
EFFECT OF POSTACTIVATION POTENTIATION ON FIFTY-METER FREESTYLE IN NATIONAL SWIMMERS

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ABSTRACT

Sarramian, VG, Turner, AN, and Greenhalgh, AK. Effect of postactivation potentiation on fifty-meter freestyle in national swimmers. *J Strength Cond Res* 29(4): 1003–1009, 2015—The purpose of this study was to examine the effect of PAP on 50-m freestyle in national-level swimmers. Four warm-ups were compared: a traditional race-specific warm-up (RSWU), upper-body PAP (UBPAP), lower-body PAP (LBPAP), and combined PAP warm-up (CPAP). Eighteen (10 men, 8 women) national-level swimmers participated in this study, which included 7 separate testing sessions. Participants' 3 repetition maximum (3RM) of the pull-up (PU) was established in session 1. In session 2, rest periods for muscle enhancement of the upper body were determined using a medicine ball throw test 4, 8, and 12 minutes after UBAP stimulus ($1 \times 3RM$ of the PU). In session 3, swimmers performed a countermovement jump 4, 8, and 12 minutes after LBPAP stimulus (1×5 jumps to a box while carrying 10% of the participants' body weight). The 50-m freestyle tests were performed on sessions 4–7, preceded by each warm-up protocol and corresponding rest periods. A repeated-measures analysis of variance ($p \leq 0.05$) and Bonferroni post hoc test revealed that RSWU elicited faster swimming times than UBAP (29.00 ± 2.05 vs. 29.36 ± 1.88 seconds, $p = 0.046$). Additionally, when data were split into gender, in the male group, the UBAP elicited significantly slower times than RSWU (27.51 ± 1.06 vs. 28.01 ± 1.17 seconds, $p = 0.047$) and CPAP (27.49 ± 1.12 vs. 28.01 ± 1.17 seconds, $p = 0.02$). These findings suggest individualized PAP warm-up may be a valuable tool to enhance performance in sprint events, particularly in male swimmers. However, the PU may not be an appropriate PAP stimulus on its own.

KEY WORDS PAP, warm-up, sprint, swimming, performance, sport

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INTRODUCTION

Postactivation potentiation (PAP), a relatively new phenomenon in sport and exercise science, provides coaches with a new tool to potentially impact sports and exercise performance. Postactivation potentiation can be defined as a condition whereby acute muscle force is increased because of previous high-resistance exercise (22). The underlying mechanisms behind PAP are unclear, but the phosphorylation of the regulatory light myosin chains and the increased recruitment of high threshold motor units have been proposed as the 2 most coherent underlying PAP mechanism theories (25).

The benefit of well-planned PAP interventions has become evident in a number of different studies. Linder et al. (17) reported an average significant improvement of 0.19 seconds for 100-m track running times in female collegiate runners. Likewise, significant improvements were found by Chatzopoulos et al. (6) for team sport players completing a 30-m sprint after performing 10 sets of 1 repetition at 90% of 1RM of back squat. In a cycling study, average power and average power relative to bodyweight significantly increased on a 10-second sprint cycle test (23). A limited number of studies have investigated the effects of PAP on upper body (9,14), reporting positive effects on performance in power output in bench press throws. In contrast, PAP has not always provoked the intended effects, with isometric PAP resulting in a significant decrease in peak leg power in male international fencers (26) and no significant effect on a population of field athletes, body builders, and physically active subjects (2). Nature and intensity of the conditioning activity, rest period after the stimuli, training experience, and gender have been identified as factors influencing the potential effects of PAP (7,25) and may explain conflicting results in research. Despite the contrasting results found in scientific literature on PAP, when used in many cases, it clearly has the potential to have an impact on the overall outcome of sprint events where differences among the athletes are minimal.

Fifty-meter freestyle swimming is an event, which may benefit from PAP, with small improvement in times being crucial (11). Tight margins among competitors in sprint events may be due to the narrow spectrum of speed in swimming, caused by the effect of water resistance (12). There is paucity of published research on the effects of PAP in competitive swimmers. A single study by Kilduff et al. (15) reported that sprint times over 15 m were similar

after PAP or a traditional warm-up. There does not seem to be any similar research over race distances. This limited research focused on the musculature of the lower body, as the swimmers were jumping from the starting blocks and completing 15 m. However, in freestyle swimming over race distances, the arms provide the main contribution to overall propulsion (8); therefore, it is reasonable to conclude that a combined PAP stimuli for upper body and lower body would be most appropriate for swimmers and should be the focus on such research.

