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REVIEW ARTICLE

EFFECTS OF POST-ACTIVATION PERFORMANCE ENHANCEMENT ON COMPETITIVE SWIMMERS' PERFORMANCE: A SYSTEMATIC REVIEW

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Abstract

Study purpose. The aim of this systematic review was to evaluate the effects of post-activation potentiation/post-activation performance enhancement (PAP/PAPE) warm-up protocols on swimmers' performance.

Materials and methods. The searches were carried out on the electronic database PubMed, Scopus, Web of Science, and EBSCO platforms. Studies from 2010 to May 2022 related to PAP/PAPE and its effect on swimming performance in swimmers aged between 18 and 35 were included.

Results. Nine of 333 studies were included in this review. In two studies, peak thrust improved by 13% to 19% for PAP vs non-PAP and by 3% on performance. One study showed improvements by 10% on speed and speed fluctuation in 25 m all-out PAP vs non-PAP. Rate of force development (RFD) 15 m maximum effort was higher for dry land warm up (DLWU) than swimming warm up (SWU). One study had higher velocity in 5 m for repetition maximum warm-up (RMWU) and eccentric fly-wheel warm-up (EWU) vs SWU. One study demonstrated enhancements for upper-body PAP (UBPAP), low-body PAP (LBPAP) and MIX (UBPAP/LBPAP) vs warm up based on general exercises (GEN) in time to 25 m freestyle (T25FS). Two studies found improvements for band squats PAP compared to swimming specific warm up (SSWU) in time to 15 m. One study demonstrated that PAP trial (PAPT) was faster than control time trial (CTT) in 50 m and 100 m freestyle trial. Dive velocity (DV) was faster for RMWU/EWU vs SWU. One study showed significant increase in power vertical force (PVF) and power horizontal force (PHF) after the PAP vs SSWU.

Conclusions. PAP/PAPE is one more tool that can be beneficial if adapted to the conditions of swimmers, controlling fatigue levels, where it is performed (land or water), and most importantly, described by many coaches, the specificity of movement.

Keywords: post-activation potentiation, post-activation performance enhancement, swimming performance.

Introduction

The investigation about the swimming sport performance is important to analyze swimmer´s progression and stability between competitions and races, helping coaches define realistic goals and select appropriate training methods to optimize performance. There are a countless training methods and systems to improve swimming performance, whereas warming up before physical exercise is commonly accepted as fundamental previous practice to optimize performance (Aagaard et al., 2002; Barbosa et al., 2020; Beato et al., 2019). However, specifically in swimming, studies on the effects of warming are scarce, which could be due to the pool environment, which has high humidity and temperature, which increases the complexity of the warm-up procedure (Neiva et al., 2014). Swimming is a complex sport where the whole body as a whole participates in propulsion, with the upper body being in charge of up to 90% of it (De Martino & Rodeo, 2018). Propulsive power in the freestyle is 80% for the stroke and 20% for the kick (King, 1995), which makes it important to know where to focus the main activation in the work leading up to the main activity. The warm-up is specifically intended to: 1) improve muscle dynamics in order to be less prone to injury and 2) prepare the athlete for the demands of exercise (Shrier, 2008). Additionally, 1° increase in body temperature may slightly increase tolerance to muscle failure and should generally be until there is some sweating (Cohen et al., 2015; Cuenca-Fernandez, Batalha et al., 2020; Cuenca-Fernandez, Gay et al., 2020). There are many types of warm-ups, which can be active or passive (Aagaard et al., 2002). Passive warming refers to raising body temperature with objects external to the body, such as a hot shower, warm pillows, or saunas (Shrier, 2008), while active warming is basically raising body temperature by physical activity that generally involves non-specific movements such as jogging, cycling and/or calisthenics (Prentice & Shellock, 1985). One of the widely used warm-up methods in sports is post-activation potentiation (PAP). PAP is a physiological phenomenon associated with an acute improvement in muscle performance after a protocol of neuromuscular, mechanical, and biomechanical changes that may temporarily induce performance enhancement, but the exact underlying mechanism is not fully understood (Beato et al., 2019). The most strongly supported explanation for the effects of PAP relates to the large number of cross-bridges as a result of myosin regulatory light chain phosphorylation during muscle contraction (Beato et al., 2019; Boullosa et al., 2018). In addition, it is proposed that PAP is the result of increased sensitivity of contractile proteins to calcium (Ca2+), released from the sarcoplasmic reticulum, the result of a cascade of events leading to an improvement in muscle response (Cuenca-Fernandez et al., 2017; De Martino & Rodeo, 2018). In recent years, the taxonomy of this term has been modified, in order to find one that best suits the characteristics of this type of pre-performance activation.

PAPE is the term that has come to replace PAP since when talking about PAP it only refers to a physiological mechanism responsible for improving performance in warm-up (Boullosa et al., 2018). The reasons behind this dualism (PAP vs PAPE) refer to the association of PAP with verification of evoked contraction, which, in turn, would be related to phosphorylation of myosin regulatory light chain (MLC) during a very short period of time (<5 min) (Cuenca-Fernandez et al., 2017). On the contrary, PAPE would be associated with increases in voluntary performance, mainly as a consequence of other potential mechanisms (for example, temperature, water content) in longer time windows (>5 min) (Blazevich & Babault, 2019). This review will refer to PAP/PAPE as one, since the investigations of potentiation protocols are referred to the PAP concept and the newer ones as PAPE. Studies on the effects of warming are scarce, specifically in swimming, which could be due to the pool environment with high humidity and temperature, increasing the complexity of warm-up procedure (Neiva et al., 2014).

