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Swimming Performance After an Eccentric Post-Activation Training Protocol

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Abstract

Applying maximum conditioning exercises temporarily improves muscle contractility thanks to post-activation performance enhancement (PAPE). However, it is now known whether the system can improve its adaptability to the procedure through a training based on the conditioning exercises themselves. This study set out to test a PAPE protocol in 14 swimmers before and after a training period. Initially, the subjects' strength in both the lower and upper extremities was tested. Subsequently, the effects of two types of warm-ups were tested in a 50-metre swimming test, one a standard warm-up and the other one a PAPE which included maximum repetitions executed on eccentric training machines. A 6-week training protocol was then applied (2 days/week), in which maximum repetitions were executed on eccentric training machines, and the effects were once again studied both on the strength tests and after both warm-ups. The performance improved at 15 metres after the PAPE compared to the standard situation, but not in the subsequent metre marks. After the 6 weeks, increases in strength in the lower extremities (14.46%) and upper extremities (12.4%) were recorded. Following the application of the PAPE warm-up, the starting speed increased and swimming time and speed improved at 25, 40 and 50 metres, which suggests that the subjects were capable of attaining a better balance between fatigue and potentiation.

Keywords: speed swimming, warm-up, power, dryland training, strength

Introduction

Any increase in speed, or actions taken in a swimming test, require a proportional increase in the strength and muscle power applied in the water or at the starting block, as well as an increase in the capacity and efficiency of the energy-production systems to maintain those requirements (Voronstov et al., 2011). The muscles work and make joint movements through contractions, which are characterised by producing strength and certain changes in length in discreet time intervals (Nasirzade et al., 2014). This suggests the existence of a logical relationships between strength skills and swimmers' performance.

In high-level competition, the difference between winning and losing a race is often determined by a fraction of a percentage difference in performance. For decades, coaches and scientists have tried to prepare athletes to perform at their maximum skill level during competition. One aspect of this preparation includes the warm-up and all the activities done in the 5-15 minutes prior to a race, since they can have a crucial effect on performance. Specifically, making brief muscle contractions at almost maximum intensity has been identified as the forerunner of an improved effect on muscle contractile capacity in terms of both strength and speed (Gilbert & Less, 2005; Seitz et al., 2016). This effect has been termed post-activation performance enhancement (PAPE) (Cuenca-Fernández et al., 2017).

One possible mechanism behind PAPE may be the positive effect of increasing muscle temperature, together with an increase in the volume of intracellular fluid in the connection and adhesion of the crossbridges which make muscle contraction possible (Blazevich & Babault, 2019). On the other hand, the effect of PAPE may also be due to the increase in neuron activation which has been detected along the backbone after any kind of intense muscle contractions (Chiu et al., 2004). Finally, the effect of PAPE may also be due to the phosphorylation of the myosin light chain (Baudry & Dechatau, 2007a; Grange et al., 1998). After a maximum muscle contraction, there is an increase in the calcium ions released in the sarcoplasmic reticulum, which are in charge of adhering to the tropomyosin and rotating the fine filament in which the actin is covered. Through this rotation, actin and myosin come into direct contact, making the crossbridges between these two molecules and consequently muscle contraction possible, thanks to the push movement that myosin produces by its very nature. Once this push has occurred, the myosin needs to separate from the actin and once again pivot its head to a distal position, where it will adhere to a new actin molecule. However, to achieve this effect, this protein needs to be phosphorylated, that is, recharged or energetically impelled for this distal rotation movement to happen inside the muscle fibre as the result of a chemical-physiological action. However, this phosphorylation effect only occurs when the stimulus which caused the previous muscle contraction is intense enough, since the organism interprets it as a response mechanism to the signs of fatigue caused (Baudry & Duchateau, 2007b; Grange et al., 1998).

