The Application of Postactivation Potentiation Methods to Improve Sprint Speed

Robin Healy, BSc and Thomas M. Comyns, PhD
Biomechanical Research Unit, Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland

ABSTRACT

THIS ARTICLE EXAMINES THE APPLICATION OF A VARIETY OF MODALITIES TO ELICIT A POSTACTIVATION POTENTIATION (PAP) RESPONSE IN SPRINTING. WE PRESENT THE EXISTING LITERATURE ON THE ACUTE EFFECTS OF BACK SQUATS, POWER CLEANS, PLYOMETRICS, AND SLED PULLING ON SPRINT DISTANCES RANGING FROM 5 TO 50 M. WE ALSO DISCUSS AND PROVIDE AN EXAMPLE OF HOW COACHES CAN ASSESS THE INDIVIDUAL EFFECTS OF PAP PROTOCOLS ON THEIR ATHLETES TO IDENTIFY WHETHER A PROTOCOL ELICITS AN ACUTE IMPROVEMENT OR IMPAIRMENT IN PERFORMANCE. FINALLY, WE PROVIDE PRACTICAL RECOMMENDATIONS ON HOW COACHES CAN INCORPORATE THESE METHODS INTO A SPRINT TRAINING SESSION.

INTRODUCTION

A vast amount of research has been performed illustrating that the execution of certain conditioning activities at maximal or near-maximal intensities can acutely enhance subsequent athletic performance given sufficient recovery. This phenomenon is known as postactivation potentiation (PAP) and its use within the field of strength and conditioning has grown rapidly as performance enhancing effects have been demonstrated within athletic movements such as jumping (29,32) and sprinting (28). There are several suggested mechanisms behind PAP, including the recruitment of higher order motor units, increase in pennation angle, and the phosphorylation of myosin regulatory light chains (32). Regardless of the mechanism involved, the aim of incorporating PAP protocols into an athlete's training program is to elicit an acute enhancement in performance.

A coach wishing to use this phenomenon within their programming must appreciate the relationship between fatigue and potentiation. In simple terms, for a protocol to be effective it must provide a stimulus large enough to initiate a state of fatigue and potentiation within the muscle (3,25). Although fatigue and potentiation coexist they do not dissipate at an equal rate with fatigue declining at a faster rate than potentiation. If the appropriate recovery is provided the fatigue will have dissipated, leaving the muscle in a potentiated state only (32). An enhanced performance is only possible in this condition. Conversely, if there is insufficient rest, the muscle will be in a fatigued state and performance will be impaired (3).

The ability to accelerate rapidly and reach high levels of maximum velocity is crucial to a number of individual and team sports. In field sports such as soccer and rugby for example, senior international players possess significantly greater acceleration abilities than their junior counterparts (1,24). Likewise in amateur level rugby league, 10, 20, and 30 m sprint ability is a key discriminator of player level with the players at the highest level being significantly quicker over all distances than players at lower levels (14). Accordingly, coaches dedicate considerable time into developing their athlete's sprinting abilities with chronic improvements being reported from a number of different modalities (24). PAP protocols using back squats, power cleans, plyometric exercises, and sled pulls have the potential to be incorporated into an athlete's training program as part of formal sprint sessions or in the case of a track

KEY WORDS:
sprinting; warm-up; acute enhancement; assessment

Address correspondence to Robin Healy, robin.healy@ul.ie.

sprinter, as a precompetition warm-up (19). In the former, the goal is to elicit a performance enhancing effect that will enhance the benefits derived from sprint training whereas in the latter, the goal is to directly improve competition performance that is sprint time.

BACK SQUAT

The back squat is the most widely studied conditioning activity used to elicit a PAP effect on sprinting. The majority of research has assessed the effects of back squats performed at heavy loads (>70% intensity) on distances ranging between 5 and 100 m with no effect (11), enhanced performance (6,21,22,26,37), and mixed results (3,10,20,36) all being reported (Table 1).

McBride et al. (22) assessed the effects of one set of 3 repetitions of heavy, 90% of 1 rep maximum (RM) back squats on sprint ability 4 minutes post warm-up in male NCAA Division III football players. Sprint times were assessed over 10, 30, and 40 m with a significant 0.05 seconds (0.87%) improvement reported over 40 m. No significant differences were found for 10 and 30 m. Similarly, in a study by Chatzoupoulos et al. (6), amateur team sport players performed 10 and 30 m sprints 3 and 5 minutes after the completion of 10 single repetitions of back squats at

Table 1
A summary of studies investigating the acute effect of back squats on sprint performance