Jumping onto a box while carrying extra weight (JB), as a conditioning activity has been shown to augment power output of the leg extensors (5,24). Such increase in power has been reported as positively correlated to increasing swimming start performance (27). To complete the PAP stimuli for the upper body, the pull-up exercise (PU) may be of equal importance in freestyle swimming. It would seem that all previous studies examining PAP on upper body have focused on pushing actions such as bench press throws (3,4,14). As such, the outcome of a PAP stimulus on pulling actions is not known.

The primary aim of this study is to compare the effectiveness of 4 different warm-up protocols on 50-m freestyle performance in national-level swimmers: (a) traditional race-specific warm-up (RSWU), (b) upper-body PAP (UPBAP), (c) lower-body PAP (LBPAP), and (d) combined upper- and lower-body PAP (CPAP). Second, the research will examine the effect of the PU and JB as conditioning activities to produce potentiation on sprint swimming.

METHODS

Experimental Approach to the Problem

National-level swimmers were tested on 7 occasions, using the same time of the day to control for circadian variation (1). At least 3 days separated each session, and participants were required to refrain from extraneous exercise before

each test. The first testing day aimed to test participants' 3 repetition maximum (3RM) of the PU exercise. In session 2, participants performed a medicine ball throw 4, 8, and 12 minutes (14) after the upper-body PAP conditioning activity (1 set of 3RM of the PU) to establish the optimal individual rest periods for the upper-body muscles enhancement. Similarly, session 3 involved the measurement of the recovery time needed to observe increased muscle performance on the lower-body muscles. Participants performed a countermovement jump (CMJ) on a jump mat, 4, 8, and 12 minutes (15) after a PAP stimulus (1 set of 5 jumps to the box wearing a weighted vest loaded with 10% of their body-weight) (5,24). During sessions 4–7, participants swam 50-m freestyle under race conditions preceded by each warm-up protocol (RSWU, UPBAP, LBPAP, and CPAP), to determine the most advantageous procedure. The rest period after the traditional warm-up was 15 minutes for all swimmers and individual rest periods established for upper and lower body in sessions 2 and 3, followed the PAP protocols. To complete the CPAP protocol, the stimuli that needed longer time to produce potentiation was performed in first place and participants who were found to have the same optimal rest intervals for upper and lower body performed 1 PAP stimulus immediately after the other (Figure 1).

This study used a repeated-measures design, with 4 warm-up protocols acting as levels of the independent variable and time to 50-m freestyle as the dependent variable. This facilitated the comparison of the effectiveness of different PAP stimulus on the 50-m freestyle swimming performance.

Subjects

Eighteen national-level competitive swimmers (10 men and 8 women) participated in this study. They all belonged to the same swimming team and were ranked at least within the

