyweight conditioning activity can be used in a 'real world' environment to facilitate an enhancement in a subsequent task, it appears that this may be true. Two maximal vertical jumps can induce an enhancement in a subsequent vertical jump, which is an integral part in many team and individual sports. Two maximal 20 m sprints can also enhance the outcome of a subsequent sprint by two minutes which has been shown to last at least four minutes and postulated to last longer. It is evident that bodyweight conditioning activities produce a small effect in a subsequent power-based task when analysed with a meta-analysis. This suggests that a bodyweight conditioning activity, which is simple, quick and requires no equipment with minimal negative consequences is a viable method for helping athletes prepare for training as well as competitions. This is more effective if athletes and coaches consider using a conditioning activity which is the same or similar to the activity requiring potentiation.

Strengths

Many previous studies attempted to investigate the longitudinal nature of PAP. The implication being that by undertaking a conditioning activity, PAP would be achieved at some point in the short-term future. Most studies investigated this using a test-retest protocol, using the participants as their own controls. The methodology becomes flawed due to the baseline testing in many cases being carried out within five minutes of the intervention. As the baseline testing was in most cases a power-based task, either jumping or sprinting, it is conceivable that this testing could influence not only the intervention but also the outcome testing. Blazevich and Babault, (2019) highlighted this as a limitation in previous research and suggested future studies should endeavour to mitigate this feed-forward risk. Study one and study two both tried to limit this risk through use of a control condition but also doing the baseline testing with adequate time before the intervention. This

was to dispel any potential fatigue or performance enhancements prior to undertaking the intervention. This was to ensure that the outcome measure was attributed solely to the intervention or lack thereof.

Another limitation presented in the previous literature was that those studies often include multiple baseline and outcome measurements. This could include a jump followed by a sprint or another power-based combination. As PAP has a longitudinal effect it became clear that each baseline and outcome measures influenced the subsequent measurement. This became problematic because the effect was skewed either due to heightened fatigue or performance incurred by the previous events other than the intervention. As study one and study two followed a similar methodology with a similar population group it was initially questioned whether these studies could be combined. It was determined that it was critical to review the effects individually as firstly neither effect could influence the other and the study could provide good evidence on whether a vertical bias or horizontal bias conditioning activity could potentiate a similar subsequent power-based task. Although study three, the systematic review did include either a vertical or horizontal bias conditioning activity, a subgroup meta-analysis demonstrated that similar activities provided better potentiation outcomes.

Limitations

A limitation not initially considered was the resultant effect of multiple outcome measurements over different time points. Both study one and study two intended to investigate the PAP effect over two time points, two and six minutes post intervention. It was hypothesised that using a bodyweight conditioning activity would result in a PAP effect. However, this effect would be relatively short lived as ballistic conditioning activities tended to produce less potentiation, but also less consequential fatigue compared to a weighted conditioning activity. This effect was conceived to be present immediately and to last between two and six minutes. Both studies indicated an enhancement at two minutes post intervention and despite the vertical jump showing no improvement in any group at six minutes, this was construed to be directly related to the intervention. The sprint study found a similar enhancement at two minutes post intervention which in this case was maintained until six minutes but what was unforeseen though not unexpected post analysis was that the control condition demonstrated no change post intervention but showed a clear enhancement between two and six minutes. This was a clear indication that firstly, power-based tasks do

provide a potentiation effect and secondly, multiple power-based outcome measurements will affect the subsequent outcome measurement at least over the following four minutes. This was not evident in study two. The vertical jump effect was assumed to last less than four minutes post the power-based task, returning both groups to their baseline levels by the six minute outcome measurement.

After the analysis of study one and two it was assumed that previous testing would affect the outcome of subsequent results. As such in the systematic review, any study which undertook multiple outcome test measurements post intervention would be included assuming the other inclusion criteria were met however, only the initial outcome measurement was included. Some studies found significant improvements post intervention at a later time point. In many cases this was reported after previous outcome measurement testing, and as such this can't be assumed to be truly attributed to the intervention alone due to the potential for enhancement or a fatigue effect contributed by the previous outcome testing. Further investigation is needed into the longitudinal effects of PAP while only including one outcome measurement at a time.

Practical implication

For over 20 years, PAP has been investigated as a performance enhancement tool. Good evidence exists that this physiological effect can be used to improve the outcome of a subsequent power-based task using both ballistic and heavy resistance training. However, this benefit was limited to a clinical setting and certain isolated training environments. This posed a challenge to coaches and athletes on how to implement PAP consistently and effectively in a training and competition environment in a 'real world' setting. The restrictions placed on coaches and athletes to incorporate highly unreliable tasks which are effective in relatively narrow parameters has expressed caution from the research community. Utilising heavy equipment, technically complex exercises and excessively long time frames has also reduced the likelihood of athletes adopting this approach. This research endeavoured to investigate an alternative and reliable way to introduce PAP into an athlete's warm-up. As such it was investigated whether a bodyweight conditioning activity, done with maximal intensity and similar to the subsequent power-based task could fully or partially potentiate athletes prior to participation. The outcome of this research demonstrated that a

vertical or horizontal bias bodyweight conditioning activity such as a vertical jump or a maximal sprint, could improve the outcome of a subsequent power-based task. The effect size when compared to other similar studies was small but significant. Whilst, previous studies highlighted the highly individualised effects of PAP and performance, it was our experience that using this approach, consistently produced a small to moderate improvement in more than 80% of the participants. This application could be implemented in the final warm-up process prior to competition or before training. It is also likely to provide a benefit in team sports before the commencement of the game and the ensuing quarters or half. The author proposes that an athlete should undertake two maximal vertical jumps and two maximal sprints within five minutes prior to participation to achieve this benefit.

Conclusion

This thesis intended to examine the potential for athletes, coaches, and rehabilitation experts to use PAP as a tool to enhance their training impulse and competition outcomes in a 'real world' setting. The criteria were that the intervention had to be effective, beneficial, and simple. For athletes to incorporate a new intervention into their preparations, it needed to enhance their current warm-up practices without the potential to detract from their performance. Three studies were undertaken to investigate this notion. The outcome of this research indicates that using a bodyweight conditioning activity to achieve a PAP response in a subsequent power-based task is possible. The benefits are simple to integrate into an athlete's warm-up activities with minimal detrimental effects. These improvements are likely to induce a PAP effect in over 80% of the participants who incorporate a vertical jump and a maximal sprint into their preparation for training and competition. It is concluded that a maximal vertical jump and a maximal sprint can produce a PAP effect in a subsequent power-based task in a 'real world' setting.

References

1. Abade, E., Sampaio, J., Goncalves, B., Baptista, J., Alves, A. & Viana, J. (2017). Effects of different re-warm up activities in football players' performance. *Plos One*, 12(6), pp.