Study	Subjects	Study protocol	Rest	Results
McBride et al. (22)	15 male NCAA Division 3 football players	1 × 3 BS at 90% 1RM	4 min	↓ 40 m ST
				No change in ST over 10 and 30 m
Chatzopoulos et al. (6)	15 male amateur team sports players	10 × 1 BS at 90% 1RM	3 and 5 min	No change in 10 and 30 m ST (3 min)
				↓ 10 and 30 m ST (5 min)
Yetter and Moir (37)	10 strength trained men	1 × 5 BS at 30%, 1 × 4 BS at 50% and 1 × 3 BS at 70%	4 min	↑ 10–20 m average SV
				↑ 30–40 m average SV
				No change in average SV over 0–10 m and 20–30 m
Comyns et al. (10)	11 male professional Rugby Union players	Four separate sessions using 1 × 3RM BS	4 min	Session 1: ↑ 30 m ST, ↓ MV and SV
				Session 2–4: No change in ST, MV, and SV
Bevan et al. (3)	16 male professional rugby players	1 × 3 BS at 91% of 1RM	4, 8, 12 and 16 min	No change in ST over 5 and 10 m at any time interval
Linder et al. (21)	12 collegiate women	1 × 4RM BS	9 min	↓ 100 m ST
Crewther et al. (11)	9 sub elite male rugby players	1 set of 3RM BS	~ 15 s, 4, 8, 12, and 16 min	No change in ST over 5 and 10 m at any time interval
Lim and Kong (20)	12 well-trained male track athletes	1 set of 3 BS at 90% 1RM	4 min	No change in ST over 10, 20, and 30 m
Seitz et al. (26)	13 elite junior rugby league players	1 set of 3 BS at 90% 1RM	7 min	↓ 20 m ST
				↑ 20 m SV
				↑ 20 m SA
Wyland et al. (36)	20 recreationally resistance-trained males	5 × 3 BS at 85% 1RM	2, 3, and 4 min	No change in ST over 9.1 m

BS = back squats; MV = maximum velocity; RM = repetition maximum; SA = sprint acceleration; ST = sprint time; SV = sprint velocity.

90% of 1RM. Sprint times were unchanged after 3 minutes, however, significantly faster 10 and 30 m times were found after 5 minutes. More recently a study by Seitz et al. (26) involved rugby league players performing 20 m sprints after 1 set of 3 repetitions of back squats using a load of 90% of 1RM. Significant improvements in sprint time (2.16 ± 1.07%), average velocity (2.25 ± 1.11%), and average acceleration (4.59 ± 2.26%) were found after a 7 minute recovery period compared with baseline values.

In contrast to the above findings, Bevan et al. (3) using a near identical protocol (back squats using a load of 91% of 1RM) examined 5 and 10 m performance in male professional rugby players after 4, 8, 12, and 16 minutes. No significant improvements were found at any time point, however, when individual responses were taken into account, that is the best performance of each athlete, a significant 0.04 seconds reduction in sprint time was found. The authors observed the best 5 and 10 m times after 8 minutes in 47 and 53% of the subjects, respectively, with the remainder of subjects dispersed evenly among the other time points. Lim and Kong (20) investigated the effects of heavy (90% 1RM) back squats on 10, 20, and 30 m performance 4 minutes post warm-up in well-trained male track athletes. No significant differences were found in any of the sprint distances however, like Bevan et al. (3) the authors did note large individual variations in responses with some athletes responding positively after the conditioning activity and others not responding at all highlighting the highly individual nature of the PAP response.

Comyns et al. (10) investigated the repeated exposure of 3RM back squats performed 4 minutes before 30 m sprints. Sprint time, instantaneous, average, and maximum velocity were assessed after the back squat protocol on 4 separate occasions. A significant increase in 30 m time (1.4%) along with a reduction in maximum velocity (2%), and average 30 m velocity (1.3%) were found in the first session compared with baseline. No significant improvements were found for any of the testing days in any of the sprint measures. Interestingly, the authors did find significant improvements in the pretest to posttest changes from session 1 to session 4 for instantaneous velocity at 20 and 30 m suggesting that athletes may need to be exposed to a preload stimulus on a number of occasions before any potential benefits can be realized. Similarly, Crewther et al. (11) examined the acute effects of a 3RM back squat on 5 and 10 m sprint times. Sprints were performed after ~15 seconds, 4, 8, 12, and 16 minutes. No significant improvements were reported in sprint times at any of the time intervals assessed. Linder et al. (19) investigated the acute effects of 4RM back squats on 100 m sprint time. Sprints were performed 9 minutes after the back squat condition with a significant 0.19 seconds (1.2%) improvement found in 100 m time compared with baseline levels.