Swimming is a complex sport where the whole body as a whole participates in propulsion, with the upper body being in charge of up to 90% of it (De Martino & Rodeo, 2018). In the freestyle, propulsive power is 80% for the stroke and 20% for the kick (King, 1995), indicating that main activation in the work should correspond to the main activity. Most of the few studies about swimming warm-ups provided information on temperature of the aquatic environment, training with elastic bands (dry), warm-up effects in different distance protocols and intensities (Czelusniak et al., 2021), but the information related to swimming warm-ups PAP/PAPE is limited, but not in other sports, where over the past decade have demonstrated positive changes in performance, particularly in sprint or highly power-derived events (Seitz & Haff, 2016).

PAP/PAPE protocols are increasing popularity in swimming sport, being a good solution for shorter periods for activation, because the competition environment tends to have a long waiting time between warm-up and competition. It is also necessary to consider the distances in which a PAP/PAPE protocol can have an effect, since the tests of longer duration and/or greater distance require resistance to force and not mainly maximum explosive speed in short periods (Boullosa et al., 2018).

Given the few knowledge about the effect of swimming warm-ups PAP/PAPE on swimmer´s performance and the swimming warm-ups PAP/PAPE could be a positive method to implement in competition. The objective of the following systematic review aimed to evaluated the effects of PAP/PAPE warm-up protocols on swimmer´s performance.

Materials and methods

Search strategy and study selection

This review aligns with the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA) guidelines (Page & Moher, 2017) and was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD42022340696). The searches were carried out in the following electronic database platforms from the year 2010 to May 2022 PubMed, Scopus, Web of Science, and EBSCO. The search strategy was not limited by language and included the following keywords: (1) Postactivation Performance Enhancement and post activation potentation; (2) Swimmers and (3) Swimming performance (Table 1). For the search of these keywords, the boolean term (AND) and (OR) was used, such as example "Post activation Performance Enhancement OR Post activation Potentation AND swimmers AND swimming performance" (Table 1).

The selection procedures are shown in Figure 1 and the total references were obtained and stored on an EndNote (EndnoteX9, Thomson Reuters, San Francisco, California) database. Then, the duplicates were removed and a filter of articles by titles and abstracts was carried out. After that, the remaining articles were completely analysed and those that did not meet the inclusion criteria were eliminated. Finally, an integral reading and analysis of all the articles that entered the review was made (Figure 1). No authors were contacted for obtaining further information whenever there was data missing.

Eligibility criteria

Studies were considered eligible if they met all the following criteria: a) The research involved an intervention study with acute effect, where the PAP/PAPE characteristics (the type of movements involved, intensity, volume, work-to-recovery ratio (WRR) between PAP/PAPE and trial and duration of the intervention) and control group warm-up protocols were given; b) The PAP/PAPE response were evaluated in swimming pool by maximum speed trial (m/s or total time race) and collecting other swimming performance variables (Rate of Force Development (RFD) and/or power-output (PO); c) Randomized designs with controlled trials (RCT) and RCT Crossover trials were considered. Groups may be mixed or only one sex; d). Outcome measures involved post warm- up, with any swimming race style (From start race up to 5, 15, 25, 50 or 100 m evaluated in race time); e) Participants of 18 to 35 years healthy and without diagnosed disease or injury; f) Articles with focus reviews, papers published in conference, dissertations, thesis or in non-peer-reviewed journals were excluded; g) Only research involving humans and written in English and Spanish were considered.

Study selection

The selection criteria were based on the on the population, intervention, comparison and outcomes (PICO) criteria used to define the characteristics of the included studies. The inclusion was evaluated according to the criteria (PICO): Population: Studies with competitive level athletes aged between 18 and 35 years. Intervention: Studies that analyze the effects of PAP/PAPE on the performance of swimmers. Comparator: Studies with active control group of specific swimming warm-up and/or traditional No-PAP/PAPE; Study design: studies RCTs and RCT crossover were included. Outcomes: Measures involved post warm-up, with any swimming race style or derive swimming race (From start race up to 5, 15, 25, 50 or 100 m evaluated in race time). Exclusion: Studies that present supplementation, doping, pathologies, injuries and/or injuries in the last 6 months. Also reviews, dissertations, theses, non-peer-reviewed journals, conference citations, and/or commentaries were excluded. One author completed the screening and selection of studies in May 2022. First, duplicates were removed and titles and abstracts were examined to identify studies that met the inclusion criteria. Second, the full texts of the eligible studies based on the screened studies were read by three authors (EM, AB and LF) to determine their final inclusion. Disagreements between the three reviewers were resolved through a consensus meeting between the four authors in October 2022. Finally, articles on acute PAP/PAPE effects on swimmers and swimming performance were included in this review. Figure 1 provides an overview of the selection process.

Data extraction process and data synthesis

The full texts were analyzed and after confirming the eligibility criteria, the following data were extracted: (a) First authors name, publication year, and country of data collection; (b) Participants age and sample size by group; (c) Study design and/or group assignment; (d) Characteristics of PAP/PAPE intervention (exercises intensity in individual maximus repetition percentage, sets, repetitions); (e) Characteristics of control group warm up intervention and (f) Main findings result related to pre-defined outcomes from the experimental group and control group, comparing each other. Data from the included studies were extracted independently by one reviewer (EM), consulted to other researchers (AB and LF) and any discrepancies were resolved by consulting a third reviewer (TRA).

Assessment of risk of bias

Three authors (EM, AB, LF) assessed study quality according to the PEDro scale (Maher et al., 2008) in each included study, shown in Table 2. Any disagreements were discussed with a third reviewer (TRA) until consensus was reached. The total PEDro score is obtained by adding points describing the quality of papers, classified with following score points: 9-10 (excellent), 6-8 (good), 4-5 (fair), and ≤3 (poor).

