Effect of Postactivation Potentiation on Swimming Starts in International Sprint Swimmers

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ABSTRACT
Kilduff, LP, Cunningham, DJ, Owen, NJ, West, DJ, Bracken, RM, and Cook, CJ. Effect of postactivation potentiation on swimming starts in international sprint swimmers. J Strength Cond Res 25(9): 2418–2423, 2011—The aim of this study was to investigate the effects of postactivation potentiation (PAP) on swim start performance (time to 15 m) in a group of international sprint swimmers. Nine international sprint swimmers (7 men and 2 women) volunteered and gave informed consent for this study, which was approved by the university ethics committee. Initially, swimmers performed a countermovement jump (CMJ) on a portable force platform (FP) at baseline and at the following time points: 15 seconds, 4, 8, 12, and 16 minutes after a PAP stimulus (1 set of 3 repetitions at 87% 1 repetition maximum [RM]) to individually determine the recovery time required to observe enhanced muscle performance. On 2 additional days, swimmers performed a swim start to 15 m under 50-m freestyle race conditions, which was preceded by either their individualized race specific warm-up or a PAP stimulus (1 set of 3 repetitions at 87% 1RM). Both trials were recorded on 2 cameras operating at 50 Hz with camera 1 located at the start and camera 2 at the 15-m mark. Peak vertical force (PVF) and peak horizontal force (PHF) were measured during all swim starts from a portable FP placed on top of the swim block. A repeated measures analysis of variance revealed a significant increase in both PHF and PVF after the PAP stimulus compared to the swim-specific warm-up during the swim start (PHF: 770 ± 228 vs. 814 ± 263 N, p = 0.018; PVF: 1,462 ± 280 vs. 1,518 ± 311 N, p = 0.038); however, time to 15 m was the same when both starts were compared (7.1 ± 0.8 vs. 7.1 ± 0.8 seconds, p = 0.447). The results from this study indicate that muscle performance during a CMJ is enhanced after a PAP stimulus providing adequate recovery (~8 minutes) is given between the 2 activities. In addition, this study demonstrated that swimmers performed equally well in terms of time to 15 m when a PAP stimulus was compared to their individualized race specific warm-up and indicates that PAP may be a useful addition to a warm-up protocol before races. However, more research is required to fully understand the role PAP plays in swim performance.

KEY WORDS power development, elite athletes, time to 15 m

Introduction
At the international level, the swim start (as measured by time to 15 m) has been reported to be a critical component of overall swimming performance and has been estimated to contribute up to 30% of the total race in the 50-m sprints (18). In a recent study from our laboratory, we reported a strong negative correlation between lower body peak power (r = −0.85) and time to 15 m in international sprint swimmers (20), which may indicate that increasing lower body peak power will lead to an improvement in swim start performance, a primary performance outcome in sprint swimming. At present, there are a number of methods purported to increase lower body power output (PO) including athletes trying to develop power while working against their body mass (e.g., plyometrics) and also while working against external loads that equate to various intensities of their 1 repetition maximum (IRM; e.g., 70–80% for Olympic-style weightlifting movements) (15). Recently, a training method that requires an athlete to work against a heavy load (>80% IRM) followed by a light load (body mass) has been proposed to be an effective training method for enhancing PO in athletes (e.g., [3,9]). This method commonly referred to as contrast training is based on the physiological condition, namely, postactivation potentiation.
(PAP), with PAP defined as an acute enhancement of muscle function after a PAP stimulus (13).

The literature regarding an athlete’s ability to harness PAP has been conflicting and can in part be explained by numerous potential methodological differences in the various studies (13). Recently, researchers have sought to investigate the optimal conditions to observe an enhancement in muscle performance after a PAP stimulus. For example, studies by Kilduff et al. (16,17) and Bevan et al. (4) have investigated the optimal recovery time to observe enhanced performance after a PAP stimulus and have reported that on average 8-minute recovery is required between the PAP stimulus and the subsequent explosive activity. However, both these studies noted that individual differences existed between each athlete’s optimal recovery time to harness the PAP effect. Although researchers now have a better understanding of the exact experimental design required to observe enhanced performance with PAP during squat jumps and ballistic bench throws (4,16,17), research still needs to be carried out to see if PAP can be harnessed to enhance performance in more functional activities such as the dive start in swimming.