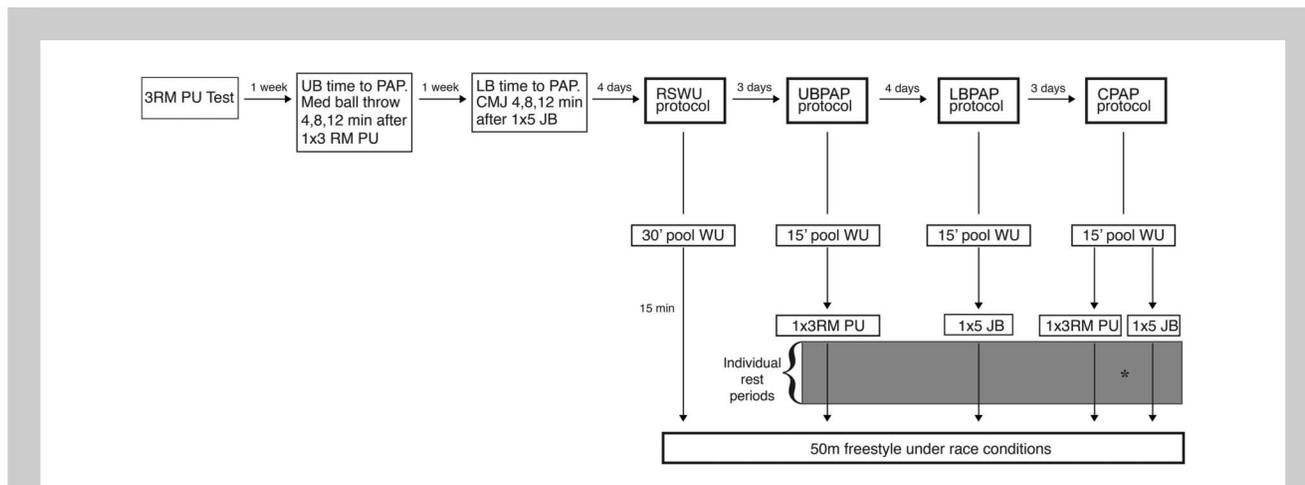


Figure 1. Time line of project design. *The 3RM PU and 1 × 5 JB's order of execution in the CPAP protocol are dependent on individual rest periods. The stimuli needing longer time to produce potentiation is performed in first place. CPAP = combined PAP warm-up; UMPAP = upper-body PAP warm-up; LBPAP = lower-body PAP warm-up.

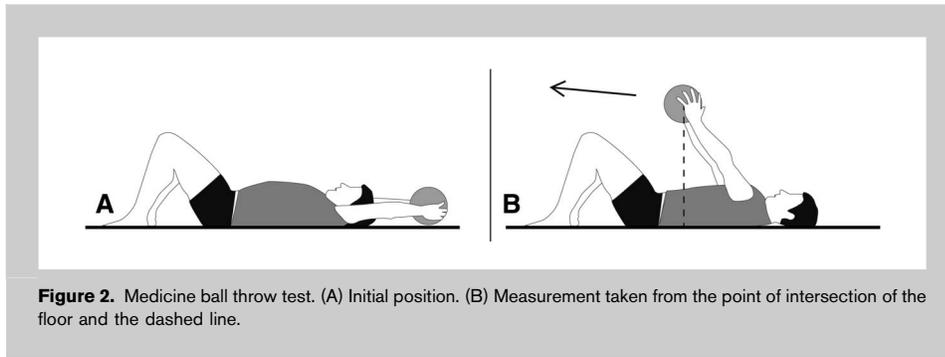


Figure 2. Medicine ball throw test. (A) Initial position. (B) Measurement taken from the point of intersection of the floor and the dashed line.

top 15 in the country in their age group. Before the commencement of the main experimental trials, participants' physical characteristics were recorded ($n = 18$) (mean \pm SD, mass: 64.05 ± 7.97 kg, height: 1.69 ± 0.06 m, age: 16.03 ± 1.62 years, 3RM pull-up: 67.72 ± 10.38 kg, CMJ: 34.91 ± 9.08 cm, med ball throw: 4.30 ± 1.32 m). At the time of testing, they were all engaged in a strength training program and were familiar with the conditioning resistance exercises proposed in this study.

The participants were fully informed of the experimental procedures and risks, and written informed parental consent was obtained for each subject, in accordance with the declaration of Helsinki before the experiment. The study was approved by a University Ethics Committee.

Procedures

The study was conducted when the swimmers were involved in the tapering phase of their yearly training program, ensuring that all swimming tests were performed under the same relative fatigue state. Participants were familiar with the PAP conditioning activities (PU and JB) and exercises proposed to assess optimal times for muscle enhancement (medicine ball throw

and CMJ), as they were included in their strength training program for 2 months before the testing sessions. The completion of 3 repetitions of the PU with at least the participant's own body-weight was a prerequisite to take part in this study. All subjects were asked to preserve uniform eating and sleeping patterns throughout the study and refrain from extraneous exercise preceding the testing sessions. Participants' weight and height was measured during the first testing day.

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Upper-Body Testing. Day 1 of testing included calculation of the 3RM PU, the effort was preceded by a warm-up of the upper body that involved pulling actions with elastic bands and 2 sets of 4 repetitions of the assisted PU. The PUs were performed with a pronated forearm grip on a standard horizontal bar with the hands placed 10–15 cm wider than shoulder width apart (22). The 3RM was determined by adding the athlete's body weight to a vest's additional weight that was worn during the 3RM PU test. The initial weight of the vest was obtained from the swimmers' training log. The completion of a PU involved the subject to lift their body mass and vest from a full arm extension hanging position until the chin was above the bar. If the swimmer completed more than 3 repetitions, another trial was undertaken with added weight to the vest until the subject could not perform the exercise through the full range of motion.