Results

Study selection

The search strategy yielded a total of 333 references, 17 were eliminated due to duplicates, 299 were removed by title and three by abstract. Four articles were removed by inclusion criteria (two for mean age and two for study type). Then, one articles were eliminated for other reasons described in figure 1. Nine articles were included for the presented review (Figure 1). Table 1 summarizes the characteristics and results of the study.

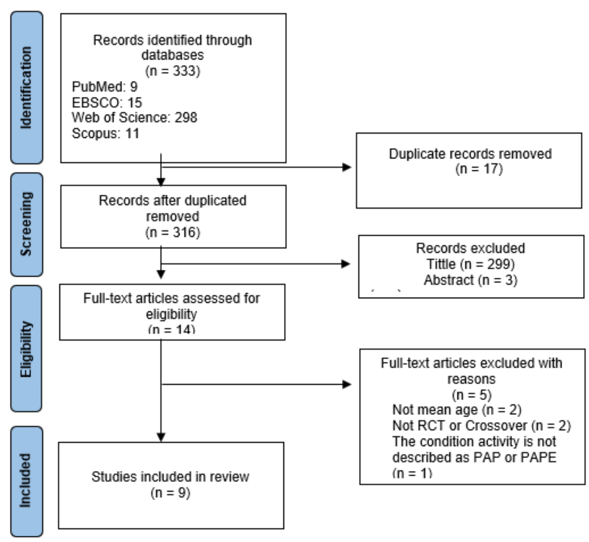

Fig. 1. PRISMA flow diagram of each stage of the study selection about the effects of post-activation potentiation/post-activation performance enhancement (PAP/PAPE) warm-up protocols on swimmer´s performance

Studies description

All the included articles assessed the effects of a PAP/PAPE activation protocol on swimming performance variables; an overview of the included studies is provided in Table 1. The present review found that the number of participants

Table 1. Summary table of studies

Author/Year/ Country/Study Type	Sample	Experimental Group intervention	Control Group intervention	Assessments	Main Results
Barbosa et al., 2020 Portugal Crossover RCT	n= 12 CS ♂= 12 Age= 23.50 ± 3.35 years old	PAP: 700 mt + 5 min recovery + PAP 2x5 one arm Band pull /2 min recovery between arm sets	non-PAP: 1400 mt	25-m all out.	Peak thrust and mean thrust were better for PAP group vs non-PAP group. Speed and speed fluctuation have no significant differences
Cuenca-Fernández et al., 2020a Spain RCT	n= 20 CS ♂= 11 Age= 18.02 ± 1.39 years old	400 mt SWU + DLWU (3 pull over al 85% 1MR)	SWU: 400 mt (2×50-m front crawl swim (12'5 fast/12'5 smooth)	15-m ME.	RFD showed to be higher after DLWU compared to SWU. The force, acceleration and power values were lower in DLWU compared to SWU
Cuenca-Fernández et al., 2020b Spain RCT	n= 14 CS ♂= 7 ♀= 7 Age= 18.37 ± 1.41 years old	PAPE: 1 x 4 ME arm-pull similar to arm-stroke + swimming start position movement (Yo-Yo Squat).	SWU: 400 m assorted styles + two block start + 4 min dynamic stretching	50-m ME.	15 m time and speed were better for PAPE comparing to SWU but to in other distances
Cuenca-Fernández et al., 2018 Spain Crossover RCT	n= 17 CS ♂= 11 Age= 18.42 ± 1.39 years old	RMWU: 1 x 3 85% 1 RM lunge + 1 x 3 85% 1RM arm stroke EWU: 1 x 4 Fly-Wheel. (Lower and upper limbs)	SWU: 400-m standard warm up + dynamic stretching	50m trial ME	BT: No differences DD: No differences DV: EWU Faster than SWU and RMWU UUSASS: No differences UUSAT: No differences T5-50M: T5 faster in both activation protocols compared SWU. No differences between protocols in 50M T25M: No differences between protocols V5M-: V5 faster in both activation protocols vs SWU V50M: no differences between protocols.
Hancock et al., 2015 United States RCT	n= 30 CS ♂= 15 ♀= 15 Age= 19-22 years old	PAPT: 900 mt WU + PAP (1 x 4 x 10-m swim using dynamic resistive sprints while attached to a Total Performance Power Rack)	CTT: 900 mt WU + 100 mt sprint	100-m freestyle ME	PAP trial was significantly faster than control trial for the first 50-m, second 50-m and 100-m
Kilduff et al., 2011 England Crossover RCT	n= 9 CS ♂= 7 ♀= 2 Age= 22 ± 2 years old	PAP (1 x 3 - 87% 1MR) squats	1.300-m specific WU	PVH and PHF in Time to 15-m ME	No significant difference between SS performance PAP stimulus compared to the DS preceded by the SSWU regard time to 15 m. Significant increase in both PVF and PHF after the PAP stimulus warm-up vs SSWU.
Ng et al., 2020 Egypt Crossover RCT	n= 16 CS ♂= 16 Age= 22.13 ± 3.84 years old	PAP warm-up: 700 mts + 2 x 5 CMJ	No PAP warm-up: 1400 m	25-m all out	Peak thrust increased by 15% in PAP vs non-PAP. Large and significant differences in speed and speed fluctuation in 10% in PAP compared with non-PAP
Sánchez et al., 2020 Spain Counterbalanced RCT	n= 10 CS ♂= 11 Age= 20,8 ± 4,7 years old	COM: 900-m freestyle (2 x 400-m/4x25-m sprint) UBPAP: COM + 3 min recovery + 1 x 6 eccentrics high pull MV. LBPAP: COM + 3 min recovery + 1 x 6 eccentric ½ squat MV. UBPAP/LBPAP mix: COM + 3 min recovery + 1 x 6 eccentric high pull MV + 1 x 6 eccentric ½ squats MV.	GEN: 5 min Upper and Lower body Dynamic stretching + 450-m freestyle 70-80% MHR	25-m freestyle ME	COM, UBPAP, LBPAP and UBPAP/LBPAP mix faster than GEN COM + PAP (UBPAP/ LBPAP mix) were no differences in effect in T25FS