Therefore, in light of the above, the aims of this study were firstly, to determine the optimal recovery time for maximal benefits from a PAP stimulus in this group of swimmers and secondly, because of the lack of research regarding PAP and its effect on activities directly transferable to sport, to observe the effects of a PAP stimulus on time to 15 m in international-level sprint swimmers compared to their traditional swim-specific warm-up.

### Methods

#### Experimental Approach to the Problem

After familiarization, swimmers initially performed a counter-movement jump (CMJ) on a portable force platform (FP) at baseline and at the following time points −15 seconds, 4, 8, 12, and 16 minutes after a PAP stimulus (1 set of 3 repetitions at 87% 1RM) to individually determine the recovery time required to observe enhanced muscle performance. On 2 additional days, swimmers performed a swim start to 15 m under 50-m freestyle race conditions, which was preceded by either their individualized race-specific warm-up or a PAP stimulus (1 set of 3 repetitions at 87% 1RM) to compare the effectiveness of a PAP stimulus on time to 15 m.

#### Subjects

Nine international sprint swimmers (7 men and 2 women) (Table 1), from whom written informed consent had been obtained, volunteered to take part in this study, which was approved by the university ethics committee. Swimmers were recruited on the basis that they were members of the British Sprint Development squad and they were engaged in a land-based conditioning program for at least 2 years before the start of the study. All swimmers in this study were within 5% of the national record in their respective events. Swimmers trained 11 times a week in the pool and in addition completed 3 land conditioning sessions a week also. Depending on the time of year and overall goal of the land conditioning program, swimmers performed incorporated traditional powerlifting, Olympic lifting, and plyometrics into their program.

#### Experimental Procedures

Before the commencement of the main experimental trials, swimmers visited the laboratory to become familiar with the testing methods and to have their 3RM squat measured. During this familiarization session, swimmers also practiced performing the CMJ with the aim to maximize jump height (JH). Forty-eight hours after the familiarization and strength testing period, all swimmers performed the first testing session, after an additional 48-hour recovery period swimmers completed the second and third testing sessions.

Swimmers reported to the laboratory on the morning of testing after having refrained from alcohol, caffeine, and strenuous exercise for the previous 48 hours. All testing was conducted at the same time of the day after a standardized meal and fluid intake. After the measurement of each subject’s stature and body mass, swimmers underwent a standardized warm-up, which comprised 5 minutes on a rowing ergometer, followed by a series of dynamic stretches with an emphasis on stretching the musculature associated with the squat and CMJ. After the warm-up, swimmers completed a baseline CMJ. After a recovery period, swimmers completed a PAP stimulus (1 set of 3 repetitions at 87% 1RM) on the back squat. Immediately after the PAP stimulus (within 15 seconds) and every 4 minutes after the PAP stimulus up to 16 minutes (4, 8, 12, and 16 minutes) the swimmers repeated the CMJ. This phase of the experiment was carried out to determine the recovery period required to observe enhanced CMJ performance after a PAP stimulus and also to determine individual variation in terms of optimal recovery. To ensure that any effect observed during this experiment was because of the PAP stimulus the 9 swimmers completed 5 CMJs after a standardized warm-up with a 4-minute recovery between each one. This was carried out to ensure that during the main experimental trial there was no warm-up effect or fatigue effect from the subsequent CMJ. A repeated measures 1-way analysis of variance (ANOVA) revealed no significant time effect over the duration of the study (ES = 0.78, p = 0.759).

### Table 1. Physical characteristics of subjects at baseline (n = 9).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>77.9 ± 11.2</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>179.2 ± 13.8</td>
</tr>
<tr>
<td>Age (y)</td>
<td>22 ± 2</td>
</tr>
<tr>
<td>1RM squat (kg)</td>
<td>127.1 ± 18.0</td>
</tr>
</tbody>
</table>
PAP and Swim Starts

On 2 additional days (each separated by 48 hours’ recovery), swimmers performed a dive start to 15 m (under 50-m freestyle race conditions), which was preceded by either their individualized race-specific warm-up (Table 2) or a PAP stimulus (1 set of 3 repetitions at 87% 1RM) in a randomized fashion.

Measurements

Strength Testing. Before the start of the strength testing session, all swimmers underwent a standardized warm-up, which comprised light intensity rowing for 5 minutes, followed by a series of dynamic movements with an emphasis on warming the musculature associated with the squat. Swimmers then performed 3 warm-up sets of 8 repetitions at 50% 1RM, 4 repetitions at 70% 1RM and finally 2 repetitions at 80% of their 1RM, which was approximately from their training log. After the final warm-up set, swimmers attempted 3 repetitions of a set load (3RM) and if successful, the lifting weight was increased until the subject could not lift the weight through the full range of motion. All swimmers had been previously exposed to 3RM testing for the squat. A 5-minute rest was imposed between all attempts to allow swimmers adequate time to replenish energy stores. The 3RM was determined after 2-3 attempts in all swimmers. After determination of each subject’s 3RM, their 1RM was estimated using the tables provided in Baechle and Earle (2). The squat movement was carried out as per the International Powerlifting Federation rules (14).