2. Barengo, N. C., Meneses-Echávez, J. F., Ramírez-Vélez, R., Cohen, D. D., Tovar, G. & Bautista, J. E. C. (2014). The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *International journal of environmental research and public health*, 11(11), pp 11986-12000.
3. Bergmann, J., Kramer, A. & Gruber, M. (2013). Repetitive hops induce postactivation potentiation in triceps surae as well as an increase in the jump height of subsequent maximal drop jumps. *PLoS One*, 8(10), pp e77705.
4. Bevan, H. R., Cunningham, D. J., Tooley, E. P., Owen, N. J., Cook, C. J. & Kilduff, L. P. (2010). Influence of postactivation potentiation on sprinting performance in professional rugby players. *J Strength Cond Res*, 24(3), pp 701-5.
5. Blazevich, A. J. & Babault, N. (2019). Post-activation Potentiation (PAP) versus Post-activation Performance Enhancement (PAPE) in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, 10(1359).
6. Bogdanis, G. C., Tsoukos, A. & Veligekas, P. (2017). Improvement of Long-Jump Performance During Competition Using a Plyometric Exercise. *Int J Sports Physiol Perform*, 12(2), pp 235-240.
7. Borba, D. d. A., Ferreira-Júnior, J. B., Santos, L. A. d., Carmo, M. C. d. & Coelho, L. G. M. (2017). Effect of post-activation potentiation in Athletics: a systematic review. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 19(1), pp 128-138.
8. Brink, N.J., Constantinou, D. and Torres, G., (2021). Postactivation performance enhancement (PAPE) of sprint acceleration performance. *European Journal of Sport Science*, pp.1-7.
9. Brink, N., Constantinou, D. & Torres, G. (2020). Postactivation performance enhancement (PAPE) of vertical jump performance. Unpublished.
10. Burkett, L. N., Phillips, W. T. & Ziuraitis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), pp 673-676.

11. Byrne, P. J., Kenny, J. & O' Rourke, B. (2014). Acute Potentiating Effect of Depth Jumps on Sprint Performance. *Journal of Strength and Conditioning Research*, 28(3), pp 610-615.
12. Colyer, S. L., Nagahara, R., Takai, Y. & Salo, A. I. (2018). Kinetic factors differentiating mid-to-late sprint acceleration performance in sprinters and soccer players. *ISBS Proceedings Archive*, 36(1), pp 674.
13. Conlon, J., Haff, G. G., Nimphius, S., Tran, T. & Newton, R. U. (2013). Vertical jump velocity as a determinant of speed and agility performance. *J. Aust. Strength Cond*, 21(88-90).
14. Cormie, P., McGuigan, M. R. & Newton, R. U. (2010). Adaptations in athletic performance after ballistic power versus strength training. *Med Sci Sports Exerc*, 42(8), pp 1582-1598.
15. Cormie, P., McGuigan, M. R. & Newton, R. U. (2011). Developing maximal neuromuscular power. *Sports medicine*, 41(1), pp 17-38.
16. Creekmur, C. C., Haworth, J. L., Cox, R. H. & Walsh, M. S. (2017). Effects of plyometrics performed during warm-up on 20 and 40 m sprint performance. *J Sports Med Phys Fitness*, 57(5), pp 550-555.
17. Cronin, J. B. & Hansen, K. T. (2005). Strength and power predictors of sports speed. *The Journal of Strength & Conditioning Research*, 19(2), pp 349-357.
18. Cuenca-Fernandez, F., Smith, I. C., Jordan, M. J., MacIntosh, B. R., Lopez-Contreras, G., Arellano, R. & Herzog, W. (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. *Applied Physiology Nutrition and Metabolism*, 42(10), pp 1122-1125.
19. De Sousa Fortes, L., Paes, P. P., Mortatti, A. L., Perez, A. J., Cyrino, E. S., De Lima-Júnior, D. R. A. A. & Moreira, A. (2018). Effect of different warm-up strategies on countermovement jump and sprint performance in basketball players. *Isokinetics and Exercise Science*, 26(3), pp 219-225.

20. de Villarreal, E. S. S., Gonzalez-Badillo, J. J. & Izquierdo, M. (2007). Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *European Journal of Applied Physiology*, 100(4), pp 393-401.
21. Desmedt, J. E. & Godaux, E. (1977). Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis anterior muscle. *The Journal of physiology*, 264(3), pp 673-693.
22. Dobbs, W. C., Toluoso, D. V., Fedewa, M. V. & Esco, M. R. (2019). Effect of Postactivation Potentiation on Explosive Vertical Jump: A Systematic Review and Meta-Analysis. *J Strength Cond Res*, 33(7), pp 2009-2018.
23. Duffield, B. & Dawson, B. (2003). Energy system contribution in track running. *New Studies in Athletics*, 18(4), pp 47-56.
24. Esformes, J. I., Cameron, N. & Bampouras, T. M. (2010). Postactivation potentiation following different modes of exercise. *Journal of Strength and Conditioning Research*, 24(7), pp 1911-1916.
25. Fashioni, E., Langley, B. & Page, R. M. (2019). The effectiveness of a practical half-time re-warm-up strategy on performance and the physical response to soccer-specific activity. *Journal of Sports Sciences*, 38(2), pp 140-149.
26. Gil, M. H., Neiva, H. P., Alves, A. R., Sousa, A. C., Duarte-Mendes, P., Marques, M. C. & Marinho, D. A. (2020). Does the inclusion of ballistic exercises during warm-up enhance short distance running performance? *The Journal of sports medicine and physical fitness*, 60(4), pp 501-509.
27. Gil, M. H., Neiva, H. P., Garrido, N. D., Aidar, F. J., Cirilo-Sousa, M. S., Marques, M. C. & Marinho, D. A. (2019). The Effect of Ballistic Exercise as Pre-Activation for 100 m Sprints. *International Journal of Environmental Research and Public Health*, 16(10), pp.
28. Gorostiaga, E. M., Llodio, I., Ibáñez, J., Granados, C., Navarro, I., Ruesta, M., Bonnabau, H. & Izquierdo, M. (2009). Differences in physical fitness among indoor and outdoor elite male soccer players. *European journal of applied physiology*, 106(4), pp 483-491.

29. Gołaś, A., Maszczyk, A., Zajac, A., Mikołajec, K. & Stastny, P. (2016). Optimizing post activation potentiation for explosive activities in competitive sports. *J Hum Kinet*, 52(95-106).
30. Hamada, T., Sale, D., MacDougall, J. & Tarnopolsky, M. (2003). Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. *Acta physiologica scandinavica*, 178(2), pp 165-173.
31. Haugen, T. (2017). Sprint conditioning of elite soccer players: worth the effort or lets just buy faster players. *Sport Performance & Science Reports*, 1(1), pp 1-2.
32. Haugen, T., Seiler, S., Sandbakk, Ø. & Tønnessen, E. (2019). The training and development of elite sprint performance: an integration of scientific and best practice literature. *Sports medicine-open*, 5(1), pp 44.
33. Healy, R. & Comyns, T. M. (2017). The Application of Postactivation Potentiation Methods to Improve Sprint Speed. *Strength and Conditioning Journal*, 39(1), pp 1-9.
34. Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J. & Welch, V. A. (2019). *Cochrane handbook for systematic reviews of interventions*: John Wiley & Sons.
35. Hilfiker, R., Hubner, K., Lorenz, T. & Marti, B. (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research*, 21(2), pp 550-555.
36. Hodgson, M., Docherty, D. & Robbins, D. (2005). Post-activation potentiation - Underlying physiology and implications for motor performance. *Sports Medicine*, 35(7), pp 585-595.
37. Howe, L., Coward, M. & Price, P. (2017). The postactivation potentiation effect of either plyometrics or speed, agility and quickness exercises on linear sprint performance.
38. Karampatsos, G., Terzis, G., Polychroniou, C. & Georgiadis, G. (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education & Sport*, 13(1), pp 3-5.