The second day of testing required that subjects complete a medicine ball throw test to assess subjects' optimal time to upper-body muscle enhancement after the upper-body PAP

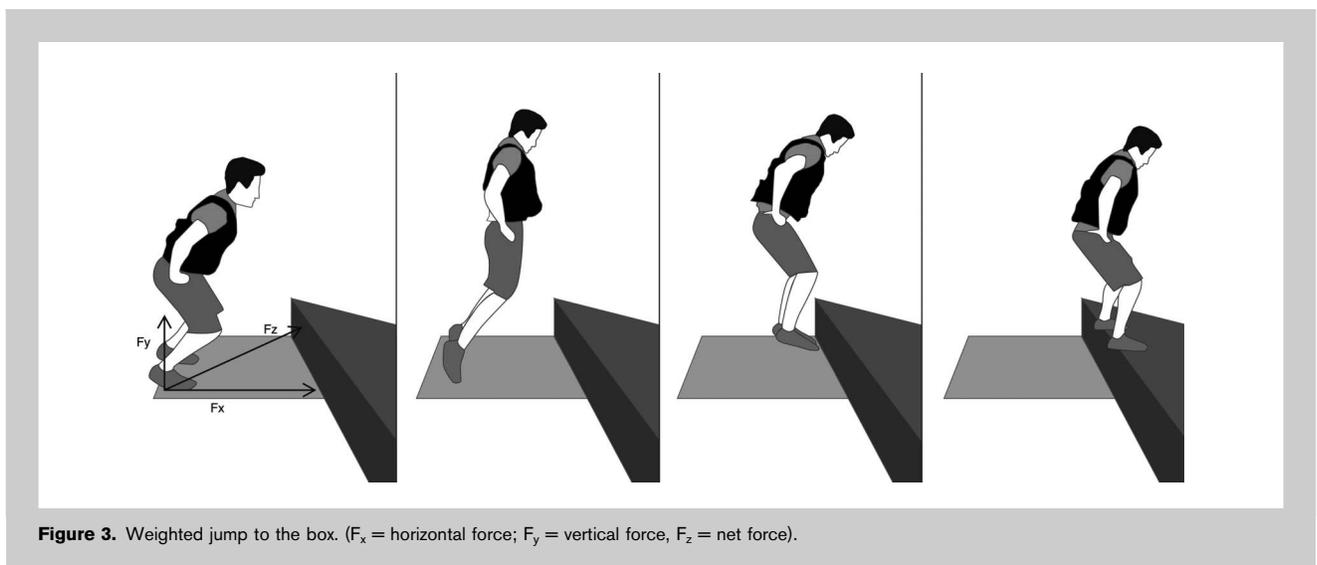


Figure 3. Weighted jump to the box. (F_x = horizontal force; F_y = vertical force, F_z = net force).