Yetter and Moir (37) evaluated the effects of a heavy squat protocol on 40 m sprint performance. Sprints were performed 4 minutes after the back squat protocol with average velocity measured during each 10 m interval of the 40 m sprint. Significant improvements were found in the 10–20 m interval (0.12 m/s) and the 30–40 m interval (0.18 m/s) only. Authors noted considerable variation in the subject's responses with greater improvements found in the 30–40 m interval in stronger individuals (5.4%) compared with weaker individuals (1.4%). Recently, Wyland et al. (36) compared the effects of 5 sets of 3 repetitions of back squats at 85% of 1RM using standard isoinertial resistance compared with accommodating resistance. In the accommodated resistance condition, 30% of the total resistance came from elastic band tension. In this study, recreationally resistance-trained men performed 9.1 m sprints at baseline and immediately, 1, 2, 3, and 4 minutes after the PAP protocols. No significant differences were found in either condition compared with baseline across all time points.

Based on the literature, sprint performance (5–40 m) can be acutely enhanced if preceded by back squats performed at heavy intensities (>90% 1RM) for 3 repetitions provided athletes are given sufficient rest periods (4–8 minutes). Coaches should be conscious that the effectiveness of PAP protocols using back squats will depend on multiple factors such as athlete strength level and the depth of squat. Considerable variation can be expected between athletes with respect to the squat volume and amount of rest required.

POWER CLEANS

To date, only 2 studies have assessed the effects of power cleans (PCs) on subsequent sprint performance (14,26) (Table 2). In the study by Guggenheimer et al. (14), athletes performed PCs at 90% of 1RM before completing a 40 m sprint. Sprint times over 5, 10, and 40 m were recorded after 3 minutes of rest. No significant differences in performance were found with the authors suggesting that possibly insufficient rest or perhaps insufficient volume were responsible for the lack of an effect. A recent paper by Seitz et al. (26) assessed the effects of an identical protocol on 20 m sprint time in elite junior rugby league players. This study, however, used a 7 minute recovery time and found significant improvements (3.05 ± 1.08%) in 20 m sprint time, average velocity (3.22 ± 1.15%), and average acceleration (6.61 ± 2.36%) compared with baseline levels. Interestingly, these improvements were greater than those observed after back squats (1 set of 3 repetitions) performed at 90% 1RM. These studies suggest that improvements in 20 m sprint performance can be achieved using PCs performed at 90% 1RM provided that sufficient rest is given (~7 minutes).

PLYOMETRIC EXERCISES

There is a growing body of literature assessing the use of plyometric exercises to elicit a PAP response over 10

Table 2
A summary of studies investigating the acute effect of power cleans on sprint performance

Study	Sample size	Intervention	Rest	Results
Guggenheimer et al. (14)	9 male track and field athletes	1 × 3 PC at 90% 1RM	3 min	No change in ST over 5, 10, and 40 m
Seitz et al. (26)	13 elite junior rugby league players	1 × 3 PC at 90% 1RM	7 min	↓ 20 m ST
				↑ 20 m SV
				↑ 20 m SA

PC = power cleans; RM = repetition maximum; SA = sprint acceleration; ST = sprint time; SV = sprint velocity.

and 20 m (5,31,33) and 50 m (4) (Table 3). It has been suggested that plyometric exercises have a greater biomechanical specificity to sprinting (e.g., similar ground contact times to the acceleration phase etc.) compared with conventional lifting movements. Till and Cooke (31) investigated whether 5 repetitions of double leg tuck jumps combined with a dynamic warm-up could improve 10 and 20 m sprint performance. No significant changes in performance were found after 4, 5, and 6 minutes compared with a dynamic warm-up alone. However, the authors did observe a variety of individual responses with some players responding positively and others negatively to the conditioning stimulus. Byrne et al. (5) assessed the acute effects of a dynamic warm-up combined with depth jumps on subsequent 20 m sprint performance. Depth jumps were performed from a predetermined "optimal height" one-minute before completing a 20 m sprint. This optimal height was determined as the box height (0.20, 0.30, 0.40, 0.50, and 0.60 m) that resulted in the highest jump height as long as the ground contact time was below 0.250 seconds. The authors reported a significant 2.93% (0.095 seconds) reduction in 20 m time compared with a dynamic warm-up only. In relation to the individual athlete responses, 27 out of the 29 athletes performed their best sprint in the depth jump condition compared with the dynamic warm-up condition.