39. Karampatsos, G. P., Korfiatis, P. G., Zaras, N. D., Georgiadis, G. V. & Terzis, G. D. (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), pp 359-364.
40. Kilduff, L. P., Finn, C. V., Baker, J. S., Cook, C. J. & West, D. J. (2013). Preconditioning Strategies to Enhance Physical Performance on the Day of Competition. *International Journal of Sports Physiology & Performance*, 8(6), pp 677-681.
41. Kummel, J., Bergmann, J., Prieske, O., Kramer, A., Granacher, U. & Gruber, M. (2016). Effects of conditioning hops on drop jump and sprint performance: a randomized crossover pilot study in elite athletes. *Bmc Sports Science Medicine and Rehabilitation*, 8
42. Leyva, W. D., Wong, M. A. & Brown, L. E. (2017). Resisted and assisted training for sprint speed: A brief review. *Journal of Physical Fitness, Medicine & Treatment in Sports*, 1(1), pp 555554.
43. Lim, J. J. & Kong, P. W. (2013). Effects of isometric and dynamic postactivation potentiation protocols on maximal sprint performance. *J Strength Cond Res*, 27(10), pp 2730-6.
44. Lima, J. C. B., Marin, D. P., Barquilha, G., Da Silva, L. O., Puggina, E. F., Pithon-Curi, T. C. & Hirabara, S. M. (2011). Acute effects of drop jump performance protocol on sprint and counter movement vertical jump performance.. *Human Movement*, 12(4), pp 324-330.
45. Lorenz, D. (2011). Postactivation potentiation: An introduction. *International journal of sports physical therapy*, 6(3), pp 234.
46. Maloney, S. J., Turner, A. N. & Fletcher, I. M. (2014). Ballistic exercise as a pre-activation stimulus: A review of the literature and practical applications. *Sports medicine*, 44(10), pp 1347-1359.

47. Margaritopoulos, S., Theodorou, A., Methenitis, S., Zaras, N., Donti, O. & Tsolakis, C. (2015). The effect of plyometric exercises on repeated strength and power performance in elite karate athletes. *Journal of Physical Education & Sport*, 15(2), pp 310-318.
48. Masamoto, N., Larson, R., Gates, T. & Faigenbaum, A. (2003). Acute effects of plyometric exercise on maximum squat performance in male athletes. *The Journal of Strength & Conditioning Research*, 17(1), pp 68-71.
49. Matthews, M. J., Matthews, H. P. & Snook, B. (2004). The acute effects of a resistance training warmup on sprint performance. *Research in Sports Medicine*, 12(2), pp 151-159.
50. Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*, 62(10), pp 1006-12.
51. Mola, J. N., Bruce-Low, S. S. & Burnet, S. J. (2014). Optimal recovery time for postactivation potentiation in professional soccer players. *The Journal of Strength & Conditioning Research*, 28(6), pp 1529-1537.
52. Nardone, A., Romano, C. & Schieppati, M. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of physiology*, 409(1), pp 451-471.
53. Nardone, A. & Schieppati, M. (1988). Shift of activity from slow to fast muscle during voluntary lengthening contractions of the triceps surae muscles in humans. *The Journal of physiology*, 395(1), pp 363-381.
54. Piper, A. (2019). Comparison of Post-Activation Potentiation Methods on Power and Sprint Acceleration.
55. Piper, A. D., Joubert, D. P., Jones, E. J. & Whitehead, M. T. (2020). Comparison of Post-Activation Potentiating Stimuli on Jump and Sprint Performance. *International Journal of Exercise Science*, 13(4), pp 539-553.

56. Prieske, O., Behrens, M., Chaabene, H., Granacher, U. & Maffiuletti, N. A. (2020). Time to differentiate postactivation “potentiation” from “performance enhancement” in the strength and conditioning community. *Sports Medicine*, 50(1559-1565).
57. Prieske, O., Maffiuletti, N. A. & Granacher, U. (2018). Postactivation Potentiation of the Plantar Flexors Does Not Directly Translate to Jump Performance in Female Elite Young Soccer Players. *Frontiers in Physiology*, 9(
58. Rassier, D. & Macintosh, B. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research*, 33(5), pp 499-508.
59. Russell, M., West, D. J., Harper, L. D., Cook, C. J. & Kilduff, L. P. (2015). Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations. *Sports Medicine*, 45(3), pp 353-364.
60. Sale, D. G. (2002). Postactivation potentiation: role in human performance. *Exercise and sport sciences reviews*, 30(3), pp 138-143.
61. Sayers, S., Harackiewicz, D., Harman, E., Frykman, P. & Rosenstein, M. (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise*, 31(4), pp 572-577.
62. Seitz, L. & Haff, G. (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports Medicine*, 46(2), pp 231-240.
63. Sharma, S. K., Raza, S., Moiz, J. A., Verma, S., Naqvi, I. H., Anwer, S. & Alghadir, A. H. (2018). Postactivation potentiation following acute bouts of plyometric versus heavy-resistance exercise in collegiate soccer players. *BioMed research international*, 2018
64. Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M. & Marinho, D. A. (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, 48(10), pp 2285-2299.

65. Sims, L. (2016). Isometric mid-thigh pull vs. plyometric post activation potentiation and their effects on maximum velocity in athletic males. Cardiff Metropolitan University.
66. Smith, C. E., Hannon, J. C., McGladrey, B., Shultz, B., Eisenman, P. & Lyons, B. (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), pp 33-41.
67. Smith, I. C. & MacIntosh, B. R. (2021). A Comment on “A New Taxonomy for Postactivation Potentiation in Sport”. *International Journal of Sports Physiology and Performance*, 16(2), pp 163-163.
68. Stieg, J. L., Faulkinbury, K. J., Tran, T. T., Brown, L. E., Coburn, J. W. & Judelson, D. A. (2011). Acute effects of depth jump volume on vertical jump performance in collegiate women soccer players. *Kinesiology*, 43(1), pp 25-30.
69. Suchomel, T. J., Comfort, P. & Lake, J. P. (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength & Conditioning Journal*, 39(1), pp 10-20.
70. Suchomel, T. J., Sato, K., DeWeese, B. H., Ebben, W. P. & Stone, M. H. (2016). Potentiation effects of half-squats performed in a ballistic or nonballistic manner. *Journal of strength and conditioning research*, 30(6), pp 1652-1660.
71. Till, K. A. & Cooke, C. (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *The Journal of Strength & Conditioning Research*, 23(7), pp 1960-1967.
72. Tillin, N. A. & Bishop, D. (2009). Factors Modulating Post-Activation Potentiation and its Effect on Performance of Subsequent Explosive Activities. *Sports Medicine*, 39(2), pp 147-166.
73. Tobin, D. P. & Delahunt, E. (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *The Journal of Strength & Conditioning Research*, 28(2), pp 367-372.