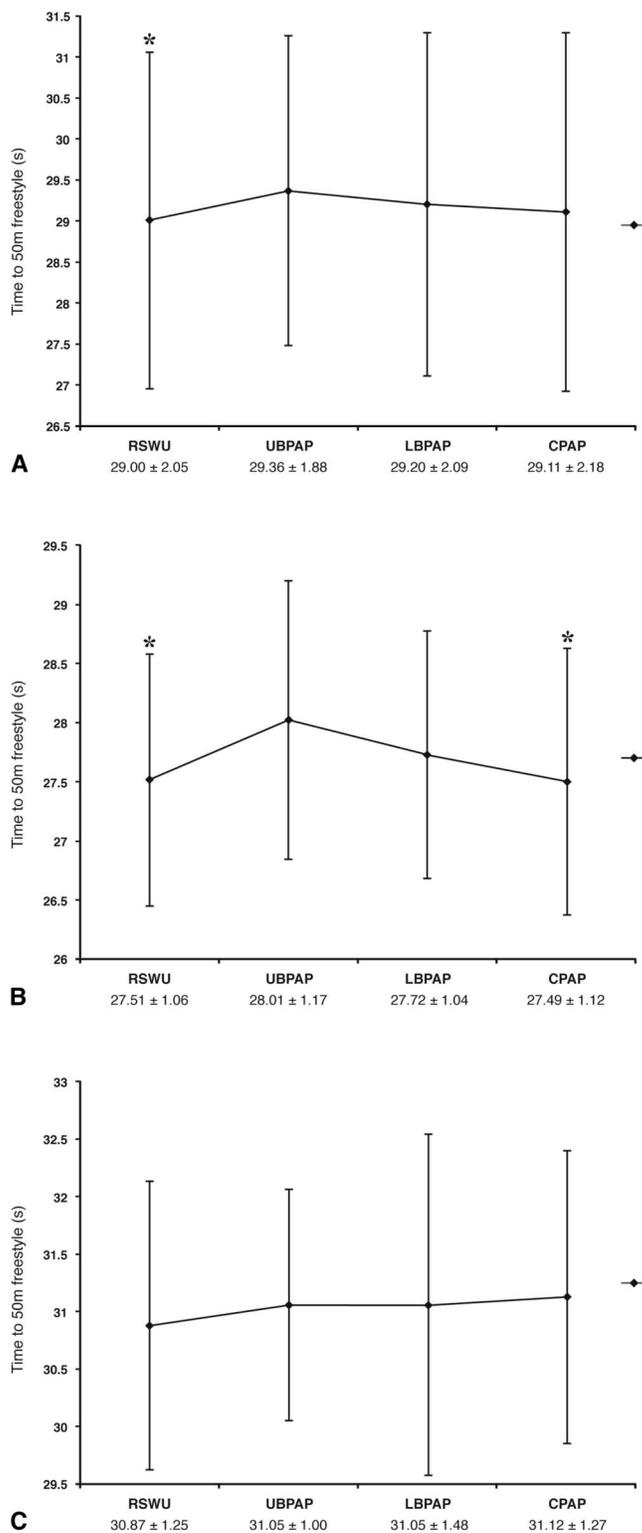


Figure 4. Mean times to 50-m freestyle after: RSWU, UBPAP, LBPAP, and CPAP for the whole group (A), men (B), and women (C) (values in the horizontal axis are expressed as mean \pm SD). *Significant decrease in time compared with the UBPAP protocol. RSWU = race-specific warm-up; UBPAP = upper-body postactivation potentiation; LBPAP = lower-body postactivation potentiation; CPAP = combined postactivation potentiation warm-up.

stimulus. Participants lay down in a supine position with their back and head in contact with the floor and knees flexed to a self-selected degree. A 4-kg medicine ball was held with the arms fully extended behind their heads (Figure 2A). Before the test, to take into consideration the athletes' arm length, participants were required to flex their shoulder at 45° in relation to their torso and extend the elbows, using a motion similar to the one adopted for the actual throw. In this position, a perpendicular line from the hand to the floor indicated the spot where the measurement was taken (Figure 2B). Participants were instructed to throw the ball as far as possible, keeping the back and head in contact with the floor to isolate the arms. The medicine ball throws were performed at 4, 8, and 12 minutes after the 3RM pull-up exercise (14).

Lower-Body Testing. After a warm-up consisting of light jogging and dynamic stretching of the lower body, swimmers performed 5 loaded CMJs onto a step 41 cm high and 73 cm deep (JB) (Figure 3). The external load of the weighted vest worn to perform the test equaled 10% of their body weight (5.24), measured to the nearest 0.5 kg. They stood with their arms akimbo to isolate their lower limbs, and on command, they squatted to a self-selected depth and jumped explosively onto the step. The height of the step represented an unequal effort for participants due to their disparate lower-body limbs' length and levels of lower-body strength and power. Therefore, swimmers were encouraged to increase the distance between the step and the point of take-off to standardize the effort and transfer the possible potentiation effect to the horizontal and vertical force components of the dive start off the block (27).

Lower-body power was measured by performing 3 CMJs on a jump mat (Fitness Technology, Adelaide, Australia) without carrying any external load. Swimmers stood with arms akimbo, squatted to a self-selected depth and jumped as high as possible. The jumps were performed 4, 8, and 12 minutes after the PAP stimulus to establish optimal rest periods for the lower body (15).