Similarly, Bonfim Lima et al. (4) examined whether depth jumps from a height of 0.75 m would acutely improve 50 m sprint performance. Athletes were instructed to react as quickly as possible once they made contact with the ground. Fifty meter sprints were performed 5, 10, and 15 minutes after the depth jumps. Significant improvements were reported after 10 minutes (1.4%) and 15 minutes (2.4%) compared with baseline values. Turner et al. (33) compared the effects of a plyometric protocol consisting of alternate leg bounding in unweighted and weighted (10% body mass) conditions compared with a walking control. Plyometric trained men performed 20 m sprints (with 10 m splits) before, immediately, 2, 4, 8, 12, and 16 minutes

Table 3
A summary of studies investigating the acute effect of plyometric exercises on sprint performance

Study	Sample	Intervention	Rest	Results
Byrne et al. (5)	29 physically active males	1 × 3 depth jumps	1 min	↓ 20 m ST
Till and Cooke (31)	12 professional academy soccer players	1 × 5 double leg tuck jumps	4, 5, and 6 min	No change in ST over 10 and 20 m at any time interval
Turner et al. (33)	23 plyometric-trained men	3 × 10 alternate leg bounding in weighted (10% BM) and unweighted	~15 s, 2, 4, 8, 12, and 16 min	Weighted: ↓ 20 m SV (15 s) ↑ 10 and 20 m SV (4 and 8 min)
				Unweighted: ↑ 10 m SA (4 min)
Bonfim Lima et al. (4)	10 male sprinters	2 × 5 drop jumps (height of 0.75 m)	5, 10, and 15 min	↓ 50 m ST (10 and 15 min)

BM = body mass; SA = sprint acceleration; ST = sprint time; SV = sprint velocity.

after the conditions. A significant mean improvement of 1.8 ± 3.3% was found in 10 m performance after 4 minutes in the unweighted condition compared with the control. The weighted condition resulted in improvements in 10 and 20 m performance after 4 minutes (2.2 ± 3.1% and 2.3 ± 2.6% respectively) and 8 minutes (2.9 ± 3.6% and 2.6 ± 2.8% respectively). A significant impairment in 20 m performance (1.4 ± 2.5%) however, was also reported immediately after the weighted plyometric condition. Individualized PAP effects were once again observed with ~52% of all athletes performing their best trial after 8 minutes in the weighted plyometric trial.

Based on the above research, sprint performance can be acutely improved by the performance of depth jumps and alternate leg bounding (weighted and unweighted). The performance of 3 depth jumps can potentially improve 20 m performance after only 1 minute, whereas 2 sets of 5 depth jumps can improve 50 m performance after 10 and 15 minutes. Weighted and unweighted bounding can be effective after 4 minutes (10 m) and 4–8 minutes (10 and 20 m), respectively. This is in line with the conclusions of Seitz and Haff (28) who reported in a systematic review that a greater PAP effect can be realized earlier after the completion of a plyometric conditioning activity compared with traditional high or moderate intensity activities. Coaches must be aware that weighted plyometrics may also impair sprint performance if insufficient rest is provided.

SLED PULLING

It has been suggested that PAP responses may be dependent on the biomechanical similarity of the conditioning activity to sprinting (11,34) (Table 4). To the authors' knowledge, only 2 studies have assessed the effects of sprint style sled pulls on subsequent sprinting performance (34,35). Whelan et al. (34) reported no evidence of short sprint (0–5 m and 0–10 m) performance enhancement after the execution of resisted sprints with a load of 25–30% of body mass. In this study, 3 sled pulls were completed over 10 m with 90 seconds of recovery between each repetition. Five and 10 meter sprint times were collected before the protocol and again after 2, 4, 6, 8, and 10 minutes of recovery. Winwood et al. (35) assessed the effects of heavier load sled pulls using 75 and 150% of body mass after 4, 8, and 12 minutes on 5, 10, and 15 m sprint performance. Small positive effects were reported in the 75% body mass load condition in 5, 10, and 15 m distances after 8 and 12 minutes, however, only the 15 m sprint times were found to be statistically significant with an improvement of 0.02 seconds observed. The authors did observe a large degree of individual variability in the decrement of sprint velocity as a result of the 2 sled pull conditions. This suggests that it may be a better approach to prescribe load based on a predetermined decrement in sprint velocity, however, this remains to be seen.

With a paucity of research regarding the use of weighted sled pulling exercises clear recommendations cannot be made until further research is undertaken on the acute PAP effects on sprinting due to this specific conditioning activity.

ASSESSING THE INDIVIDUAL EFFICACY OF PAP PROTOCOLS

Several studies have highlighted that due to the individual nature of the PAP response conventional group statistics may not be able to discern positive effects (9,16,34). In response to this, authors have recommended that PAP protocols should be considered on an individual basis (20,31). Indeed, it is of primary interest to the coach to know whether a protocol designed to elicit an acute performance enhancement is effective with their athletes on an individual basis as opposed to an overall group effect. With this in mind, an athlete can be classified as either a positive responder (performance is enhanced postconditioning activity), negative responder (performance is impaired post-conditioning activity), nonresponder (performance is neither enhanced nor impaired) or inconsistent responder (subsequent performances are both enhanced and impaired). To determine this, coaches can perform their own in-house research with their athletes. This will involve estimating upper and lower limits of variation based on an individual's standard deviation or typical error (TE) (17,18). TE represents the error or variation in an athlete's performance from trial to trial. It is composed of

Table 4
A summary of studies investigating the acute effect of sled pulling on sprint performance

Study	Sample size	Intervention	Rest	Results
Whelan et al. (34)	12 active males	3 × resisted sled sprints over 10 m with a load of 25–30% BM	2, 4, 6, 8, and 10 min	No change in ST over 5 and 10 m at any time interval
Winwood et al. (35)	22 resistance-trained rugby players	7.5 m sled pulls using 75% of BM and 15 m sled pulls using 150% of BM	4, 8, and 12 min	↓ 15 m ST

BM = body mass; ST = sprint time.