The benefits of PAPE are more effective when a rest period is provided between the conditioning exercise and the competitive activity (Seitz et al., 2015). This reasoning makes sense bearing in mind the model proposed by Sale (2004), since fatigue and potentiation are two inherent responses to contractile activity, and the predominance of one over the other may have a crucial influence on performance. In trained athletes, this state of fatigue may dissipate relatively quickly, while the phosphorylation state can remain active for up to 5-8 minutes until the organism requires the same maximum muscle contraction again. Therefore, finding the window of opportunity in which to do the competitive activity with the absence of fatigue while the neuromuscular system remains in a potentiated state is essential to obtaining the athlete's maximum performance (Tillin & Bishop, 2009). This makes PAPE a method with a highly individualised application and response methods conditioned by the physical condition of the athletes to whom it is applied.

One of the principles of PAPE is providing a conditioning exercise that is as similar as possible to the real action (Seitz et al., 2016; Tillin & Bishop, 2009). Therefore, if the body movement is the outcome of a clearly defined, particular sequence of activation of certain motor units to produce the strength and movements required to make a given movement, then identifying the most biomechanically optimal exercise to stimulate the motor units needed for a specific task, in this case swimming, is extremely important. One study (Naczk et al., 2016) which analysed the relationships between specific strength training using an inertia training machine and swimming performance found significant improvements at the 50- and 100-metre marks, which were associated with the gains in strength and power caused by the training. Therefore, it was used as inspiration when applying the protocols presented below.

This study experimented with the effects of a standard warm-up on performance in a speed swimming test compared to a PAPE warm-up which included specific maximum strength exercises executed on an eccentric training machine. In the second phase, the subjects underwent a 6-week training which included the same exercises as in the first phase, and the effects after a standard warm-up and the PAPE warm-up were studied once again. The strength values of the subjects' upper and lower extremities were studied both at the beginning of the experiment and after the 6-week training period.

Methodology

Sample

Fourteen trained swimmers (7 males and 7 females) participated in the study. They provided their informed consent, and the swimmers under the age of 18 also provided parental permission. Their physical characteristics were: age 18.37 ± 1.41; weight 72.46 ± 8.97 kg; and height 1.78 ± 0.11 m. All the swimmers were recruited only if they had been participating in federated competitions for at least five years. They usually did a polarised training regimen, which enabled power and speed to be developed while lowering the volume of aerobic training (Hydren & Cohen, 2015).

None of the swimmers took narcotics or performance-enhancing substances. The tests were planned to be carried out just before their daily training time, and the subjects were asked to avoid any physical activity several hours before. All the procedures were carried out in accordance with the Helsinki Declaration on research with human subjects, and the study was approved by the university's Ethics Committee with number 852.

Experimental approach

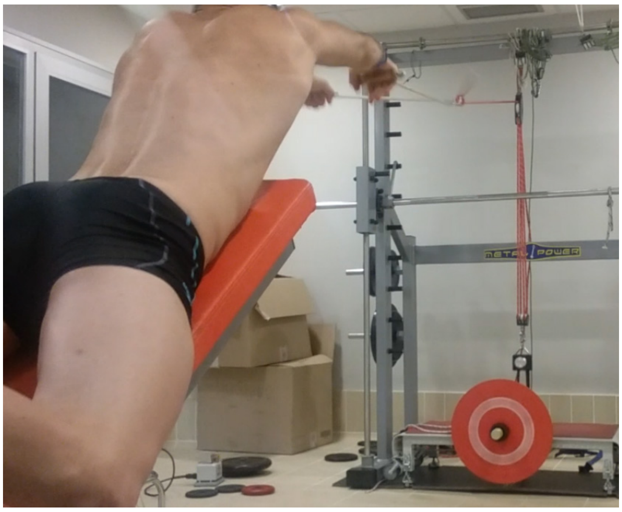
A repeated measures design was used to compare four different situations. First, the physical state of the subjects was evaluated, and then the effects on their performance in a 50-metre test were studied after a standard warm-up and after the PAPE warm-up. Secondly, a 6-week training was applied, and the effects after a standard and PAPE warm-up were studied again.