Swimming Tests. Participants completed four 50-m freestyle swimming tests under race conditions on 4 different days. Each test was preceded by a different warm-up protocol in the following order: RSWU, UBPAP, LBPAP, and CPAP. Because of organizational and schedule limitations of the swimmers national-level training, the tests were not performed in a randomized order. A 25-m swimming pool set up with starting blocks and electronic timing equipment in the 2 central lanes was used for all tests. Their RSWU lasted 30 minutes and consisted of swimming at different speeds, leg-kick drills, short sprints, and a cool down. The remaining swimming tests were preceded by a short 15-minute warm-up in the pool and the different PAP protocols. The participants completed the brief warm-up in the water to familiarize themselves with the structural characteristics of the swimming pool, such as the height of the starting blocks, the pool depth, the wall surfaces, and the electronic timing system.

An interval of 10 minutes after the short warm-up in the water, allowed swimmers to change into suitable clothing (tracksuit and sports shoes) to keep themselves warm and perform the PAP stimuli safely.

Statistical Analyses

All data were checked for normality and expressed as mean values and *SDs*. The sphericity was checked using the Mauchly test. A 1-way repeated-measures analysis of variance (ANOVA) and intraclass correlation coefficients (ICCs) were conducted to determine differences between medicine ball throws attempts and the reliability of the medicine ball throw test. Participants' times to 50-m freestyle were analyzed as a whole and divided into male and female groups, as the effect of PAP may be influenced by gender (20). A repeated-measures ANOVA was then used to identify potential differences in the 50-m freestyle test performance, for the participants under each of the warm-up protocols in both gender- and non-gender-specific groupings. Post hoc Bonferroni test determined which measures differed significantly pairwise. Significance was set at $p \leq 0.05$ for all statistical tests and SPSS Statistics 19.0 for Windows was used to analyze data.

RESULTS

Repeated-measures ANOVA revealed the warm-up protocols had a significant effect ($F_{3,51} = 3.551, p = 0.021$) on the mean times. The mean values and *SDs* for all swimming tests are shown in Figure 4. Post hoc analysis using the Bonferroni correction revealed that swimming times after a traditional warm-up were significantly faster than those followed by an upper-body PAP (Figure 4A) (29.00 ± 2.05 s vs. 29.36 ± 1.88 s, $p = 0.046$). No other significant differences were identified between specific warm-up protocols ($p > 0.05$).

When data were split into gender, results indicated significant differences in times to 50 m only in the male group (Figure 4B). Post hoc test, using the Bonferroni correction revealed that swimming tests' times were significantly faster after an RSWU than an UBPAP protocol (27.51 ± 1.06 vs. 28.01 ± 1.17 seconds, $p = 0.047$). Likewise, the CPAP protocol was significantly faster than UBPAP protocol. (27.49 ± 1.12 vs. 28.01 ± 1.17 seconds, $p = 0.02$). No significant differences were found between times to 50-m front crawl in the female group (Figure 4C). In regards to the medicine ball throw test, repeated-measures ANOVA results did not reveal any significant differences between scores (data not shown). Additionally, test-retest reliability was measured using ICC and resulted in 0.88, thus showing strong reliability.

DISCUSSION

Considering the results as a whole population, irrespective of gender, no significant potentiation effect was found for 50-m freestyle swimming after a PAP protocol. Furthermore, the UBPAP warm-up showed to elicit significantly slower times

than the RSWU (Figure 4A). Taking into account that the LBPAP and CPAP protocols did not differ statistically with RSWU, the results of this study are in agreement with the findings by Kilduff et al. (15), where times to 15 m were similar after a traditional warm-up and a PAP protocol. However, further analysis of data revealed that gender seemed to influence the subsequent effect of PAP. The different warm-up protocols produced similar mean times to 50-m freestyle in the female group (Figure 4C). In contrast, male participants swam significantly faster after the RSWU and CPAP when compared with the UBPAP protocol, which did not seem to enhance performance (Figure 4B).

Gender may be a variable influencing PAP due to variation in muscle fiber structure. Larger type II fiber cross-sectional area and shorter twitch contraction times in males may explain this phenomenon (19). Past studies investigating the effect of gender in PAP revealed inconsistent results. O'Leary et al. (18) did not find differences in the influence of PAP on performance in either gender; this circumstance may be explained by a comparable magnitude and pattern of twitch force potentiation in the ankle dorsiflexors (18). However, gender seemed to influence potentiation since vertical jump was significantly increased only in men in a study conducted by Rixon et al. (19). Similarly, in a study conducted by Tsolakakis et al. (26), men showed a better response to PAP stimuli in both, lower body and upper body.