Table 5
Athlete baseline sprint times with mean performance and typical error (TE)

Athlete	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Mean (s)	TE (s)
1	1.8	1.77	1.79	1.79	0.02
2	1.72	1.75	1.73	1.73	0.02
3	1.74	1.7	1.73	1.72	0.02
4	1.77	1.75	1.78	1.77	0.02

Values within the table have been rounded to 2 decimal places.

biological variation combined with technological error (2,18). A threshold of 1.5 times the TE has been proposed as a realistic threshold for determining if an individual's observed change in performance after a PAP protocol can be considered a real change (17,18,34). Using this method, an enhanced sprint performance is considered only when sprint times are equal to or below the lower typical error limit, whereas an impaired sprint performance is considered only when sprint times are equal to or above the upper typical error limit (15,34).

In Table 5 a coach is seeking to establish the effectiveness of a PAP protocol in his/her athletes. Before the athletes perform the PAP protocol, baseline data must first be collected after a full warm-up typical of that which they would normally perform before an acceleration session. If baseline data from a previous testing day is used, it may lead to erroneous results as various factors (i.e., improvements due to training, residual fatigue from the previous day's training, lack of sleep etc.) may have resulted in differences between the athlete's testing day performance and their performance on the current day. Three baseline short sprints (<20 m) are sufficient provided they are performed at maximal effort. With these data the coach can then calculate the mean sprint time for each athlete along with the TE. A fully worked example is provided below.

Mean performance is used instead of best performance as it represents the time an athlete would typically be expected to complete 10 m on that particular day. For several reasons (i.e., lack of concentration or poor motivation), it may not be possible for the athlete to perform better than their previous best performance on every repetition after a conditioning activity. From the above data the thresholds for fatigue (impaired performance) and potentiation (enhanced performance) can be estimated by multiplying the TE by 1.5. This value can then be added and subtracted to the mean sprint time to get the upper threshold (fatigue) and lower threshold (potentiation) as illustrated below in Table 6.

Table 6
Athlete mean sprint times with 1.5 TE, upper, and lower thresholds

Athlete	Mean (s)	1.5 TE	Upper threshold	Lower threshold
1	1.79	0.02	1.81	1.76
2	1.73	0.02	1.76	1.71
3	1.72	0.03	1.75	1.69
4	1.77	0.02	1.79	1.74

Values within the table have been rounded to 2 decimal places.

The Figure provides sample data of the 4 athletes from Table 5 after undergoing a plyometric protocol adapted from Byrne et al. (5) consisting of 3 depth jumps followed by five 10 m sprints with 2 minutes rest between sprints within the same session as the baseline sprints. Thresholds for enhanced performance and impaired performance are taken from Table 6.

The coach must then make a decision whether the PAP protocol should be implemented for each athlete. From the Figure, it seems that athlete 1 is a positive responder, athlete 2 is a negative responder, athlete 3 is a nonresponder, and athlete 4 is an inconsistent responder. Table 7 illustrates potential actions that can be taken once the response type of an athlete is known.

Athletes with large between trial differences will have larger TE values which will in turn make it more difficult to accurately detect enhanced and impaired performances. Additional baseline trials can be performed in an attempt to reduce the TE and give a mean that is a truer reflection of the athlete's abilities on that given day. Poor trials or trials that the coach considers "slow" should never be removed unless there is justifiable cause to consider them invalid, for example, the athlete stumbles during the trial or decelerates early. If the thresholds remain too large, the above method may not be suitable for assessing PAP responses until there is greater consistency in their baseline performance.

PAP PROTOCOLS AND GUIDELINES FOR SPEED ENHANCEMENT

Before the implementation of PAP complexes to enhance sprinting performance the coach should adhere to the guidelines presented in the previous section to assess if their athlete is a responder to PAP. After this, PAP complexes can be used in both training and competition settings.

