Postactivation performance enhancement (PAPE) of sprint acceleration performance

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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 20m maximal sprint accelerations at a baseline and at 2 and 6 minutes post-intervention after 1 of 3 interventions; 2 repetitions of 20m 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 10m and 20m at 2 minutes of $0.12 m \cdot s^{-1}$ and $0.11 m \cdot s^{-1}$ and at 6 minutes of $0.11 m \cdot s^{-1}$ and $0.12 m \cdot s^{-1}$. Relative to the baseline P also had a significant improvement over 10m and 20m at 2 minutes $0.09 m \cdot s^{-1}$ and $0.09 m \cdot s^{-1}$ and at 6 minutes of $0.11 m \cdot s^{-1}$ and $0.09 m \cdot s^{-1}$ There was also a significant improvement in C between 2 and 6 minutes post-intervention at 10m and 20m of $0.06 m \cdot s^{-1}$ and $0.08 m \cdot s^{-1}$. 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 2 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.

Abstract word count: 250

Total manuscript word count: 3985

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 (1, 2). 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 (3). When preparing for maximal exertion, maximal sprinting is often incorporated as the apex of the warm-up sequence (4). 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 (2). 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 (5, 6).

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 (7, 8). 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 (7, 9, 10). 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 (10). These effects are untested in a competition environment especially in team sports and limited to isolated testing scenarios in training (11, 12). 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 (10). 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 (2, 13, 14). 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 (15).

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 (16). Although much of the research associated with PAPE and plyometrics involves a weighted CA, (17) unweighted activities have also shown improvements (18). 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 (19). Karampatsos et al. (20, 21) 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 (22) 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. (23). Smith et al. (19) 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. (18) demonstrated how body-weighted bounding; an action similar to high intensity running (24) 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 (14). Similarly, a common theme relating to the effectiveness of PAPE, is how closely the CA relates to the outcome task (25). Van den Tillaar et al. (2) 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. (2) 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. (4) 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 (23)

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 (18).

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 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 20m pre-intervention sprint accelerations, with timing gates at the start, 10m, and 20m. 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 (16). 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 (18, 26).

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. (18) 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. (18), 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 2 maximal sprints accelerations at 2 and 6 minutes respectively post-intervention (27). 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 m and 20 m. The participants started 0.3 m behind the first gates (14) 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 ± 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, 2 minutes post-intervention and 6 minutes post-intervention). Mauchly's test was consulted and Greenhouse-Geisser correction was applied if sphericity was violated. Significant main events observed in the within subject factor for each time point was compared to the baseline and were investigated further with a Bonferroni pairwise comparison. Where significant p values were identified for the interaction effect (time x group), posthoc testing used Cohen's *d* for each pairwise comparison. The magnitude of effect size was evaluated and considered trivial (<0.2), small (0.2–0.50), moderate (0.50–0.80), and large (>0.80) as proposed by Cohen. 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 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 2 minutes ($6.73 m{\cdot}s^{-1} \pm 0.19$, $p < 0.001$) and 6 minutes ($6.73\ m{\cdot}s^{-1} \pm 0.19$, $p < 0.001$) and for P ($F_{2,\,44} = 6.61$, $p = 0.003$, partial $\eta^2 = 0.23$) at 2 minutes ($6.73\ m{\cdot}s^{-1} \pm 0.15$, $p = 0.038$) and 6 minutes ($6.74\ m{\cdot}s^{-1} \pm 0.17$, $p < 0.001$) over 20 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at 2 minutes, there was a significant mean difference between 2 minutes post-intervention and 6 minutes post-intervention ($6.71 m{\cdot}s^{-1} \pm 0.17$, $p = 0.003$). 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 minutes 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 minutes ($5.82 m{\cdot}s^{-1} \pm 0.17$, $p = 0.001$) and 6 minutes ($5.80 m{\cdot}s^{-1} \pm 0.18$, $p < 0.001$) and P ($F_{2,\,44} = 6.02$, $p = 0.005$, partial $\eta^2 = 0.22$) at 2 minutes ($5.81 m{\cdot}s^{-1} \pm 0,15$ $p < 0.05$) and 6 minutes ($5.81 m{\cdot}s^{-1} \pm 0.16$, $p < 0.05$) over 10 m. Although C showed no mean difference between the pre-intervention baseline and post intervention at time point 2 minutes, there was a significant mean difference between 2 minutes post-intervention and 6 minutes post-intervention ($5.80 m{\cdot}s^{-1} \pm 0.16$, $p <$