Table 1 (continued)

Autor/year/Study Type	Sample	Experimental Group intervention	Control Group intervention	Assessments	Main Results
Waddingham et al., 2018 England Crossover RCT	n= 11 CS ♂= 8 ♀= 3 Age= 18–22 years old	1: Band Squats (3x3) 2: Weighted Jumps (3x3) 3: Drop jump 45-cm (2x5)	SSWU 400-m swims 4x50 kick/drill 4x50 freestyle, rest 15 s (1-build, 2-25 fast/25 easy, 3-easy, and 4-pace) 2x15 m start race condition	15-m swimming start ME	15-m start times were significantly quicker in the band squat protocol compared with the sport-specific warm-up condition

BT: Block time; CMJ: countermovement jump; CS; Competitive swimmers; CTT: Control time trial; DD: dive distance; DLWU: Dry land warm up; DS: dive start; DV: dive velocity; ; EWU: eccentric fly-wheel warm-up; GEN: warm up based on general exercises; LBPAP: Lower body PAP; m: metros; ME: Maximum effort; MHR: Maximum heart rate; MR: Maximum repetitions; MV: Maximum velocity; PAP; Post activation potentiation; PAPE; Post activation performance enhancement; PAPT: PAP trial; PHF: power horizontal force; PVF: power vertical force; RMWU: Repetition maximum warm-up; RCT: Randomized controlled trial; RFD: rate of force development; SS: Swimming start; SSWU: swimming specific warm up; SWU: standard warm-up; T5M-50M: time to 5 and 50-m; T25M: time to 25-m; T25FS: Time to 25 m freestyle; UBPAP: Upper body PAP; UUSAT: underwater undulatory swimming after turn; UUSASS: Underwater Undulatory Swimming After swim start; V5-V50M: Velocity to 5-m and 50-m; WU: Warm up; ♂, boys; ♀, girls.

in each study ranged from 9 to 30, with ages ranging from 18 to 26 years. These studies were conducted in England (Neiva et al., 2014; Page & Moher, 2017), Spain (Maher et al., 2008; McCrary et al., 2015; McGowan et al., 2015; Ørtenblad et al., 2000) United State (Hancock et al., 2015), Egypt (Ng et al., 2020), Portugal (Barbosa, Jia Wen Yam, Danny Lum, 2020). All the included studies evaluated and compared the acute warm up PAP/PAPE effects with a control group which performed a traditional warm-up. All participants were informed about the study procedure and an introducing session was provided to familiarization in a different day previous their assessments.

The type of exercise intervention consisted in submaximal singles efforts session protocols compared with a traditional swimming warm up protocol. In terms of the recovery between warm up and trial, different times were given to each swimmer in order to obtain their best recovery duration, within a range between 15 secs to 12 min. Additionally, the swimming variables assessed: were 15-m start; FT; T5M; T15M; T25M; T50M; T100M; BT; SS performance; DS; PVF; PHF; BT; RFD; DD; DV; UUSASS; UUSAT; V5M; V50M. Two studies assessed different performance swimming variables in order only to obtain the arm-pull in front-crawl performance while the legs held a pull-buoy (Barbosa, Jia Wen Yam, Danny Lum, 2020) and the flutter kick using a kickboard on hands (Ng et al., 2020). Two studies (MacIntosh et al., 2012; Ng et al., 2020) measured swimming variables; Peak thrust and speed and speed fluctuation in 25 m all-out. Peak thrust improved 13% to 19% (MacIntosh et al., 2012; Ng et al., 2020), only 3% on performance (MacIntosh et al., 2012) and have no differences on speed and speed fluctuation in 25 m all-out (MacIntosh et al., 2012) while in other study improvement by 10% (Ng et al., 2020). One Study (Maffiuletti et al., 2016) assessed the rate of force development and power in 15 m maximum effort, where experimental group (DLWU) showed to be higher than active control (SWU) when is performed in dryland, but not in force, acceleration and power values, which could not improve performance. Two studies found improvements on time to 15 m (Maher et al., 2008; Page & Moher, 2017). Two studies (McCrary et al., 2015; Neiva et al., 2014) showed no significative differences in the same distance (15 m) for experimental groups (EWU and RMWU) vs active control group (SWU). The same study (Cuenca-Fernández et al., 2019) showed that EWU and RMWU groups were faster than SWU on time to 5 m. One study (Sánchez et al., 2020) demonstrated enhances in experimental groups (UBPAPA, LBPAP and MIX) vs active control group (GEN) in 25 m speed (T25FS). Two studies (Maher et al., 2008; McCrary et al., 2015) found no differences in 25 m and 50 m between experimental group (PAP/PAPE; RMWU; EWU) vs active control group (SWU). One study (Hancock et al., 2015) demonstrated that PAP/PAPE was faster than control trial in 50 m and 100 m freestyle trial. One study (Cuenca-Fernández et al., 2019) had higher velocity in 5 m for experimental conditions (RMWU and EWU) vs active control condition (SWU). One study (Cuenca-Fernández et al., 2019) did not show differences between protocols in velocity for 50 m. One study (McCrary et al., 2015) had no differences in BT, DD. DV was faster, UUSASS and UUSAT had no differences between experimental groups and control active group. One study (Kilduff et al., 2011) showed significant increase in both PVF and PHF after the PAP/PAPE stimulus warm-up vs control active group (SSWU).