Sprinting is a highly technical motor skill that requires focused practice to develop efficient and effective

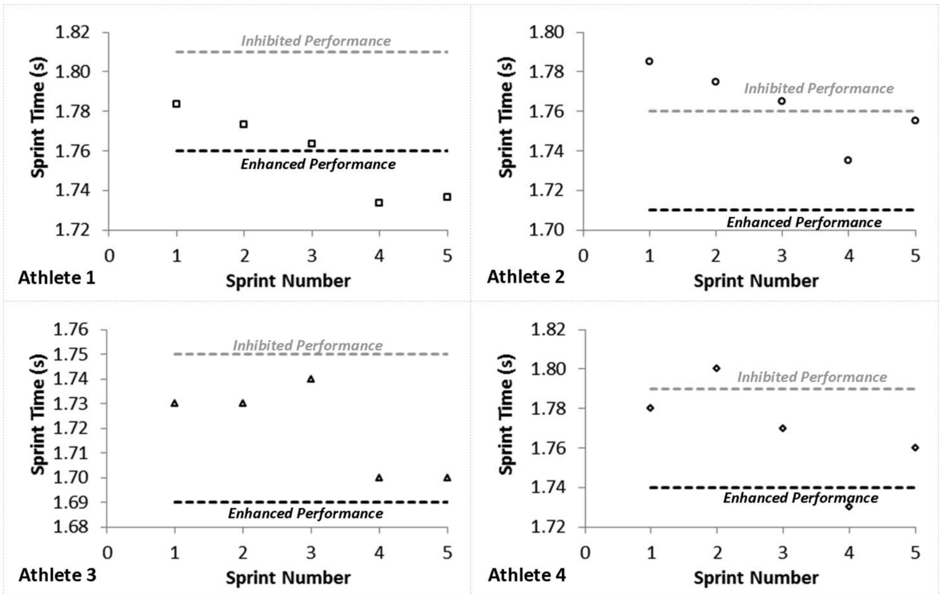

Figure. Sample athlete sprint performance post plyometric PAP protocol with thresholds for enhanced performance (black broken line) and impaired performance (grey broken line).

movement patterns. If an athlete has poor acceleration/maximum velocity sprinting technique, they are more likely to benefit from additional technical work or drills as opposed to a PAP training intervention. The development of sprint technique should remain the focus until a desired level of competency is reached. At this point the coach can consider the addition of PAP protocols. It is worth noting that a greater PAP effect has been reported in resistance-trained individuals (≥3 months) compared with untrained individuals (23). Similarly, stronger (relative 1RM back squat ≥2 × body mass) athletes have been found to potentiate to a greater extent than their weaker (relative 1RM squat ≤2 × body mass) counterparts (27,30). Suggested levels of strength as outlined in the research (relative 1RM back squat ≥1.5 × body mass) (7,22) may be considered as a prerequisite for using the back squat in a PAP protocol with greater positive effects being found at higher strength levels (relative 1RM squat ≥2 × body mass). Consequently, coaches should prioritize the development of maximum strength as part of an athlete's physical preparation.

From a training perspective, PAP complexes can be used to acutely enhance speed performance and thus, enhance the training effect. The majority of research in this area has been undertaken on team sport players so the guidelines on PAP complexes are more relevant for this population group. Exercises such as the back squat and power clean can be performed provided the athletes have the necessary technical competence, especially with the power clean. Although the use of weightlifting derivatives to elicit PAP effects have yet to be assessed in the literature, movements such as the mid-thigh clean pull could potentially provide the necessary stimulus as greater peak force, power, and rate of force development have been found in the mid-thigh clean pull compared with the hang and power clean (7,8). These movements could provide a reasonable alternative to the full weightlifting movements if lifting proficiency is low. If back squats or power cleans are chosen, one set of 3 repetitions at 90% 1RM with a recovery period of at least 5 minutes before the completion of the sprinting activity should be sufficient. The combination of lifting and sprinting in the same session for team sport players is logistically favorable as it is difficult in the team setting to cover all aspects of training due to both heavy training and game schedules. Covering 2 aspects of the strength and conditioning program, that is strength/power and speed, within one session frees up time for other aspects of the program to be completed.

The sprinting activity that is incorporated into the PAP complex can be designed to develop key speed requirements of the team sport. This would be particularly useful and relevant during the main competitive season for the team. For example, in Rugby Union, the sprinting activity could involve the player changing pace from jogging to sprinting on receiving a pass and sprinting 15 m to score a try. In soccer, the sprinting activity could incorporate the ball and have the players reacting to a pass and accelerating onto the ball.