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 minutes respectively.

Eighteen (78%) and 19 (83%) of the 23 participants in S did their fastest 10 m sprint acceleration at 2 and 6 minutes respectively, while 20 (87%) of the participants did their fastest 20 m sprint acceleration at 2 and 6 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 10m and 20m. There was no significant difference between the baseline velocity and the intervention velocity in S over 10m ($p=0.23$) or 20m ($p=0.22$)

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 (18); using a weighted plyometric intervention, the sprint acceleration group showed improvements in sprint velocity within a similar range over 2 and 6 minutes 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 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 2 and 6 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 2 minutes and these improvements can be maintained for at least 6 minutes. However, these improvements at 6 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 (7, 9, 10). This is likely due to an initial heightened fatigue effect which is less evident when ballistic or plyometric CA's were used (22). 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 (16). 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 (16, 28). 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 (10, 28).

Blazevich and Babault, (5) 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 (12, 19, 22), 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 2 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 (5). 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 2 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 2 minutes post-intervention to 6 minutes post-intervention. This improvement was attributed to the testing impulse at 2 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 2 minutes, showing no significant difference. This indicates a maximal sprint acceleration at 2 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 2 minutes and 6 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 6 minutes post-intervention cannot be directly attributed to the effect of the intervention and were also affected by the sprint acceleration at 2 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 2 and 6 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 2 and 6 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 6 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, 2 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 2 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.

ACKNOWLEDGMENTS

Funding

No external funding was sourced for this study.

Conflicts of interest

The authors declare no conflict of interest.

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APPENDIX

Tables

Table 1. Sprint velocity over 20 m mean and SD values.

	Groups	Pre-intervention baseline	Post-intervention 2 minutes	Post-intervention 6 minutes
20 m sprint velocity (m·s^{-1})	Sprint	6.62 ± 0.15	6.73 ± 0.19*	6.73 ± 0.19*
	Plyometric	6.63 ± 0.13	6.73 ± 0.15*	6.74 ± 0.17*
	Control	6.64 ± 0.15	6.63 ± 0.16	6.71 ± 0.17†
p-value (ES) **ES assessment**	Sprint compared to control	1.00 (0.13) Trivial	>0.05 (0.57) Moderate	1.00 (0.11) Trivial
p-value (ES) **ES assessment**	Plyometric compared to control	1.00 (0.07) Trivial	>0.05 (0.64) Moderate	1.00 (0.17) Trivial

* Significantly different from pre-intervention baseline, ES = Effect size, p-value = significant level.

† Significantly different from post-intervention time point 2 minutes. No significant between group differences observed.

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

	Groups	Pre-intervention baseline	Post-intervention 2 minutes	Post-intervention 6 minutes

10 m sprint velocity ($m \cdot s^{-1}$)	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) **ES assessment**	Sprint compared to control	1.00 (0.13) Trivial	>0.05 (0.51) Moderate	1.00 (0.17) Trivial
p-value (ES) **ES assessment**	Plyometric compared to control	1.00 (0.09) Trivial	>0.05 (0.48) Small	1.00 (0.06) Trivial

* Significantly different from pre-intervention baseline, ES = Effect size, p-value = significant level.

† Significantly different from post-intervention time point 2 minutes. No significant between group differences observed.