The PU, as a stimulus to potentiate the upper body in swimmers did not show a significant effect on swimming performance. Several reasons may explain the ineffectiveness of this exercise as a conditioning activity. The freestyle swimming stroke is a complex movement, which is divided into 6 different phases such as entry, downsweep, catch, insweep, upsweep, and exit. In each phase, the pitch, pathway, and velocity of the hand vary considerably (17). The hands do not apply force against a solid base of support and follow curvilinear patterns of movement under the water. Consequently, the kinematic characteristics of the freestyle stroke are extremely hard to replicate out of the water, which may impede the transfer into performance enhancement. The PU, regardless of its pulling nature may differ extensively from the actual motion of the arms under the water. Furthermore, Figueiredo et al. (10) revealed high activation of the triceps brachii muscle during the upsweep phase of the freestyle stroke. The upsweep is the most propulsive sweep in freestyle swimming (17) and the PU may not be an appropriate exercise to produce high activation of the triceps brachii. (28). Despite the significance of upper-body pulling performance on a variety of sports (e.g., swimming, judo), no studies have investigated the outcome of specific conditioning activities to trigger PAP for pulling motions. Postactivation potentiation stimulus performed in the water, such as tethered or resisted swimming may be an area of research for PAP studies that warrants further investigation.

The JB as stimuli to elicit PAP for the lower body may show benefit to performance on the diving start and the

push-off from the wall since both skills are influenced by leg-extensor power (27). The racing times achieved after the JB stimuli did not differ significantly from any other PAP protocol, but when completed with the PU, mean swimming times decreased in the male group. The CPAP produced the fastest mean times in male swimmers, despite being only significantly faster than the performances accomplished after the PU stimulus on its own. This finding suggests that both conditioning activities may complement each other to elicit potentiation when used together.

To the best of authors' knowledge, this is the first study investigating the effects of a combined PAP protocol to enhance upper- and lower-body performance simultaneously. The results show similar racing times using the CPAP and a more traditional warm-up, with both showing significant improvements over an upper-body PAP protocol. These results suggest a CPAP protocol may be as effective as a RSWU, allowing swimmers to warm-up more effectively when a swimming pool is not available before a race. Future research on conditioning activities for the upper body in swimmers could investigate the poor efficiency of the pull-up and complete a combined PAP protocol with a more advantageous stimulus that may increase performance in sprint swimming to a greater degree.

One limitation of this study is that the experimental protocol was not randomized in that the 4 different warm-ups were performed in a fixed order. As a result, all subjects were exposed to the different PAP protocols in the same order (RSWU, UBPAP, LBPAP, and CPAP). A nonrandomized design was chosen because of limited access to the swimmers. Consequently, the researchers in this study had to schedule the PAP protocols according to the duration of the subjects' training sessions. There could have been a learning effect; however, the researchers in this study ensured that the athletes underwent an extensive familiarization period with the PAP stimulus to minimize a possible learning effect (13). In addition, all the national-level swimmers in the study have a minimum of 4 years of experience with the distance being used for the test, both during training and competitions.

PRACTICAL APPLICATIONS

Postactivation potentiation has the potential to be a useful tool for coaches to warm-up swimmers participating in sprinting events. It is customary to hold the relay events shortly after the individual races, and in many occasions, space and time limitations can impede performance of a warm-up in the water. In such circumstances, a timely implementation of a PAP protocol could provide swimmers with a competitive edge. However, it is imperative to identify the conditioning activities and following rest intervals that trigger potentiation in each swimmer. The combined protocol has shown to be a valuable method to boost performance to some extent, and it may be advantageous not only for the elite sprinter whose achievements are dictated by a few hundredths of a second but also for the national- or county-level swimmer who may experience

pool-space restrictions to re-warm-up. Additionally, conditioning activities such as the JB described in this study represent an effective and simple method to warm-up the lower body, the vest's load can be easily adjusted to meet individual needs and can be taken into any swimming pool, as opposed to more voluminous and heavier weightlifting material.

We encourage swimming coaches to evaluate sprinters' individual responses to PAP and experiment with different conditioning activities, number of sets, and repetitions to determine the warm-up protocols that enhance performance to the greatest degree.

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