Discussion

The purpose of this systematic review was to evaluate the effects of PAP/PAPE and on swimming performance. PAP/PAPE is a relatively new phenomenon in sport and exercise science, which provides coaches with a good tool with which to impact sport and performance (Sarramian et al., 2015). It was found that the type of PAP/PAPE protocols (dryland, water, upper body, lower body or a combination of the two limbs, etc.) had effect on performance. Yet, in all studies, it was found that after PAP/PAPE warm-up, protocol swimmers improve at least one swimming variable on swimming performance. As is already known, the warm up is a well-accepted activity in most sport and impacts

Table 2. Quality assessment/ PEDRo Scale

Criteria:	Selection				Comparability			Outcomes					
Studies:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Score**	**Quality**
Waddingham et al., 2018	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good
Hancock et al., 2015	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5	Fair
Kilduff et al., 2011	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5	Fair
Cuenca-Fernández et al., 2018	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good
Ng et al., 2015	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good
Sánchez et al., 2020	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good
Cuenca-Fernández et al., 2020a	Y	N	N	Y	N	N	N	Y	Y	Y	N	4	Fair
Cuenca-Fernández et al., 2020b	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good
Barbosa et al., 2020	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	Good

PEDro score is obtained by adding points describing the quality of papers, for example, 9–10 (excellent), 6–8 (good), 4–5 (fair), and ≤3 (poor), Yes (Y); No (N). Maher CG, Moseley AM, Sherrington C, Elkins MR, Herbert RD. A Description of the Trials, Reviews, and Practice Guidelines Indexed in the PEDro Database. PhysTher 2008; 88(9): 1068–77.

the body's physiology and primes the athlete to perform at a high intensity with a lower risk of injury (Bishop, 2003). Understanding the specific impact, a warm-up and specifically PAP/PAPE and swimming performance has on time would benefit both coaches and swimmers.

Peak thrust, speed and speed fluctuation in 25 m all-out

In-water test, using arm-pull in front-crawl, while lower-limbs were held by a pull-buoy on a 25 m all-out bout, the findings were that after PAP/PAPE sets, have a large improvement in arm-pull thrust (about 13% to 19%) and a small improvement in performance (almost 3%) when a one arm band pull for each arm PAP/PAPE protocol was applied. Variables commonly used to characterize thrust are strongly correlated (50–75% of variance). Peak thrust and mean thrust were better for PAP/PAPE group vs non-PAP group (Barbosa et al., 2020). Speed and speed fluctuation have no significant differences (Barbosa et al., 2020). In other study (Ng et al., 2020), the researchers assessed front-crawl flutter kick while only holding on to a kickboard after a PAP/PAPE protocol vs Non-PAP/PAPE situation. There was a medium-large enhancement of the kicking thrust in 15,14% (peak thrust) and whereas kinematics and performance improved by 10% (speed and speed fluctuation) after a warm-up that includes PAP/PAPE sets comparing to non-PAP/PAPE situation. In one study (Takagi & Wilson, 1999) using differential pressure sensors on a triathlete, swimming at 0.8 m/s, thrust was noted as ranging between 20–40 N with each arm-pull. In another study, selecting the same set-up, but at 0.90 m/s, authors reported peak force ranging between 35-50 N. The peak force of an US Olympic champion, swimming at 1.66 m/s, was estimated to be 175 N by 3D video analysis and vector computation (Schleihauf et al., 1988). In another study, also on an US Olympic champion, but not reporting the swim speed, the peak thrust in the upsweep was 134N (Higdon, 1979). Conversely, using a tethered technique, the mean thrust and peak thrust were 39N and 158N, respectively (Higdon, 1979). A coupled biomechanical smoothed particle hydrodynamics fluid model estimated a peak force of 250–300 N at 1.45–1.47 m/s, on a highly-skilled Australian swimmer (Cohen et al., 2015). Therefore, if benchmarked with literature, and having as reference the competitive level of the swimmers recruited and the swim speed, thrust values are within the expected range. Although both studies were performed holding a pull-buoy between legs and other using a kickboard on hands, these are variables that could determinate the swimming performance and the mechanisms of pull-arm thrust and flutter kick on swimmers to improve race in competition. If a sprinter races the 100 m freestyle in 50 s, a 2.5–3.0% improvement in performance translates to a 0.98–1.25 s reduction in the final race time. Converting a d=0.18 to percentile gain, it represents a 7% improvement. I.e., everything else being equal, undergoing PAP/PAPE can lead to moving up 7 places in a ranking featuring 100 contenders. According to some studies (De Martino & Rodeo, 2018; King, 1995), the upper-limbs are 90% involved in thrust power and for freestyle is a 80%, while only a 20% for lower limbs, which could not explain the different small results in speed and speed fluctuation by Barbosa et al (Barbosa et al., 2020) when the potentiation protocol is targeting to upper limbs, whereas in lower limbs PAP/PAPE protocols, the speed and speed fluctuation were faster than control (Ng et al., 2020). Therefore, both upper and lower limbs are relevant to improve the swimming performance in race, especially in 25 m distance as evidenced before. It is important to understand due to the large amounts of variables that it is possible to extract, one may wonder how redundant are they. I.e., if these variables can be interpreted interchangeably. More studies are needed to give a conclusion about the different styes and distances.