74. Tufanaru, C., Munn, Z., Stephenson, M. & Aromataris, E. (2015). Fixed or random effects meta-analysis? Common methodological issues in systematic reviews of effectiveness. *Int J Evid Based Healthc*, 13(3), pp 196-207.
75. Turner, A. N. (2009). Training for power: Principles and practice. *Professional Strength & Conditioning*, 14), pp 20-32.
76. Turner, A. P., Bellhouse, S., Kilduff, L. P. & Russell, M. (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res*, 29(2), pp 343-50.
77. Van Cutsem, M., Duchateau, J. & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *The Journal of physiology*, 513(1), pp 295-305.
78. van den Tillaar, R., Lerberg, E. & von Heimburg, E. (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*, 8(6), pp 574-578.
79. Vandenboom, R. (2011). Modulation of skeletal muscle contraction by myosin phosphorylation. *Comprehensive Physiology*, 7(1), pp 171-212.
80. Vandervoort, A., Quinlan, J. & McComas, A. (1983). Twitch potentiation after voluntary contraction. *Experimental neurology*, 81(1), pp 141-152.
81. Wakeling, J. M. (2009). Patterns of motor recruitment can be determined using surface EMG. *Journal of Electromyography and Kinesiology*, 19(2), pp 199-207.
82. Watterdal, Ø. (2013). The impact of warm up intensity and duration on sprint performance.
83. Wilson, J. M., Duncan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Wilson, S. M., Jo, E., Lowery, R. P. & Ugrinowitsch, C. (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), pp 854-859.

84. Young, W. (1992). Sprint bounding and the sprint bound index. *NSCA J*, 4(6), pp 44-44.
85. Zimmermann, H. B., MacIntosh, B. R. & Dal Pupo, J. (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology Nutrition and Metabolism*, 45(4), pp 349-356.

Chapter 6 - Appendix

Appendix 1 – Ethical clearance certificate



R14/48 Mr Nicholas Brink

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M190623

NAME: Mr Nicholas Brink
(Principal Investigator)
DEPARTMENT: School of Therapeutic Sciences
Bidvest Wits Football Club

PROJECT TITLE: The 'real world' application of postactivation potentiation in a physical training and competition environment

DATE CONSIDERED: 28/08/2019

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Demetri Constantinou and Georgia Torres

APPROVED BY: 
Dr. CB Penny, Chairperson, HREC (Medical)

DATE OF APPROVAL: 12/08/2019

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and ONE COPY returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with those conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. I agree to submit a yearly progress report. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in June and will therefore be due in the month of June each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature _____

Date _____

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 2 - Athlete code sheet



Investigator		Nicholas Brink
Study Title		The 'real world' application of postactivation potentiation in a physical training and competition environment.
Institution		University of the Witwatersrand, Faculty of Health Science
#	Athlete Code	Athlete Name
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Appendix 3 – Study one Information document



Study one information Document

Information Document

Study title: The ‘real world’ application of postactivation potentiation in a physical training and competition environment.

Investigator: Nicholas Brink

Contact email: nicjbrink@gmail.com

Principal supervisor: Prof Demitri Constantinou

Contact email: Demitri.Constantinou@wits.ac.za

Supervisor: Dr Georgia Torres

Contact email: Georgia.torres@wits.ac.za

Institution: University of the Witwatersrand, Faculty of Health Sciences

Greetings,

My name is Nicholas Brink, A PhD student from the University of the Witwatersrand, Faculty of Health Sciences. I am conducting a randomised controlled trial (you will be randomly assigned to one of three groups) to evaluate the effect of postactivation potentiation: a short-term improvement in performance as a result of using a conditioning exercise, in the training and competition environment. The factor to be evaluated in this study is the sprint acceleration.

I would like to invite you to participate in this research study. Your participation will involve the following:

- (1) participate in a controlled football orientated warm-up for approximately 20 minutes.
- (2) complete in two maximal baseline sprint accelerations over 20 m.
- (3) participate in 20 minutes of ‘head tennis’.
- (4a) complete three maximal sprint accelerations over 20 m, or
- (4b) complete a series of three sets of ten bounds, or
- (4c) completes two minutes of walking to maintain raised body temperature.
- (5) complete two maximal sprint accelerations over 20 m after two minutes.

(6) complete two maximal sprint accelerations over 20 m after six minutes.

The total time involvement will be approximately one hour.

Your participation in this study is entirely voluntary. Before agreeing to participate, it is important that you read and understand the explanation of the purpose of the study and study procedures. This information sheet is to help you decide if you would like to participate. If you have any questions, do not hesitate to ask me. You are free to decline to participate if you so wish. You are free to withdraw from the study at any stage and this will not be held against you. If you decide to take part in this study, you will be asked to sign this document to confirm that you understand the study and agree to take part. You will be given a copy to keep.

Purpose of the study

The focus of this proposed study is on whether postactivation potentiation can be achieved from using a conditioning activity similar to the potentiated task, in this case a sprint acceleration.

Risks and Benefits

The participants will be at a similar risk of injury compared to any other ‘normal’ training session. These risks have been reduced by providing a thorough warm-up. The benefit of the study is that we intend to broaden the pool of knowledge with regard to training and competition preparation strategies.

No financial benefit or reimbursements will be provided for participation in this study.

Confidentiality

All information obtained during the course of the study, will be kept strictly confidential. Data that may be reported in the research report and scientific journals will not include any information that identifies you as participants in this study. There are no names on the data collection sheet which will be coded and only the researcher will have access to codes.

On completion of the study, the results will be disseminated to you along with your personal results.

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg (“Committee”). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research. If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.

July 2020

Appendix 4 – Study two information document



Study two Information Document

Information Document

Study title: The ‘real world’ application of postactivation potentiation in a physical training and competition environment.

Investigator: Nicholas Brink

Contact email: nicjbrink@gmail.com

Principal supervisor: Prof Demitri Constantinou

Contact email: Demitri.Constantinou@wits.ac.za

Supervisor: Dr Georgia Torres

Contact email: Georgia.torres@wits.ac.za

Institution: University of the Witwatersrand, Faculty of Health Sciences

Greetings,

My name is Nicholas Brink, A PhD student from the University of the Witwatersrand, Faculty of Health Sciences. I am conducting a randomised controlled trial (you will randomly be assigned to one of three groups) to evaluate the effect of postactivation potentiation; a short-term improvement in performance as a result of using a conditioning exercise, in the training and competition environment. The factor to be evaluated in this study is the vertical jump.

I would like to invite you to participate in this research study. Your participation will involve the following:

- (1) participate in a controlled football orientated warm-up for approximately 20 minutes.
- (2) complete in two maximal baseline vertical jumps defined as starting from an upright standing position, making a preliminary downward movement by flexing at the knees and hips, then immediately extending the knees and hips to jump vertically up off the ground.
- (3) participate in 20 minutes of ‘head tennis’.
- (4a) complete two maximal vertical jumps, or
- (4b) complete a series of forty submaximal jumps, or

(4c) completes two minutes of walking to maintain raised body temperature.

(5) complete two maximal vertical jumps after two minutes.

(6) complete two maximal vertical jumps after six minutes.

The total time involvement will be approximately one hour.

Your participation in this study is entirely voluntary. Before agreeing to participate, it is important that you read and understand the explanation of the purpose of the study and study procedures. This information sheet is to help you decide if you would like to participate. If you have any questions, do not hesitate to ask me. You are free to decline to participate if you so wish. You are free to withdraw from the study at any stage and this will not be held against you. If you decide to take part in this study, you will be asked to sign this document to confirm that you understand the study and agree to take part. You will be given a copy to keep.

Purpose of the study

The focus of this proposed study is on whether postactivation potentiation can be achieved by using a conditioning activity similar to the potentiated task, in this case a vertical jump.

Risks and Benefits

The participants will be at a similar risk of injury compared to any other 'normal' training session. These risks have been reduced by providing a thorough warm-up. The benefit of the study is that we intend to broaden the pool of knowledge with regard to training and competition preparation strategies.

No financial benefit or reimbursements will be provided for participation in this study.