Countermovement Jump. For the measurement of lower body power, swimmers completed CMJ on a portable FP. To isolate the lower limbs, subject’s stood with arms akimbo (1,11). After an initial stationary phase of at least 2 seconds, in the upright position, for the determination of body weight, the subject’s performed a CMJ, dipping to a self-selected depth and then exploding upwards in an attempt to gain maximum height. Subject’s landed back on the FP and their arms were kept akimbo throughout the movement. Subject’s completed 6 CMJs at the following times: baseline, immediately after PAP stimulus (~15 seconds) and then every 4 minutes up to and including 16 minutes. The PAP stimulus consisted of 1 set of 3 repetitions at 87% of the swimmers estimated 1RM on the squat. A Kistler portable FP with built-in charge amplifier (type 92866AA, Kistler Instruments Ltd., Farnborough, United Kingdom) was used for data collection of the ground reaction force (GRF) time history of the CMJ. A sample rate of 1,000 Hz was used for all jumps and the platform’s calibration was confirmed pre and posttesting.

Countermovement Jump Data Analysis. The vertical component of the GRF as the subject performed the CMJ was used in conjunction with the subject’s body weight to determine the instantaneous velocity and displacement of the subject’s center of gravity (CG) (11). Instantaneous power was determined using the following standard relationship:

\[
\text{Power (W)} = \text{vertical GRF (N)} \times \text{vertical velocity of CG (m s}^{-1}\).
\]

To determine the velocity of the subject’s CG, numerical integration was performed using Simpson’s rule with intervals equal to the sample width. Before the calculation of the strip area, the subject’s body weight (as measured in the stationary phase) was subtracted from the GRF values. The area of the strip, of width equal to the sample rate, then represented the impulse for that time interval. Using the relationship that impulse equals change in momentum, the strip area was then divided by the subject’s mass to produce a value for the change in velocity for the CG (it was assumed that the swimmers’ mass remained constant throughout the jump). This change in velocity was then added to the CG’s previous velocity to produce a new velocity at a time equal to that particular interval’s end time. This process was continued throughout the jump. Because this method can only determine the change in velocity, it was necessary to know the CG’s velocity at some point in time. For this purpose, the velocity of the CG was taken to be zero before the initiation of the jump (during the period of body weight measurement) and specifically at the point identified as the start of the jump. The start point was defined as the time when the subject’s GRF exceeded the mean ± 5 SDs from the values obtained in the second (of the stationary body weight measuring phase) immediately before the command to jump, in a fashion similar to Vanrenterghem et al. (19). Integration started from this point.

Vertical displacement was determined by a second integration. The instantaneous velocity time history was numerically integrated (in the same way as described above) from the start point of the jump. The height (vertical displacement) of the CG at the start point of the jump was defined as zero. Jump height was then defined as the difference in the vertical displacement of the CG, between take off (toes leave the force plate) and maximum vertical displacement achieved.

Test–retest reliabilities (intraclass correlation [ICC]) for PO and maximum JH were 0.979 and 0.976, respectively.

Time to 15 m. On 2 separate test days, swimmers performed a dive start to 15 m under 50-m freestyle race conditions, which was preceded by either their race specific warm-up or a PAP stimulus (1 set of 3 repetitions at 87% 1RM). In each trial, the subject was requested to mount the block. When in

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**Table 2. Example of individualized warm-up.**

<table>
<thead>
<tr>
<th>300-m Easy Freestyle Swim</th>
<th>10 × 100-m Freestyle (3 pull @ 100 s, 3 kicks at 110 s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 × 50-m Freestyle Swim</td>
<td>(25 m fast/25 m easy, 50-m lowest stroke count, 50-m build up, 2 × 50 at 200-m race pace) (repeat)</td>
</tr>
<tr>
<td>100 m Looseen</td>
<td></td>
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</tbody>
</table>

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position, the subject was given verbal command ‘take your mark,’ and shortly after the starting signal was sounded. The subject performed the start and a maximal freestyle sprint to a distance further than the 15-m mark. All starts were performed from a standard poolside mounted starting block under simulated race conditions with a portable FP mounted on the block to record both peak vertical force (PVF) and peak horizontal force (PHF). In addition, both starts were recorded by 2 cameras mounted on poolside. Test–retest reliability (ICC) for time to 15 m was 0.987.