Rate of force development and power in 15 m maximum effort

Rate of force development (RFD), which is derived from the force or torque time curves recorded during explosive voluntary contractions (Aagaard et al., 2002) hereafter also referred to as rapid or ballistic actions is increasingly evaluated to characterize explosive strength of athletes. In swimming performance could be relevant to develop the RFD to produce fastest movement during the race. In the study Cuenca Fernandez et al. (Cuenca-Fernandez, Batalha, et al., 2020), RFD showed to be higher after DLWU compared to SWU. The force, acceleration and power values were lower in DLWU compared to SWU when the potentiation protocol was performed in dryland. The force, acceleration and power values were lower in DLWU compared to SWU. Therefore, potentiation responses were present after the resistance warm-up, but they were not accompanied by PAP/PAPE effects. however, there are several reasons to discuss why it would be inappropriate to link the effects provided by DLWU with this response mechanism. first of all, as muscle biopsy was not conducted to verify the phosphorylation levels (Vandenboom, 2017), it prevented a conclusion favoring the presence of PAP/PAPE effects. Thus, the results of this study were based on an alternative interpretation provided by the encoder dynamic recordings The peaks reached in force and velocity after SWU were not achieved after DLWU, which seems to be lower average values on these variables. At this point, it is important to note that the RFD in this study was calculated as the slope of the force-time curve. Therefore, the reduction of the slope within the stroke-cycle produced a shorter time to reach the peak, which could result in higher RFD. This fact has been reported in other studies (Blazevich & Babault, 2019; Maffiuletti et al., 2016), where apparent RFD increases did not produced performance enhancements. Mechanic factor are very important to improve the performance in race. This study (Cuenca-Fernandez, Batalha, et al., 2020) concluded that an improvement in RFD is not enough to enhance the velocity, force, acceleration and impulse in 15 m ME, and the water mechanisms are not transferred from DLWU warm up. The improvement of RFD led in fastest strokes but also could explain the shortest length strokes. These could explain the reduction in velocity, acceleration, force and impulse.

Time to 5 m, 15 m, 25 m, 50 m and 100 m freestyle

Cuenca-Fernández et al. (Cuenca-Fernández et al., 2019) found a great improvement in the first meter's race to 15 m under two PAP/PAPE protocols (EWU and RMWU). Time to 5 m was faster in both activation protocols compared SWU (Cuenca-Fernández et al., 2019). The results obtained suggested that protocols based on PAP/PAPE could generate improvements in the first 15 m. Waddingham (Waddingham et al., 2021) also concluded that 15 m start times were significantly quicker in the band squat protocol compared with the sport-specific warm-up condition. However, because of either fatigue or a modification in the swimming patterns, the final performance obtained with the experimental protocols (RMWU and EWU) in Cuenca-Fernández et al (Francisco Cuenca-Fernández et al., 2019) was not better than that obtained with the SWU.

In other studies (Kilduff et al., 2011; Ng et al., 2020) there were not significant differences between SS performance PAP/PAPE stimulus compared to the DS preceded by the SSWU regard time to 15m. It is important to mention that one of the studies did not evaluated the whole body swimming performance, but only assessed the flutter kick performance, which could be relevant in only a 20% of propulsion in freestyle (De Martino & Rodeo, 2018; King, 1995). Cuenca-Fernández et al. (Cuenca-Fernandez, Gay et al., 2020) also found a performance improve at 15 m after the PAP/PAPE in eccentric machine, compared to the standard situation, but not in the subsequent meter marks. However, PAP/PAPE benefits are most effective when a rest period is provided between conditioning exercise and competitive activity (Seitz & Haff, 2016). Reasoning that makes sense if we look at the model proposed by Sale (Sale, 2004), since fatigue and potentiation are two inherent responses to contractile activity and the predominance of one over the other can have a crucial influence on performance. In trained athletes, this state of fatigue can dissipate relatively quickly, while the state of phosphorylation can last up to 5-8 minutes while waiting for the aforementioned maximum muscle contraction to be required by the body.

The other distances did not show significative differences. In the beginning the race, some gains on performance as a consequence of the PAP/PAPE warm-ups were registered on the block. For instance, the improvement on diving velocity after EWU showed that swimmer's flight was longer and faster. In addition, this improved performance was transferred to the swimming time and velocity at the beginning of the race (5 and 10 m marks), where the swimmers have just entered the water and have not executed actions other than gliding or underwater swimming. No differences were found between protocols in 50 m, time to 25 m (MacIntosh, Robillard & Tomaras, 2012; Maffiuletti et al., 2016), this could be due to the great fatigue accumulate after both experimental conditions resulting in a deteriorated kinetics and kinematics variable. Rest interval between conditioning exercise and measurement of performance outcome is also a point of contention in the determination of the most effective use of PAP/PAPE. In Cuenca-Fernández et al (Cuenca-Fernández et al, 2018), only 6 min was given between the potentiation protocol and trial, and a recent meta-analysis indicates that a rest interval of 8–12 minutes provides the greatest benefit, which could explain the reduce of performance (Hancock et al., 2015). In other hand, Hancock et al. (Hancock et al., 2015) noticed that 6 minutes of rest between the conditioning swims, and the 100-m swim was adequate to enhance swim performance. However, some have suggested that true muscle potentiation dissipates as quickly as 5 minutes after a conditioning exercise (MacIntosh et al., 2012).