Confidentiality

All information obtained during the course of the study, will be kept strictly confidential. Data that may be reported in the research report and scientific journals will not include any information that identifies you as participants in this study. There are no names on the data collection sheet which will be coded and only the researcher will have access to codes.

On completion of the study, the results will be disseminated to you along with your personal results.

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research. If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.

July 2020

Appendix 5 – Consent document



Informed Consent Document

Study title: The ‘real world’ application of postactivation potentiation in a physical training and competition environment.

Investigator: Nicholas Brink

Contact email: nicjbrink@gmail.com

Principal supervisor: Prof Demitri Constantinou

Contact email: Demitri.Constantinou@wits.ac.za

Supervisor: Dr Georgia Torres

Contact email: Georgia.torres@wits.ac.za

Institution: University of the Witwatersrand, Faculty of Health Sciences

Informed consent,

I hereby confirm that I have been informed by study investigator Mr. Nicholas Brink about the nature, conduct, benefits and risks of this study. I have also received, read and understood the above written participant information sheet regarding the study. I am aware that results of the study will be anonymously processed in to a study report and may, at any stage without prejudice withdraw my consent and participation in the study. I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.

Participant

_____	_____	_____
Print name	Signature	Date

I, Nicholas Brink, herewith confirm that the above participant has been fully informed about the nature and conduct of the above study

Investigator

<u>Nicholas Brink</u>	_____	_____
Print name	Signature	Date

Appendix 6 - Data Capture Sheet



Data Capture Sheet

Investigator		Nicholas Brink							
Study Title		The 'real world' application of postactivation potentiation in a physical training and competition environment.							
Institution		University of the Witwatersrand, Faculty of Health Science							
#	Date	Athlete Code	IC	Age	Weight	Height	Team	Absolute Strength	Relative Strength
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Appendix 7 – Study one data collection document



Data Collection Document Study one – Group S

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of a maximal sprint performance using a maximal sprint										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1st WU	Base 1	Base 2	2nd WU	CA 1	CA 2	CA 3	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing maximal sprint

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA 1, 2 & 3 – Conditioning activity (maximal sprint)

PT 1a, 1b, 2a & 2b – Potentiated task (maximal sprint)

Data Collection Document Study one – Group P

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of a maximal sprint performance using a maximal sprint										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1st WU	Base 1	Base 2	2nd WU	CA - PS	CA - PS	CA - PS	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing maximal sprint

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA - PS – Conditioning activity (bounding series)

PT 1a, 1b, 2a & 2b – Potentiated task (maximal sprint)

Data Collection Document Study one – Group C

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of a maximal sprint performance using a maximal sprint										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1 st WU	Base 1	Base 2	2 nd WU	CA - C	CA - C	CA - C	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing maximal sprint

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA - C – Conditioning activity (control group – gentle activity)

PT 1a, 1b, 2a & 2b – Potentiated task (maximal sprint)

Appendix 8 – Study two data collection document



Data Collection Document Study two – Group VJ

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of the vertical jump performance using a vertical jump										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1st WU	Base 1	Base 2	2nd WU	CA 1	CA 2	CA 3	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing vertical jump

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA 1, 2 & 3 – Conditioning activity (vertical jump)

PT 1a, 1b, 2a & 2b – Potentiated task (vertical jump)

Data Collection Document Study two – Group MJ

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of the vertical jump performance using a vertical jump										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1 st WU	Base 1	Base 2	2 nd WU	CA - PS	CA - PS	CA - PS	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing vertical jump

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA - PS – Conditioning activity (multiple jump series)

PT 1a, 1b, 2a & 2b – Potentiated task (vertical jump)

Data Collection Document Study two – Group C

Investigator		Nicholas Brink										
Study Title		Postactivation potentiation of the vertical jump performance using a vertical jump										
Institution		University of the Witwatersrand, Faculty of Health Science										
Date												
#	Athlete Code	1 st WU	Base 1	Base 2	2 nd WU	CA - C	CA - C	CA - C	PT 1a	PT 1b	PT 2a	PT 2b
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Key

- Athlete number

Athlete Code – Confidential Athlete Code

1st WU – Initial 20 min warm-up

Base 1 & 2 - Baseline testing vertical jump

2nd WU – Follow up 20 min warm-up ('head-tennis')

CA - C – Conditioning activity (control group – gentle activity)

PT 1a, 1b, 2a & 2b – Potentiated task (vertical jump)

Appendix 9 – Article published in the European Journal of Sports Science



European Journal of Sport Science



ISSN: (Print) (Online) Journal homepage: <https://www.tandfonline.com/loi/tejs20>

Postactivation performance enhancement (PAPE) of sprint acceleration performance

Nicholas J. Brink, Demitri Constantinou & Georgia Torres

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To link to this article: <https://doi.org/10.1080/17461391.2021.1955012>



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ORIGINAL INVESTIGATION



Postactivation performance enhancement (PAPE) of sprint acceleration performance

Nicholas J. Brink^{a,b}, Demitri Constantinou^{a,b} and Georgia Torres^{a,b}

^aFaculty of Health Sciences, Centre for Exercise Science and Sports Medicine, University of the Witwatersrand, Johannesburg, South Africa; ^bFIMS Collaborating Centre of Sports Medicine, Johannesburg, South Africa

ABSTRACT

Postactivation performance enhancement (PAPE) is a principle that an acute bout of high-intensity voluntary exercise is followed by an enhancement in strength, speed or power production. This study intended to show a direct correlation between intensity, specificity and the outcome of a maximal task of sprint accelerations compared to a previously defined weighted plyometric intervention. In a randomised controlled, double-blind trial, professional footballers undertook 20 m maximal sprint accelerations at a baseline and at 2 and 6 min post-intervention after 1 of 3 interventions: 2 repetitions of 20 m sprint accelerations (S), 3 × 10 alternative leg weighted bounding (P) and control (C). Relative to the baseline there was a significant improvement for S over 10 and 20 m at 2 min of 0.12m.s⁻¹ and 0.11m.s⁻¹ and 6 min of 0.11m.s⁻¹ and 0.12m.s⁻¹. Relative to the baseline P also had a significant improvement over 10 and 20 m at 2 min 0.09m.s⁻¹ and 0.09m.s⁻¹ and 6 min of 0.11m.s⁻¹ and 0.09m.s⁻¹. There was a significant improvement in C between 2 and 6 min post-intervention at 10 and 20 m of 0.06m.s⁻¹ and 0.08m.s⁻¹. This finding suggests a maximal sprint acceleration may enhance the outcome of a subsequent maximal sprint acceleration at 2 min, but the latter results could not be directly attributed to the interventions as previous testing is likely to have influenced these outcomes.

KEYWORDS

PAPE; intensity; PAP; specificity; plyometric; sprinting

Introduction

Sprinting requires a high rate of force production that is linked to acceleration, speed, change of direction and power and relates directly to training effect and competition outcomes (Colyer, Nagahara, Takai, & Salo, 2018; van den Tillaar, Lerberg, & von Heimburg, 2019). The warm-up plays an important role in enhancing or diminishing this desired effect so even small deviations; especially evident in isolated sprinting events, can influence success or failure (Gil et al., 2019). When preparing for maximal exertion, maximal sprinting is often incorporated as the apex of the warm-up sequence (Silva, Neiva, Marques, Izquierdo, & Marinho, 2018). There is evidence that high velocity, high-intensity tasks at the end of a warm-up can acutely enhance an athletes' potential which exceeds the enhancement attained by a submaximal warm-up alone (van den Tillaar et al., 2019). In this study, postactivation potentiation (PAP) will refer to enhancements in muscle twitch response while postactivation performance enhancement (PAPE) will refer to an acute bout of high-intensity voluntary exercise followed by an enhancement in strength, speed or power production

(Blazevich & Babault, 2019; Zimmermann, MacIntosh, & Dal Pupo, 2020).