The physical condition of the subjects was evaluated by a maximum repetitions test performed on both the lower and upper extremities. Both tests found the maximum load that the subjects could move, and the power and speed curves expressed at 25, 50, 75 and 100% of the subjects' maximum resistance (MR) were obtained (González-Badillo & Sánchez-Medina, 2010).

The PAPE warm-up was conducted via a protocol entailing four repetitions of exercises of the upper and lower extremities on an adapted eccentric training machine (YoYo™ Technology AB, Stockholm, Sweden). The exercises for the lower extremities consisted of making the flexion-extension movement that is made when starting a swim race in the same position and placement of the legs (asymmetrically) that swimmers use on the starting block (Figure 1). The conditioning exercise for the upper extremities consisted of making arm pulling movements similar to the arm movements in swimming while reclining

Figure 1
PAPE induction for the lower extremities on an nHANCE™ Squat Ultimate eccentric training machine (YoYo™ Technology AB, Stockholm, Sweden)

Figure 2
PAPE induction for the upper extremities on an nHANCE™ Squat Ultimate adapted eccentric training machine (YoYo™ Technology AB, Stockholm, Sweden)



on a training bench from which they pulled grips connected to the eccentric training machine by ropes (Figure 2).

Procedure

The experimental setting was an indoor 25-metre pool (with water and air temperatures of 28.1ºC and 29.0ºC, respectively). Each swimmer individually did 3 protocols on 3 separate days (one protocol per day). In the first session, strength was analysed by a MR test on a training machine in accordance with the guidelines proposed by the American College of Sports Medicine (Ferguson, 2014). The machine was connected to a T-Strength iso-inertial dynamometer (Ergotech, Murcia, Spain), which transmitted all the values recorded during the strength test directly to a computer. The exercises done in the strength test were based on the study by Cuenca-Fernández et al. (2018), which included: 1) strides on a training machine with the same position and asymmetrical leg placement that swimmers use on the starting block, and 2) exercises done on an adapted training machine with pulleys that allowed arm pulling movements similar to swimming strokes to be made.

In a second session, reference points on the swimmers' hips, knees, ankles, hands and elbows were marked (using a black marker). After that, the swimmers were informed about the test protocol, which included a warm-up, a rest period, and finally a 50-metre test at maximum intensity. Each test was done only once to simulate competition "one attempt" conditions (FINA regulations). Throughout the session, a researcher monitored each subject's rest time. A sound stimulus similar to what is used in competition was used as the starting signal. In each test, the subjects were asked to climb onto the starting block. Once in position, they were given the "take your marks" signal and then the starting signal was given.

First, all the swimmers did the standard warm-up (SWU) protocol, which consisted of 400 metres of varied strokes and two starts from the block. After swimming, the participants began a dynamic stretching protocol which consisted of exercises of the muscles most closely associated with dives and arm pulls. Each exercise was done 10 times, and the whole set was repeated twice. At all times, the dynamic stretching protocol was conducted under the supervision of a researcher, who made sure that it did not last more than 4 minutes and that they were allowed at least 6 minutes of rest before doing the 50-metre test at maximum intensity. All the tests were recorded with several cameras placed along the length of the pool with the goal of getting kinematic variables related to swimming.

Two hours later, the swimmers did the SWU followed by the PAPE induction by means of a protocol proposed by Cuenca-Fernández et al. (2018), which consisted of doing four repetitions of exercises of the lower and upper extremities on an adapted eccentric training machine (YoYo™ Technology AB, Stockholm, Sweden) at maximum intensity. This warm-up was called EWU.

In the course of the following 6 weeks, the swimmers performed a training protocol 2 days a week in which they carried out exactly the same exercises as they had done during the PAPE warm-ups. On arrival, the swimmers did the warm-up of 400 metres of varied strokes, followed by the dynamic stretching protocol and then the exercises on the eccentric training machines. At the end of the 6 weeks, they did the strength tests once again, as well as the swimming tests after a standard warm-up and the PAPE warm-up, following the same protocols and methodologies mentioned above.