Hancock et al. (Hancock et al., 2015) has shown that not only 100-m freestyle performance can be improved as a result of a PAP/PAPE loading protocol performed before the event, also the first and seconds 50 m race. For the 100 m race the mean time for the PAP/PAPE trial was significantly faster than the mean time for the control trial when the activation protocol was 4 set of 10 m swimming with an individualized weight being tethered to a system pulley adapted machine. In addition, the PAP/PAPE trial showed a trend for improvement in the first 50-m of 0.26 seconds over the control trial, which is a large margin in sprint swimming where races are routinely decided by tenths and hundredths of a second. The results for the second 50-m split were similar to those of the first, with the PAP/PAPE trial being 0.27 seconds faster than the control trial. It may be hypothesized that the warm up environment plays an important role in the PAP/PAPE protocol and if is applied in swimming pool could be more effective for the swimmer´s sensibility water. Sanchez et al. (Sánchez et al., 2020) demonstrated that pre competition activation protocols based on eccentric contractions performed for upper limbs, lower limbs or mix enhances the swimmer´s men performance in T25EL when added and comparing to a general warm-up. In this sense, the lower volume performed in GEN (500-m) compared to the other protocols (900-m) could have negatively influenced the metabolic changes necessary to improve performance in T25 m (Neiva et al., 2014). However, their PAP/PAPE effect is not observed when added to a specific competition warm-up. Pre-competition activation protocols directed at the upper, lower, or upper + lower limbs seem to offer similar effects, although the latter (combined upper + lower limbs) require more demand and, therefore, could be less efficient.

Velocity in 5 and 50 m

Cuenca-Fernández et al. (Cuenca-Fernández, et al., 2018) assessed the velocity up to 50 m. The results showed that higher velocity was obtained to 5 and 10 m with both experimental protocols EWU and RMWU compared with the SWU protocol. No differences in velocity were found at any point between 15 and 50 m between the 3 protocols applied. It could be concluded the same as before. The lack of fatigue tolerance plays an important role in performance. Although, it does exist an improvement in the first swimming performances speed, the lack of capacities to keep the velocity up to the end of the race or more than 10 m, could be due the need of adaptation to the stimulus and fatigue tolerance. If we observed the result obtained in another study (Cuenca-Fernandez, Gay et al., 2020), after the 6 weeks training, following the application of the PAP/PAPE warm-up, the starting speed increased and swimming time and speed improved at 25, 40 and 50 meters, which suggests that the subjects were capable of attaining a better balance between fatigue and potentiation.

Block time, dive distance, dive velocity, underwater undulatory swimming after swim start, underwater undulatory swimming after turn

According to Cuenca-Fernández et al. (Cuenca-Fernández et al., 2018), and though BT and DD showed no differences, the analyses of the DV and takeoff angle yielded superior values, i.e., faster and higher values, with the experimental protocols, specifically after EWU. In the study was not possible to discern if improvements at start came because swimmers changed the takeoff angle or because lower limbs muscles were potentiated. Nonetheless when the kinetics variables were measured, some improve in performance as a consequence of the PAP/PAPE warm-ups were registered on the block. For instance, some improvement on DV after EWU showed that swimmer's flight was longer and faster. DV demonstrated to be faster for EWU than SWU and RMWU (Cuenca-Fernández et al., 2018), which could be due the differences between PAP/PAPE protocols, where the improvement was seen after the eccentric protocol, this is according to a study (Cuenca-Fernandez, Gay et al., 2020) which analyzed the relationships between specific strength training using an inertia training machine and swimming performance. It was found significant improvements at the 100 m marks, which were associated with the gains in strength and power caused by the training. This study (Cuenca-Fernández et al., 2018), experimented with the effects of a standard warm-up on performance in a speed swimming test compared to a PAP/PAPE warm-up which included specific maximum strength exercises executed on an eccentric training machine. The total distance during underwater undulatory swimming was similar between the 3 protocols studied, both after the swimming start and after the turn. These results in this study (Cuenca-Fernández et al., 2018), could be explained because the warm up protocols are not focus in the whole-body specific technique, specifically, underwater, resulting in a not one-hundred percent transferrable ability to water.

Power vertical force and power horizontal force

Measuring the PVF and PHF is important to understand the starting block in swimming performance and the forces from both variables. The result of starting block jump to the pool comes from PVF and PHF average forces and can be useful for swimmers in SS. The measures were obtained from a star block platform with a 10° elevation. In a study (Kilduff et al., 2011) there was a significative increase in both PVF and PHF after the PAP/PAPE stimulus warm-up vs SSWU. However, there were not differences in 15 m SS between conditioning protocols and standard or individualized race specific warm up. Although these two variables showed an enhancement in the jump from the block start, the results suggested that those variables (if are well-trained) could be relevant to improve the total time race, especially in 15 m race. Breed and Young (Breed & Young, 2003) identified CMJ performance as being significantly related to flight distance attained via grab, swing, and rear- weighted track starts. An additional finding there is a strong negative correlation between lower body strength and time to 15 m. The mechanisms behind the link between strength and starting performance (e.g., power) are probably multi-factorial in nature. For example, heavy-resistance training has been shown to induce hypertrophy within the high force–generating type II fiber isoforms (West et al., 2011) and concomitantly increase the size and number of the sarcoplasmic reticulum (Ørtenblad et al., 2000), thus increasing the rate of release and reuptake of calcium, and improving muscle contraction and relaxation rate (Ross & Leveritt, 2012) all of which would be positive adaptations for increasing power in the swim start. Also, there is a strong relationship between lower body strength and PVF and PHF indicating the important role force production plays in swim starts; this is further supported by the relationship between lower body strength and time to 15 m.