Postactivation performance enhancement is a physical training principle which proposes that a muscle can be acutely optimised by its contractile history, which in turn affects the outcome of a subsequent task (Hodgson, Docherty, & Robbins, 2005; Lorenz, 2011). There is a plethora of evidence linking heavy resistance training (HRT) with a PAPE response using a heavy resistance isotonic preload stimulus (75–90% 1RM) to achieve this enhanced state (Hodgson et al., 2005; Matthews, Matthews, & Snook, 2004; Wilson et al., 2013). Although HRT has shown effective results, the nature of heavy lifting constraints coaches and athletes to use equipment and requires individualised time frames to dispel the associated fatigue consequence, making this strategy impractical in a training and competitive environment (Wilson et al., 2013). These effects are untested in a competition environment especially in team sports and limited to isolated testing scenarios in training (Bevan et al., 2010; Tobin & Delahunt, 2014). The guidelines for PAPE using HRT exist within narrow parameters with a high proportion of

non-responders prompting cautionary recommendations from investigators to individualise the delay times after the conditioning activity (CA) to achieve the desired effect (Wilson et al., 2013). However, there seems to be a proportional association between the specificity and the intensity of the CA and PAPE which has been similarly defined in many warm-up practices (van den Tillaar et al., 2019; Burkett, Phillips, & Ziuraitis, 2005; Russell, West, Harper, Cook, & Kilduff, 2015). This concept suggests that athletes could optimise prior to performing a maximal activity by using a CA similar in nature and intensity to the expected outcome (Suchomel, Comfort, & Lake, 2017).

There is a growing interest in the PAPE effects elicited by ballistic movements and plyometrics. By utilising high velocity, high power movements, the larger muscle fibres can theoretically be recruited extremely quickly, underpinning the success seen with plyometrics and PAPE (Maloney, Turner, & Fletcher, 2014). Although much of the research associated with PAPE and plyometrics involves a weighted CA, (Piper, Joubert, Jones, & Whitehead, 2020) unweighted activities have also shown improvements (Turner, Bellhouse, Kilduff, & Russell, 2015). Research suggests that using an unweighted CA very similar to the final task can enhance performances within specific populations as much as a comparable weighted CA (Smith et al., 2014). Karampatos et al. (2013, 2017) observed that field event athletes achieved significantly greater throw distances 1 min after a 20 m sprint at maximal effort in training. Sharma et al. (2018) showed that multiple unweighted plyometric tasks had a greater effect on a 20 m sprint performance compared to that of HRT, suggesting that unweighted plyometrics may play an important role in acutely enhancing muscle tissue, a concept reiterated by Creekmur et al. (2017). Smith et al. (2014) found that unloaded sled pull improved athletes 20 m sprint times as much as weighted sled pulls. This indicates that high-intensity running without excess weight may have similar benefits to high-intensity weighted runs. Turner et al. (2015) demonstrated how body-weighted bounding; an action similar to high-intensity running (Young, 1992) acutely enhanced 10 and 20 m sprint accelerations.

Common aspects associated with PAPE seem to include the specificity to the outcome task and the intensity of the CA. Coaches would closely emulate the tasks and skills required in competition within the warm-up phase to affect this specificity principle. There is a positive performance correlation between a sport and its warm-up processes (Russell et al., 2015). Similarly, a common theme relating to the effectiveness of PAPE, is how closely the CA relates to the outcome task (Till &

Cooke, 2009). Van den Tillaar et al. (2019) found that specificity is an important constituent in the development of an enhanced outcome. A warm-up with activities similar to the subsequent task were used with significant benefit compared to an alternate non-specific warm-up. Van den Tillaar et al. (2019) also investigated the effect of a slower warm-up involving dynamic exercises and jogging to a similar warm-up with increasing intensity sprinting. The higher velocity warm-up showed significantly greater improvements over the timed distance. Silva et al. (2018) found that sprints at the end of a warm-up improve athletic performance by 2–3% which is in line with the reported benefits of PAPE using plyometrics (Creekmur et al., 2017).

This study intended to demonstrate how a CA similar in specificity and intensity to a sprint acceleration could be used to improve a subsequent sprint acceleration over 10 and 20 m. It was hypothesised that this sprint acceleration intervention would improve a subsequent sprint acceleration as much as a previously defined weighted, plyometric PAPE intervention, and more than that of a control group.

Methods

Study design

A randomised, double-blinded controlled study design was used to compare the effects of maximal sprint accelerations in relation to a weighted plyometric activity and a control condition on the outcome of 20 m sprint accelerations. Although a crossover design might have been better, 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).

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 squat strength [absolute squat 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 randomly and uniformly allocated to either; the sprint acceleration group (S), the plyometric group (P) or the control group (C) by an independent assessor 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. A minimum sample of 69 (effect size = 0.54, 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 Düsseldorf, Germany), effect size specification as in Cohen (1988) and the sprint velocity over 20 m influenced by time x condition interaction from Turner et al. (2015).

Procedures

All participants had 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. Testing occurred 48-hours after the most recent training session. Each randomised group was separated from the other groups allowing for blinding to the different interventions. A designated member of the coaching staff (UEFA A-licensed), familiar with the testing procedure was selected to administer the warm-up, intervention, pre- 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.

Participants reported to training as normal and undertook a standardised preparation football warm-up of approximately 20 min 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 and testing occurred on a football pitch, with football boots which the participants were accustomed to using. After the warm-up, the participants progressed to the maximal baseline testing; 2 x 20 m pre-intervention sprint accelerations, with timing gates at the start, 10 m, and 20 m. This was followed by low-intensity ball-related games (head tennis) for 20 min to maintain an estimated elevated body temperature but expel any potential PAPE effects accrued during the baseline testing (Maloney et al., 2014). After 20 min S, P and C performed their individual interventions.

Intervention

To account for the possible PAPE and fatiguing consequences of the intervention testing, C participated in

the pre-intervention testing and the post-intervention testing while omitting the intervention. A 20 min period between the pre-intervention testing and the intervention was used to ensure that any PAPE effects incurred during the pre-intervention testing were completely dispelled prior to performing the interventions, a consequence not previously discussed in previous studies (Turner et al., 2015; Vandenboom, 2011).

The S group participants performed 2 maximal sprint accelerations over 20 m at 95% or above of their baseline maximum to account for specificity and intensity. The P group participants undertook 3 sets of 10 weighted alternative leg bounds as defined by Turner et al. (2015) using 10% body mass-weighted vests (Fit for Life, adjustable weighted vest; Fizique, Johannesburg, RSA). It is worth noting that the investigators used this intervention exactly as described by Turner et al. (2015), however, the pre- and post-intervention protocol differed allowing for this study's objectives to be investigated. The C group participants continued to walk during the intervention period to maintain estimated elevated muscle temperature. The total time for intervention period was ~90 sec and was comparable between all participants. Following the interventions, the participants completed 2 maximal sprints accelerations at 2 and 6 min respectively post-intervention (Gołaś, Maszczyk, Zajac, Mikołajec, & Stastny, 2016). Participants completed the 4 post-intervention test sprint accelerations with the aim to achieve the best outcome.