Results

Descriptive statistics were obtained, and all the data were expressed as the Mean ± SD with a 95% confidence interval (SPSS Version 21.0, IBM, Chicago, IL, USA). After the Saphiro-Wilk normality test, a one-way repeated measures ANOVA was applied to the four protocols to determine inter- and intra-subject differences in the kinetic and kinematic variables. To detect differences, the alpha level was set at < .05. The comparisons by pairs were performed using the Bonferroni method to control type-1 errors.

An improvement was found in the strength test after the 6 weeks of training, which was particularly significant for the lower extremities ($p < .01$), where the subjects' MR values improved from 76.53 ± 21.97 kg to 89.46 ± 24.78 kg after the 6 weeks of training. For the upper extremities, the values also improved ($p < .05$), from 34.34 ± 7.01 kg to 39.20 ± 7.86 kg (Figure 3).

The power-speed curves obtained in the strength tests showed an improvement in the execution of both power and speed exercises, which was particularly significant in the power values of the lower extremities (Figure 4, above), executed at 25 ($p < .05$), 50 ($p < .01$), 75 ($p < .05$) and 100% of MR ($p < .05$). However, the values found in the upper extremities remained the same after the 6 weeks of training in the executions at 25, 50 and 75% of the MR, and these values were even lower at 100% of MR (Figure 4, below).

The analysis revealed differences in swimming times and speeds at 15 metres after the PAPE warm-up compared to the standard warm-up (T15: $F_{3.48} = 5.073$; $p = .028$; S15: $F_{3.48} = 5.082$; $p = .031$), but there were no differences in the other tests even after the 6 weeks of training either after the standard warm-up or after the PAPE warm-up (Table 1). Differences were found in swimming time and speeds following the PAPE after the 6 weeks of training compared to the standard warm-up after the 6 weeks of training at the 40-and 50-metre marks (T40_PAPE: $F_{3.48} = 4.625$; $p = .045$; S40_PAPE: $F_{3.48} = 4.028$; $p = .039$; T50_PAPE: $F_{3.48} = 5.795$; $p = .024$; S50_PAPE: $F_{3.48} = 4.982$; $p = .033$). However, no statistically significant differences were found at 25 metres, even though the values were better after the PAPE warm-up (Table 1).

The starting speed values recorded at the hip while in flight were different after the 6 weeks of training applying the PAPE protocol compared to the values

Figure 3

Maximum strength values recorded in the maximum repetitions (MR) test for the lower and upper extremities at the beginning of the experiment (PRE) and after the 6 weeks of eccentric training (POST)

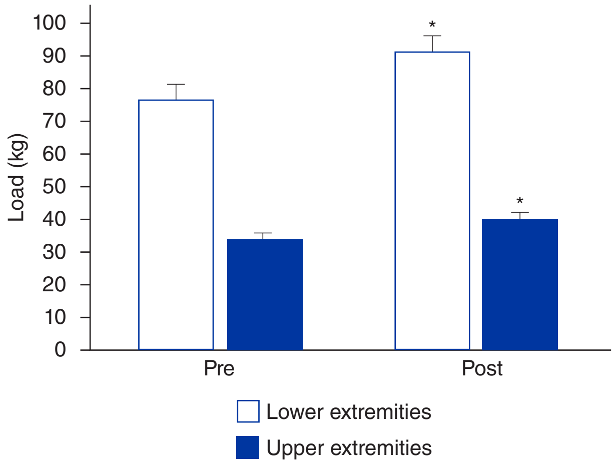


Figure 4

Power-speed curves obtained in the strength tests performed on the lower extremities (above) and upper extremities (below) at the beginning of the experiment and after the 6 weeks of training. Values expressed at 25, 50, 75 and 100% of the subjects' MR