Data Collection for Swim Starts. Each trial was recorded with 2 digital video cameras (Sony DCR-PC120E, Sony Manufacturing Co UK Ltd, Wales, United Kingdom), operating at a sampling rate of 50 Hz. The shutter speed was not manually adjustable; however, the camera was placed in a modality (Sports Mode) that maximized the shutter speed within the limits of the cameras being used (1/4,000 seconds), consequently minimizing any distortion within the movement of the swimmers. The 2 cameras were mounted on tripods, positioned on the poolside perpendicular to lane 5 and were set to record continuously throughout the experimental part of the trials. Camera 1 was placed at 15 m and was used to determine the sprint time over this distance only. The second camera was mounted on a tripod positioned 15 m from the end of the pool, and initially focused on the starting system to view the light emitted from the starting signal. The starting system simultaneously emitted an audible signal and a strobe flash; this was used to synchronize the starting signal with the video image. After the start, camera 1 was immediately panned to focus on a marked point on the opposite side of the pool at the 15-m mark (to record the moment the swimmers head reached the 15-m mark). Simultaneously, camera 2 was static with its optical axis horizontal, and approximately 1 m in front of the vertical plane of the leading edge of the starting block and 1 m above the surface of the water. The subject was visible throughout the start, up to the point of entry. The start system was visible in the background of the image, allowing the strobe light to be used for synchronizing the timing system. All starts were performed from lane 5, using the camera’s maximum zone facility.

Data Analysis for Swim Starts. Start time ($t_s$): Time from the starting signal to the first frame in which the swimmers head reaches the 15-m mark. Start time was measured directly by viewing each trial frame by frame.

Calculation of Peak Vertical and Horizontal Forces. Data were collected via an FP, which was mounted to a standard starting block such that the platform was elevated by 10° (Figure 1). $F_z$ can be resolved into vertical and horizontal components, $F_{z1}$ and $F_{x1}$ respectively. $F_x$ can be resolved into vertical and horizontal components, $F_{z2}$ and $F_{x2}$ respectively. The 2 vertical components ($F_{z1}$ and $F_{z2}$) and the 2 horizontal components ($F_{x1}$ and $F_{x2}$) are then added to given the total vertical and horizontal components, $F_z$ and $F_x$ respectively, giving

$$F_z = F_{z1} \sin 80 + (\text{2nd force} \cdot \sin 10),$$

$$F_x = F_{x1} \cos 80 + F_{x2} \cos 10.$$

Statistical Analyses

After a test for the normality of distribution, data were expressed as the mean ± SD. Statistical analysis was carried out using a repeated measures 1-way ANOVA to determine whether PO,
maximum JH, and peak rate of force development (PRFD) changed throughout the testing session. When significant F values were observed (p < 0.05), paired comparisons were used in conjunction with Holm’s Bonferroni method for control of type 1 error to determine significant differences. Differences between time to 15 m performed after the race specific warm-up or the PAP stimulus was assessed using a paired t-test. The level of significance was set at p < 0.05 in this study, and all statistics were performed using SPSS 13.1 (SPSS Inc., Chicago, IL, USA).

RESULTS
Power Output
A repeated measures ANOVA revealed a significant time effect over the duration of the study (F = 14.634, p < 0.05) with follow-up paired comparisons indicating a significant decrease in PO in the CMJ performed ~15 seconds after the PAP stimulus compared to the baseline CMJ (Figure 2A). After 4 minutes of recovery, PO returned to a similar value to baseline with no significant difference between these 2 values (Baseline: 4,024 ± 974 vs. 4 minutes: 4,038 ± 982 W, p > 0.05). All swimmers in this study produced their peak power output after 8 minutes of recovery from the preload stimulus, and this PO was significantly higher than the POs at all other time points (Figure 2A).

Jump Height
The repeated measures ANOVA revealed a significant time effect on JH (F = 20.963, p < 0.001). Maximum JH during the CMJ was observed after 8 minutes of recovery from the PAP stimulus, and this was significantly higher when compared to JH recorded at baseline (34.1 ± 4.7 vs. 35.7 ± 5.6 cm, p < 0.01). In addition, the height jumped at the 8-minute time point was significantly higher than the JH at any other time point throughout the study (Figure 2B). When the players performed the CMJ immediately (~15 seconds) after the PAP stimulus, their JH was significantly reduced compared to their baseline jump (34.1 ± 4.7 vs. 32.3 ± 4.8 cm, p < 0.01) (Figure 2B).