Measurements

The sprint accelerations were measured using speed gates (Fusion Sport, SmartSpeed, v.1.5.2) at 0 m, 10 and 20 m. The participants started 0.3 m behind the first gates (Russell et al., 2015) on their own time following a ready command. They were instructed to sprint with maximal effort past the final gate. The participants performed 2 maximal sprints at the pre-intervention and post-intervention tests with the goal of achieving the fastest outcome. The sprint acceleration intervention was compared to the baseline to assess for intensity as one of the highly influential factors in achieving PAPE. The S 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 data were

tested for normality using the Shapiro–Wilk test. The data are presented as a mean $\pm$ standard deviation. A 3×3 mixed-design analysis of variance with a within-between interaction was used to investigate the 10 and 20 m sprint accelerations. The between-group factor being the groups (S, P and C) and the within-subject factor being time (pre-intervention, 2 min post-intervention and 6 min post-intervention). Mauchly's test was consulted and Greenhouse-Geisser correction was applied if sphericity was violated. Significant main effects 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 $\times$ 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. Individual performances were recorded and monitored for significant differences from before and after the CA 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 also showed good test-retest reliability of (0.81) and (0.85) for 10 and 20 m respectively. The 20 m sprint acceleration was influenced by a significant interaction between time $\times$ group, ($F_{4, 132} = 3.19$, $p < 0.05$, partial $\eta^2 = 0.09$) and time ($F_{2, 132} = 23.76$, $p < 0.001$, partial $\eta^2 = 0.27$). There was no significant difference between the groups at baseline ($p = 0.894$) and the control group did not change between the intervention. Relative to the baseline there was a significant difference for S ($F_{2, 44} = 20.14$, $p < 0.001$, partial $\eta^2 = 0.49$), at 2 min ($6.73 \text{ m s}^{-1} \pm 0.19$, $p < 0.001$) and 6 min ($6.73 \text{ m s}^{-1} \pm 0.19$, $p < 0.001$) and for P ($F_{2, 44} = 6.61$, $p = 0.003$, partial $\eta^2 = 0.23$) at 2 min ($6.73 \text{ m s}^{-1} \pm 0.15$, $p = 0.038$) and 6 min ($6.74 \text{ m s}^{-1} \pm 0.17$, $p < 0.001$) over 20 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at 2 min, there was a significant mean difference between 2 min post-intervention and 6 min post-intervention ($6.71 \text{ m s}^{-1} \pm 0.17$, $p = 0.003$). There was no significant difference between the groups at any time point. However, S and P were 1.47% and 1.44% faster than C at 2 min respectively.

The mean and SD values for the between and within group results are reported in Table 2. The 10 m sprint

acceleration was influenced by a significant interaction between time and group, ($F_{4, 132} = 2.53$, $p < 0.05$, partial $\eta^2 = 0.07$) and time ($F_{2, 132} = 22.07$, $p < 0.001$, partial $\eta^2 = 0.25$). There was no significant difference between the groups at baseline ($p = 0.776$) and the control group did not change between the intervention. Relative to the baseline there was a significant difference for S ($F_{2, 44} = 16.40$, $p < 0.001$, partial $\eta^2 = 0.43$), at 2 min ($5.82 \text{ m s}^{-1} \pm 0.17$, $p = 0.001$) and 6 min ($5.80 \text{ m s}^{-1} \pm 0.18$, $p < 0.001$) and P ($F_{2, 44} = 6.02$, $p = 0.005$, partial $\eta^2 = 0.22$) at 2 min ($5.81 \text{ m s}^{-1} \pm 0.15$, $p < 0.05$) and 6 min ($5.81 \text{ m s}^{-1} \pm 0.16$, $p < 0.05$) over 10 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at time point 2 min, there was a significant mean difference between 2 min post-intervention and 6 min post-intervention ($5.80 \text{ m s}^{-1} \pm 0.16$, $p < 0.05$). There was no significant difference between the groups at any time point. However, S and P were 1.44% and 1.22% faster than C at 2 min respectively.

Eighteen (78%) and 19 (83%) of the 23 participants in S did their fastest 10 m sprint acceleration at 2 and 6 min respectively, while 20 (87%) of the participants did their fastest 20 m sprint acceleration at 2 and 6 min compared to their baseline sprint acceleration. All 23 participants within this group achieved $> 95\%$ of the baseline velocity during the intervention over both the 10 and 20 m. There was no significant difference between the baseline velocity and the intervention velocity in S over 10 m ($p = 0.23$) or 20 m ($p = 0.22$).

Discussion

The outcome of this study supports the hypothesis that a maximal sprint acceleration intervention may improve the outcome of a subsequent maximal sprint acceleration. When compared to a previously tested PAPE effect (Turner et al., 2015); using a weighted plyometric intervention, the sprint acceleration group showed improvements in sprint velocity within a similar range over 2 and 6 min post-intervention. Furthermore, following a standardised football warm-up, some improvement were observed following a maximal sprint acceleration intervention compared to no intervention. Although this between group outcome was not significant, a medium effect size of $d = 0.57$ and 0.51 for 20 m and 10 m was found at 2 min between group S and group C indicating a moderate difference in magnitude. Group C demonstrated a significant improvement during the post-intervention testing between 2 and 6 min. Additionally, groups S and P significantly improved their within group times relative to their baselines. This shows that a maximal sprint acceleration

Table 2. Sprint velocity over 10 m mean and SD values.

Groups		Pre-intervention baseline	Post-intervention 2 min	Post-intervention 6 min
10 m sprint velocity ($\text{m}\cdot\text{s}^{-1}$)	Sprint Plyometric Control	5.70 $\pm$ 0.15 5.72 $\pm$ 0.11 5.72 $\pm$ 0.15	5.82 $\pm$ 0.17 ^a 5.81 $\pm$ 0.15 ^a 5.74 $\pm$ 0.14	5.80 $\pm$ 0.18 ^a 5.81 $\pm$ 0.16 ^a 5.80 $\pm$ 0.16 ^a
p-value (ES)	Sprint compared to control	1.00 (0.13)	>0.05 (0.51)	1.00 (0.17)
ES assessment		Trivial	Moderate	Trivial
p-value (ES)	Plyometric compared to control	1.00 (0.09)	>0.05 (0.48)	1.00 (0.06)
ES assessment		Trivial	Small	Trivial

^aSignificantly different from pre-intervention baseline, ES = Effect size, p-value = significant level.^bSignificantly different from post-intervention time point 2 min. No significant between group differences observed.

2 min and 6 min post-intervention cannot be directly attributed to the intervention either and that the results during the second post-intervention testing were affected by the initial post-intervention testing. This shows that in this study the results at 6 min post-intervention cannot be directly attributed to the effect of the intervention and were also affected by the sprint acceleration at 2 min post-intervention. This makes previous findings questionable where multiple post-intervention tests are undertaken and suggests caution when reviewing literature where significant change is reported with multiple post-intervention testing scenarios administered. Future consideration needs to be given to the effect testing protocols have on subsequent testing protocols when investigating PAPE.