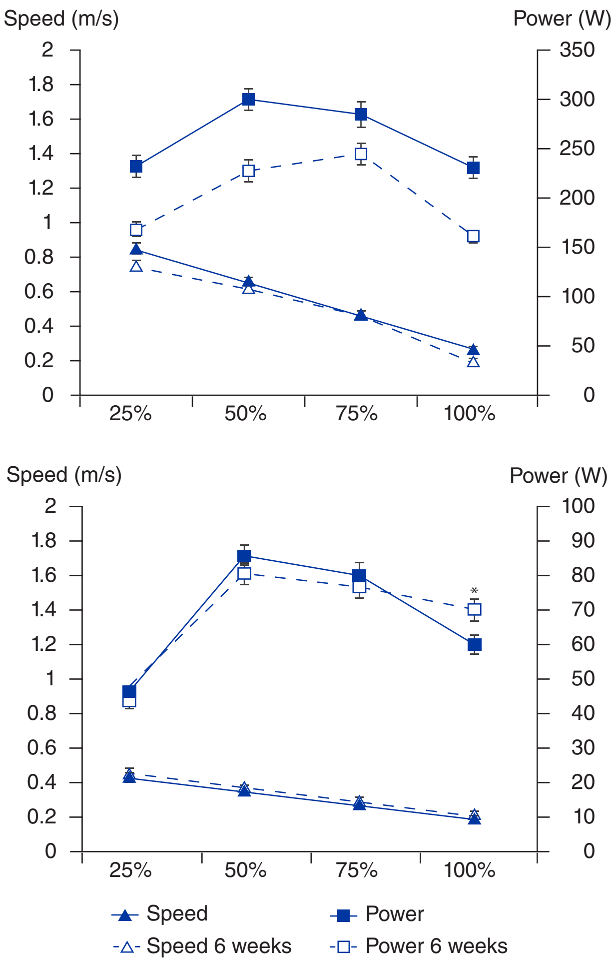


Table 1
Mean and standard deviation of the swimming times and speeds (15, 25, 40 and 50 m) and the start of swimming (from the starting signal to the hands' first contact with the water)

	Pre-test								Pre-test + PAPE								Post-test (6 weeks)								Post-test (6 weeks) + PAPE							
	T		SD	Speed		SD			T		SD	Speed		SD			T		SD	Speed		SD			T		SD	Speed		SD		
15 m	7.30	±	0.50	1.71	±	0.13			7.12*	±	0.90	2.17*	±	1.62			7.37	±	0.55	1.70	±	0.13			7.34	±	0.57	1.70	±	0.12		
25 m	13.51	±	0.85	1.53	±	0.10			13.57	±	1.03	1.50	±	0.13			13.74	±	0.96	1.52	±	0.10			13.68	±	1.00	1.53	±	0.13		
40 m	21.76	±	1.38	1.64	±	0.10			21.95	±	1.64	1.61	±	0.12			22.14	±	1.53	1.61	±	0.13			21.97#	±	1.62	1.65#	±	0.13		
50 m	27.73	±	1.72	1.59	±	0.09			28.08	±	2.18	1.58	±	0.17			28.31	±	2.03	1.54	±	0.14			27.98#	±	2.10	1.59#	±	0.13		
Start	0.90	±	0.09	3.28	±	0.39			0.91	±	0.10	3.27	±	0.36			0.91	±	0.08	3.29	±	0.39			0.92	±	0.11	3.31†	±	0.33		

* Differences compared to the standard warm-up; # Differences compared to the standard warm-up after the 6 weeks of training; † Differences compared to the PAPE warm-up after the 6 weeks of training.

obtained after the PAPE warm-up at the beginning of the test ($F_{3.36} = 7.042$, $p = .045$). There were no significant differences in the flight time recorded during the start in any of the 4 protocols (Table 1).

Discussion

The first objective of this study was to evaluate whether muscle performance may be higher after maximum intensity conditioning exercises. The results showed that performance can be improved at the 15-metre mark after a warm-up based on PAPE. The second objective of the study was to evaluate the effects of that same kind of warm-up after a 6-week training using the same protocols, and the results showed that the subjects attained a better balance between fatigue and potentiation. Furthermore, this study also demonstrated that the subjects were capable of improving their absolute and relative strength after the 6-week training of the warm-up protocol.