Limitations

One of the important limitations observed in this systematic review is related to the lack of statistical information from a meta-analysis, which could limit the precision of the data to give an exact conclusion of the results. On the other hand, the change of nomenclature from PAP to PAPE was a limitation for the understanding of both concepts, where some researches the potentiation and performance improvement effect were only referred as PAP, instead, now the PAP effect has been widely explained by an increase in the phosphorylation of the myosin light chain that occurs in type II muscle fibers, with or without effects in performance enhancement. Therefore, for the newest researches from 2019, PAP effect by its self, does not explain the whole performance enhancement resulting from the changes in other variables such as: changes in temperature, flexibility, technique and phycological activation, etc., which PAPE does. For these reasons, these concepts (PAP/PAPE) as one was a limitation.

Conclusions

The present systematic review, concluded that PAP/PAPE is one more tool that can be beneficial if it is adapted to the conditions of swimmers (competitive level), controlling fatigue levels, the environment where it is performed (land or water), and most importantly still, described by many coaches worldwide, the specificity of the movement. The most favorable results of the PAP/PAPE in the current review are from movements that focus on swimming gestures, such as: the lunge in the jump height at the start of the platform, the first meters of swimming in a "fly-wheel" device and specific swimming works on a pulley adapted for the so-called "stroke" or swimming arm movement, and when the trial were short distances like 15 m in SS. The negative effect in conditioning protocols were when there was not an adaptation long or middle-term training period for PAP/PAPE and when the fatigue was higher in trial after potentiation protocols. An important aspect in order to obtain benefits from the potentiation protocol is when after the PAP/PAPE stimulus, a time of at least 8 minutes is carried out to guarantee recovery from the fatigue given before the competition or swimming test.

Practical applications

It is common to see swimmers perform different types of warm-ups for training and competitions through ballistic stretching, increasing their breathing and heart rate, or clapping the difficulty of their chest or extremities. Although many of these protocols are common (not being the objective of this review), swimmers are required to integrate protocols that have been studied and proven by sports science and not reject an extra activation protocol. It is recommended that coaches and swimmers include PAP/PAPE in their training protocols, at least for short sprints, and/or to improve the first meters and, finally, based on the results given in this review. The exercises with which they were carried out and saw benefits in the PAP/PAPE can be integrated and adapted to the training as a method of transfer to the aquatic environment, and above all, that the systematic training of the potentiation protocols is trained for at least 6 weeks for it to be adapted to the needs of the swimmers and their tolerance to fatigue.

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Conflict of interest

The author has no conflicts of interest to declare.

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ВПЛИВ ПОСТАКТИВАЦІЙНОГО ПОСИЛЕННЯ РЕЗУЛЬТАТИВНОСТІ НА РЕЗУЛЬТАТИВНІСТЬ ПЛАВЦІВ, ЯКІ ЗМАГАЮТЬСЯ: СИСТЕМАТИЧНИЙ ОГЛЯД

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 12 с., 2 табл., 1 рис., 43 джерела.

Мета дослідження. Метою цього систематичного огляду було оцінити вплив протоколів розминки постактиваційної потенціації/постактиваційного посилення результативності (PAP/PAPE) на результативність плавців.

Матеріали та методи. Пошуки проводили в електронній базі даних на платформах PubMed, Scopus, Web of Science та EBSCO. Були включені дослідження, опубліковані з 2010 року до травня 2022 року, пов'язані з протоколом розминки PAP/PAPE та його впливом на результативність плавання у плавців віком від 18 до 35 років.

Результати. До цього огляду були включені дев'ять із 333 досліджень. У двох дослідженнях максимальна короткочасна тяга покращилася на 13% – 19% для PAP порівняно з не-PAP і на 3% щодо результативності. Одне дослідження показало покращення на 10% швидкості та коливань швидкості на дистанції 25 м із повним застосуванням PAP порівняно з не-PAP. Швидкість зростання сили (RFD) на дистанції 15 м з максимальним зусиллям була вищою для розминки на суші (DLWU), ніж для розминки під час плавання (SWU). Одне дослідження показало вищу швидкість на дистанції 5 м для розминки з повторним максимумом (RMWU) і розминки на ексцентричному маховому колесі (EWU) порівняно з розминкою під час плавання (SWU). Одне дослідження продемонструвало покращення для PAP верхньої частини тіла (UBPAP), PAP нижньої частини тіла (LBPAP) і змішаного протоколу розминки MIX (UBPAP/LBPAP) порівняно з розминкою на основі загальних вправ (GEN) у часі на дистанції 25 м вільним стилем (T25FS). Два дослідження виявили покращення для присідань зі стрічковим еспандером за протоколом розминки PAP порівняно зі спеціальною розминкою для плавання (SSWU) у часі на дистанції 15 м. Одне дослідження продемонструвало, що спроба за протоколом розминки PAP (PAPT) була швидшою за контрольну спробу на час (CTT) на дистанції 50 м і 100 м вільним стилем. Швидкість занурення (DV) була вищою для RMWU/EWU порівняно з SWU. Одне дослідження показало значне збільшення вертикальної складової сили (PVF) і горизонтальної складової сили (PHF) після PAP порівняно з SSWU.

Висновки. Протокол розминки PAP/PAPE – це ще один інструмент, який може бути корисним, якщо його адаптувати до фізичних кондицій плавців, контролюючи рівні втоми, середовища його виконання (земля чи вода), а головне, описане багатьма тренерами, специфіки руху.

Ключові слова: постактиваційна потенціація, постактиваційне посилення результативності, результативність плавання.

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