This study demonstrated that the majority (>75% over 10 m and >80% over 20 m) of the participants in S improved their velocity at the 2 and 6 min post-intervention compared to their pre-intervention baseline outcome. In contrast P showed an improvement in >65% of the participants over the same distances and time points. An unexpected outcome of this study was that approximately 75% of the participants in the C group showed significant improvements over both the 10 and 20 m, between the 2 and 6 min post-intervention tests. This may suggest that within this population and this environment, more participants overall will elicit improvements doing a sprint acceleration rather than a weighted bounding intervention, up to 6 min post-intervention. This supports the claim that specificity and intensity may be highly influential in producing an early PAPE response in more participants within a group. Achieving this PAPE response may help to mitigate the individual response effect as even if some individuals are non-responders or partial responders the odds of this are reduced.

Conclusion

The findings of this study have important implications for coaches looking to take advantage of the PAPE

conundrum. This study proposes that a sprint acceleration; specifically, 2 sets of 20 m maximal intensity runs, may induce a PAPE response in a subsequent maximal 10 and 20 m maximal sprint acceleration at 2 min. The improvements observed from a sprint acceleration CA are of a similar magnitude to a weighted plyometric CA with a horizontal bias. Comparable to other plyometric CA's utilising body weight, sprint accelerations seem to exhibit immediate enhancements without the associated fatigue effects commonly observed with PAPE and HRT. Future consideration needs to be given to the effect testing protocols have on subsequent testing protocols when investigating PAPE. This format of inducing a PAPE response promotes a practical warm-up solution for athletes and coaches seeking to achieve performance enhancement without using laborious equipment, determining individual response times or eliciting a dominant initial fatigue consequence. In conclusion the implementation of a CA or preload stimulus similar in nature and intensity to the subsequent task may be effective in delivering an enhancement to competitive athletes and teams.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

- Bevan, H. R., Cunningham, D. J., Tooley, E. P., Owen, N. J., Cook, C. J., & Kilduff, L. P. (2010). Influence of postactivation potentiation on sprinting performance in professional rugby players. *Journal of Strength and Conditioning Research*, 24 (3), 701–705.
- Blazevich, A. J., & Babault, N. (2019). Post-activation potentiation (PAP) versus post-activation performance enhancement (PAPE) in humans: Historical perspective, Underlying mechanisms, and current issues. *Frontiers in Physiology*, 10, 1359.
- Burkett, L. N., Phillips, W. T., & Ziuraitis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), 673–676.
- Colyer, S. L., Nagahara, R., Takai, Y., & Salo, A. I. (2018). Kinetic factors differentiating mid-to-late sprint acceleration

- performance in sprinters and soccer players. *ISBS Proceedings Archive*, 36(1), 674.
- Creekmur, C. C., Haworth, J. L., Cox, R. H., & Walsh, M. S. (2017). Effects of plyometrics performed during warm-up on 20 and 40 m sprint performance. *Journal of Sports Medicine and Physical Fitness*, 57(5), 550–555.
- Gil, M. H., Neiva, H. P., Garrido, N. D., Aidar, F. J., Cirilo-Sousa, M. S., Marques, M. C., & Marinho, D. A. (2019). The effect of Ballistic exercise as Pre-activation for 100 m sprints. *International Journal of Environmental Research and Public Health*, 16(10), 1850.
- Golaś, A., Maszczyk, A., Zajac, A., Mikołajec, K., & Stastny, P. (2016). Optimizing post activation potentiation for explosive activities in competitive sports. *Journal of Human Kinetics*, 52, 95–106.
- Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation – underlying physiology and implications for motor performance. *Sports Medicine*, 35(7), 585–595.
- Karampatos, G. P., Korfiatis, P. G., Zaras, N. D., Georgiadis, G. V., & Terzis, G. D. (2017). Acute effect of countermovement jumping on throwing performance in track and field athletes during competition. *The Journal of Strength & Conditioning Research*, 31(2), 359–364.
- Karampatos, G., Terzis, G., Polychroniou, C., & Georgiadis, G. (2013). Acute effects of jumping and sprinting on hammer throwing performance. *Journal of Physical Education & Sport*, 13(1), 3–5.
- Lorenz, D. (2011). Postactivation potentiation: An introduction. *International Journal of Sports Physical Therapy*, 6(3), 234.
- Maloney, S. J., Turner, A. N., & Fletcher, I. M. (2014). Ballistic exercise as a pre-activation stimulus: A review of the literature and practical applications. *Sports Medicine*, 44(10), 1347–1359.
- Matthews, M. J., Matthews, H. P., & Snook, B. (2004). The acute effects of a resistance training warmup on sprint performance. *Research in Sports Medicine*, 12(2), 151–159.
- Piper, A. D., Joubert, D. P., Jones, E. J., & Whitehead, M. T. (2020). Comparison of post-activation potentiating stimuli on jump and sprint performance. *International Journal of Exercise Science*, 13(4), 539–553.
- Russell, M., West, D. J., Harper, L. D., Cook, C. J., & Kilduff, L. P. (2015). Half-Time Strategies to enhance second-Half performance in team-Sports players: A review and recommendations. *Sports Medicine*, 45(3), 353–364.
- Seltz, L. B., & Haff, G. G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body Ballistic performances: A systematic review with meta-analysis. *Sports Medicine*, 46(2), 231–240.
- Sharma, S. K., Raza, S., Moiz, J. A., Verma, S., Naqvi, I. H., Anwer, S., & Alghadir, A. D. (2018). Postactivation potentiation following acute bouts of plyometric versus heavy-resistance exercise in collegiate soccer players. *Biomed Research International*, 2018, 3719039.
- Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M., & Marinho, D. A. (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, 48(10), 2285–2299.
- Smith, C. E., Hannon, J. C., McGladrey, B., Shultz, B., Eisenman, P., & Lyons, B. (2014). The effects of a postactivation potentiation warm-up on subsequent sprint performance. *Human Movement*, 15(1), 33–41.
- Suchomel, T. J., Comfort, P., & Lake, J. P. (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength & Conditioning Journal*, 39(1), 10–20.
- Till, K. A., & Cooke, C. (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *Journal of Strength and Conditioning Research*, 23(7), 1960–1967.
- Tobin, D. P., & Delahunt, E. (2014). The acute effect of a plyometric stimulus on jump performance in professional rugby players. *Journal of Strength and Conditioning Research*, 28(2), 367–372.
- Turner, A. P., Bellhouse, S., Kilduff, L. P., & Russell, M. (2015). Postactivation potentiation of sprint acceleration performance using plyometric exercise. *Journal of Strength and Conditioning Research*, 29(2), 343–350.
- Vandenboom, R. (2011). Modulation of skeletal muscle contraction by myosin phosphorylation. *Comprehensive Physiology*, 7(1), 171–212.
- van den Tillaar, R., Lerberg, E., & von Heimburg, E. (2019). Comparison of three types of warm-up upon sprint ability in experienced soccer players. *Journal of Sport and Health Science*, 8(6), 574–578.
- Wilson, J. M., Duncan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Wilson, S. M., et al. (2013). Meta-analysis of postactivation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. *The Journal of Strength & Conditioning Research*, 27(3), 854–859.
- Young, W. (1992). Sprint bounding and the sprint bound index. *NSCA J*, 4(6), 44.
- Zimmermann, H. B., Macintosh, B. R., & Dal Pupo, J. (2020). Does postactivation potentiation (PAP) increase voluntary performance? *Applied Physiology Nutrition and Metabolism*, 45(4), 349–356.

Appendix 10 – Turn-it-in report

Nic Brink thesis

by Adj. Prof Demitri Constantinou

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