From the perspective of a track athlete, certain conditioning activities can easily be incorporated into track warm-ups before training and competition. In particular, there is potential with track sprinters to incorporate PAP before competing. It may not always

Table 7
Athlete response type with corresponding possible actions

Response Type	Potential actions to take
Positive Responder	Continue using PAP protocol where appropriate
Negative Responder	Increase rest of protocol and reassess on another occasion
	Reduce volume/intensity of protocol and reassess on another occasion
	Change PAP modality
	Discontinue PAP protocol
Nonresponder	Continue using PAP protocol where appropriate as athlete may chronically benefit from the additional stimulus
	Increase rest of protocol and reassess on another occasion
	Reduce volume/intensity of protocol and reassess on another occasion
	Change PAP modality
	Discontinue PAP protocol
Inconsistent Responder	Increase rest of protocol and reassess on another occasion
	Reduce volume/intensity of protocol and reassess on another occasion
	Change PAP modality
	Discontinue PAP protocol

be possible for athletes to perform barbell exercises such as back squats or power cleans given logistics (difficulty accessing weights room) before competition, thus plyometric exercises such as depth jumps and bounding can provide the necessary stimulus to elicit an acute enhancement effect. The use of such high intensity exercises should only be used provided the athlete possesses sufficient technical competency and appropriate landing mechanics. In the case of depth jumps, coaches should experiment to try to find the box height that is optimal for their athletes.

Flanagan and Comyns (12) suggested that the optimal box height can be identified by performing depth jumps using incremental box heights. The box height yielding the highest reactive strength index (height jumped divided by ground contact time) is considered optimal. This test can be accomplished using a force platform, a high speed video camera, photoelectric cells, a contact mat or alternatively, an iPad/iPhone application (My Jump 2) (13). Once this has been determined a suitable starting point would be one set of 3 depth jumps with >1 minute recovery. Alternatively if bounds are performed, moderate rest intervals are recommended (~4 minutes). The suggestion here is for sprinters to incorporate plyometric exercises such as bounding or depth jumps close to the competition event to gain an enhancement effect during the competitive performance. Although the research supports the use of these methods, further research is still required in sprinters to determine how various factors, such as intensities, volumes and rest intervals, modulate performance.

SUMMARY

Sprint performance (5–50 m) can be acutely enhanced by PAP protocols if appropriately implemented. The selection of a conditioning activity will depend on the equipment/facilities available in addition to the technical proficiency of the athlete in sprinting, lifting, jumping, and landing. Coaches should attempt to carry out their own in house research to determine the suitability of specific PAP protocols for their individual athletes. Plyometric exercises are recommended for sprint athletes to include in their precompetition warm-up to acutely enhance performance. If technical proficiency is not an issue, athletes can incorporate heavy load (90%) back squats and power cleans into their sprint training session provided adequate recovery is provided (4–8 minutes).

Conflicts of Interest and Source of Funding: The authors have no conflict of interest to disclose and would like to thank the Irish Research Council for financially supporting this research.

Robin Healy *is a sports biomechanics PhD candidate within the Department of Physical Education and Sport Sciences at the University of Limerick (UL).*

Tom Comyns *is a lecturer in the Physical Education and Sport Sciences department in the University of Limerick.*

REFERENCES

1. Barr MJ, Sheppard JM, Gabbett TJ, and Newton RU. Long-term training-induced changes in sprinting speed and sprint

momentum in elite rugby union players. *J Strength Cond Res* 28: 2724–2731, 2014.