Swim Start Performance
There was no significant difference between swim start performance preceded by the PAP stimulus compared to the dive start preceded by the swim-specific warm-up with regard to time to 15 m (Figure 3C). There was a significant increase in both PVF and PHF after the PAP stimulus warm-up compared to the swim-specific warm-up (PVF: 1,462 ± 280 vs. 1,518 ± 311 N, p = 0.038; PHF: 770 ± 228 vs. 814 ± 263 N, p = 0.018) (Figure 3A and B).

DISCUSSION
The results of this study demonstrate that PAP can be harnessed to enhance PO during a CMJ in a group of international sprint swimmers providing adequate recovery (~8 minutes) is given between the PAP stimulus and subsequent explosive activity (Figure 2). In addition, the PAP stimulus used in this study produced a similar dive start time (as measured by time to 15 m) compared to the swimmers traditional race-specific warm-up (Figure 3) indicating a potential role for PAP during sprint swimming. However, future research is required to assess if adding PAP to the swimmers traditional race warm-up produces additional benefits compared to the either along.

The initial aim of this study was to determine the optimal recovery period between the PAP stimulus and the subsequent explosive activity for enhancing performance during the explosive activity. Previous studies have used recovery periods ranging from 0 to 18.5 minutes (3,6,7,8,10,21) with no uniform agreement to date on the optimal time required. The majority of the studies have used recovery periods of approximately 4 minutes presumably to allow for PCr resynthesis after the preload stimulus (e.g., [3,6,8,21]). In previous studies from our laboratory, we demonstrated that ~8-minute recovery was required between the PAP stimulus and the subsequent explosive activity for both the upper and lower body (4,16,17) and this is a similar finding to this study. The results of this study help clarify the recovery period needed to achieve maximal increases in CMJ performance in well-trained athletes.

The second key finding from this study was that a PAP warm-up comprising of 1 set of 3 repetitions on the squat exercise lead...
to a similar dive start time compared to the swimmers traditional swim specific warm-up. Based on a recent review by Bishop (5), it can be speculated that the mechanism behind the 2 warm-up protocols would be different, with any improvements in dive start performance being related to temperature associated effects such as increased oxygen delivery to the muscles and increased nerve conduction rate. Although the mechanism for the PAP-mediated effect have 2 primary theories have to date: (a) the preload stimulus acts to enhance motor-unit excitability, possibly affecting a number of processes such as increased motor-unit recruitment, increased motor-unit synchronization, decreased presynaptic inhibition or greater central input to the motor neuron; and (b) enhanced phosphorylation of the myosin light chain (MLC), where the preload causes an increase in sarcoplasmic Ca2+, which activates MLC kinase which in turn increases actin–myosin cross bridging (13).

The results from this study provide the basis for further examination of the effectiveness of PAP strategies for enhancing time to 15 m in international swimmers. Future studies should examine the combination of the swimmers traditional swim specific warm-up and a PAP stimulus, also because of the constraints of getting swimmers to lift heavy weights ~8 minutes before they start their event other high velocity low force activities (e.g., plyometrics) should be examined to see if they can induce a similar PAP effect. Some evidence for this exists from Hilfiker et al. (12) who demonstrated the effectiveness of adding a set of drop jumps into a warm-up for explosive force development and found a consistent tendency for improved PO.

In conclusion, this study demonstrated the international sprint swimmers observed improvements in lower body power after a PAP stimulus when adequate recovery was given between the PAP stimulus and the sprint and that this PAP improvement was able to be harnessed in a more functional performance measure as time to 15 m as demonstrated by the similar performance time compared to their traditional swim warm-up.

**Practical Applications**

The current findings indicate that time to 15-m performance was similar when swimmers performance their individualized race warm-up compared to a much lower volume PAP warm-up. This study further highlights the need for individual determination of the optimal recovery time required for enhanced performance after a PAP stimulus. These findings point toward a potential role for the inclusion of a PAP stimulus into swimmers’ warm-ups which may lead to a improvement of time to 15-m performance. In addition, PAP may also be a useful training tool on sessions dedicated to improving time to 15 m; however, further investigations are required on this topic.

**References**