The study by Kilduff et al. (2011) was the first case in which PAPE protocols were applied to swimming starts from the swim deck. Significant improvements were found on the peak strength generated at the starting block; however, no difference was found at the 15-metre mark. The swimmers in this study did not experience any significant change in the variables collected at the starting block, even though they were able to reach the 15-metre mark in less time (Table 1). According to some authors, it is important to consider the influence of the starting block phase on the performance obtained in the components after the start, and therefore it is important for swimmers to optimise this phase (Mason et al., 2007). Some studies have demonstrated the relationship between strong lower extremities and good start performance; the results suggest that the subjects who tended to have higher speeds at the starts also had higher absolute and/or relative strength values on the lower extremities (Béretic et al., 2013). After the 6 weeks of training, the subjects showed an improvement in the strength tests, which was especially significant for the lower extremities (Figure 3). This did not lead to a major improvement in starting speed after the standard warm-up, but it did after the PAPE warm-up had been applied (Table 1). These results were in accordance with the study by Cuenca-Fernández et al. (2015), which demonstrated that swimmers with higher relative strength values in their lower extremities were not only capable of executing a better start but were also capable of reacting to the PAPE protocols better. If the swimmers in this study were capable of increasing their absolute strength values after 6 weeks of training, then they also improved their relative strength and thus their capacity to react better to the PAPE protocols.

In the swimming phase, a lower time at the 15-metre mark was only obtained after PAPE: however, the lower time at 50 metres was obtained after the standard warm-up, which suggests that there is a deterioration in swim speed after PAPE (Table 1). Fatigue and potentiation coexist as responses to PAPE, which means that the responses are highly individualised according to the athlete's level or physical condition, and that a more appropriate intensity or rest period must be found for the conditioning activities applied to the upper extremities. The study by Naczk et al. (2016) applied a specific training of the muscles related to the pulling phase in the front crawl for 4 weeks using an inertial training machine. This resulted in improvements in swimming performance at both 50 metres

(–0.76%) and 100 metres (–1.83%), and these improvements were associated with swift gains in strength (12.8%) and muscle power (14.2%), perhaps caused by the major stimulation generated by the eccentric overload. The gains in absolute strength in the upper extremities obtained in this study were 12.4%. However, bearing in mind the values found in the power-speed tests, the exercise chosen for the upper extremities may have not provided enough training stimulus. The values found in the speed of execution worsened, constituting a deterioration with a variability of ~ –11.59%, while the improvements in power had a variability of ~ 5.88% at 25, 50 and 75% of MR, but a worsening of –14.55% when mobilising 100% of the MR (Figures 3 and 4).

In any case, it should be noted that even if the PAPE protocol is applied and a comparison is made with the standard situation, the results compared to the start of the 6 weeks of training worsened (Table 1), the same tendency was not found after the 6 weeks of training, although there were improvements in the final test marks (25, 40 and 50 metres). This result suggests that the subjects were capable of achieving a better balance between fatigue and potentiation, perhaps because they increased their MR value in the upper extremities (Figure 3). Furthermore, according to Morouço et al. (2011), performance in a 50-metre race is more closely related to absolute strength values than to body weight values.

In conclusion, a warm-up based on PAPE protocols may influence performance in the first few metres of a 50-metre race. However, other factors, such as fatigue, may change swimming patterns and yield contradictory, instead of the desired, results. Evaluating and monitoring swimmers' strength via specific strength tests like the ones conducted in this study is a useful, necessary tool which coaches should use more often to self-assess the training procedures they undertake with athletes. One of the main results found in this study, thanks to the strength tests, indicated that the overload offered by the eccentric training machines seems to show more benefits in the training and stimulation of the lower extremities than of the upper extremities, possibly because of the subject's position when doing the exercise and the action of gravity. Future studies should use the same protocol with the application of individual loads as the training method, especially to apply greater intensity to the upper extremities.

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