2. Beattie K and Flanagan EP. Establishing the reliability & meaningful change of the drop-jump reactive strength index. *J Aust Strength Cond Res* 23: 12–18, 2015.
3. Bevan HR, Cunningham DJ, Tooley EP, Owen NJ, Cook CJ, and Kilduff LP. Influence of postactivation potentiation on sprinting performance in professional rugby players. *J Strength Cond Res* 24: 701–705, 2010.
4. Bomfim Lima J, Marin D, Barquilha G, Da Silva L, Puggina E, Pithon-Curi T, and Hirabara S. Acute effects of drop jump potentiation protocol on sprint and countermovement vertical jump performance. *Hum Mov* 12: 324–330, 2011.
5. Byrne PJ, Kenny J, and O'Rourke B. Acute potentiating effect of depth jumps on sprint performance. *J Strength Cond Res* 28: 610–615, 2014.
6. Chatzopoulos DE, Michailidis CJ, Giannakos AK, Alexiou KC, Patikas DA, Antonopoulos CB, and Kotzamanidis CM. Postactivation potentiation effects after heavy resistance exercise on running speed. *J Strength Cond Res* 21: 1278–1281, 2007.
7. Comfort P, Allen M, and Graham-Smith P. Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *J Strength Cond Res* 25: 1235–1239, 2011.
8. Comfort P, Allen M, and Graham-Smith P. Kinetic comparisons during variations of the power clean. *J Strength Cond Res* 25: 3269–3273, 2011.
9. Comyns TM, Harrison AJ, Hennessy L, and Jensen RL. Identifying the optimal resistive load for complex training in male rugby players. *Sport Biomech* 6: 59–70, 2007.
10. Comyns TM, Harrison AJ, and Hennessy LK. Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *J Strength Cond Res* 24: 610–618, 2010.
11. Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, and Yang GZ. The acute potentiating effects of back squats on athlete performance. *J Strength Cond Res* 25: 3319–3325, 2011.
12. Flanagan EP and Comyns TM. The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength Cond J* 30: 32–38, 2008.
13. Gallardo-Fuentes F, Gallardo-Fuentes J, Ramírez-Campillo R, Balsalobre-Fernández C, Martínez C, Caniuqueo A, Cañas R, Banzer W, Loturco I, Nakamura F, and Izquierdo M. Inter and intra-session reliability and validity of the my jump app for measuring different jump actions in trained male and female athletes. *J Strength Cond Res* 30: 2049–2056, 2016.
14. Guggenheimer JD, Dickin DC, Reyes GF, and Dolny DG. The effects of specific preconditioning activities on acute sprint performance. *J Strength Cond Res* 23: 1135–1139, 2009.
15. Harrison A and McCabe C. The effect of a gluteal activation protocol on sprint and drop jump performance. *J Sports Med Phys Fit* 2015 [Epub ahead of print].
16. Harrison AJ. Throwing and catching movements exhibit post-activation potentiation effects following fatigue. *Sport Biomech* 10: 185–196, 2011.
17. Healy R and Harrison AJ. The effects of a unilateral gluteal activation protocol on single leg drop jump performance. *Sport Biomech* 13: 33–46, 2014.
18. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1–15, 2000.
19. Kilduff LP, Finn CV, Baker JS, Cook CJ, West DJ, de Koning JJ, Noordhof DA, Uitslag TP, Galiart RE, and Dodge C. Preconditioning strategies to enhance physical performance on the day of competition. *Int J Sports Physiol Perform* 8: 677–681, 2013.
20. Lim JJ and Kong PW. Effects of isometric and dynamic postactivation potentiation protocols on maximal sprint performance. *J Strength Cond Res* 27: 2730–2736, 2013.
21. Linder EE, Prins JH, Murata NM, Derenne C, Morgan CF, and Solomon JR. Effects of preload 4 repetition maximum on 100-m sprint times in collegiate women. *J Strength Cond Res* 24: 1184–1190, 2010.
22. McBride JM, Nimphius S, and Erickson TM. The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. *J Strength Cond Res* 19: 893–897, 2005.
23. Miyamoto N, Wakahara T, Ema R, and Kawakami Y. Further potentiation of dynamic muscle strength after resistance training. *Med Sci Sports Exerc* 45: 1323–1330, 2013.
24. Mujika I, Santisteban J, Impellizzeri FM, and Castagna C. Fitness determinants of success in men's and women's football. *J Sport Sci* 27: 107–114, 2009.
25. Rassier D and Macintosh B. Coexistence of potentiation and fatigue in skeletal muscle. *Braz J Med Biol Res* 33: 499–508, 2000.
26. Seitz L, Trajano G, and Haff G. The back squat and the power clean: Elicitation of different degrees of potentiation. *Int J Sports Physiol Perform* 9: 643–649, 2014.
27. Seitz LB, de Villarreal ES, and Haff GG. The temporal profile of postactoivation potentiation is related to strength level. *J Strength Cond Res* 28: 706–715, 2014.
28. Seitz LB and Haff GG. Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Med* 46: 231–240, 2015.
29. Suchomel TJ, Lamont HS, and Moir GL. Understanding vertical jump potentiation: A deterministic model. *Sports Med* 46: 809–828, 2016.
30. Suchomel TJ, Sato K, DeWeese BH, Ebben WP, and Stone MH. Potentiation following ballistic and non-ballistic complexes: The effect of strength level. *J Strength Cond Res* 30: 1825–1833, 2016.
31. Till KA and Cooke C. The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J Strength Cond Res* 23: 1960–1967, 2009.
32. Tillin NA and Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147–166, 2009.
33. Turner AP, Bellhouse S, Kilduff LP, and Russell M. Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res* 29: 343–350, 2015.
34. Whelan N, O'Regan C, and Harrison AJ. Resisted sprints do not acutely enhance sprinting performance. *J Strength Cond Res* 28: 1858–1866, 2014.
35. Winwood PW, Posthumus LR, Cronin JB, and Keogh JW. The acute potentiating effects of heavy sled pulls on sprint performance. *J Strength Cond Res* 30: 1248–1254, 2016.
36. Wyland TP, Van Dorin JD, and Reyes GC. Post-activation potentation effects from accommodating resistance combined with heavy back squats on short sprint performance. *J Strength Cond Res* 29: 3115–3123, 2015.
37. Yetter M and Moir GL. The acute effects of heavy back and front squats on speed during forty-meter sprint trials. *J Strength Cond Res* 22: 159–165, 2008.