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Psychophysiological and performance-related responses of a potentiation activity in swimmers of different competitive levels

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ABSTRACT

Athletes' competitive level has an effect on several psychophysiological parameters during the execution of sports-related tasks. This study analyzed the acute effect of a potentiation activity (PAP), composed by 5 loaded box jumps, on specific psychological, physiological and performance-related parameters in 22 trained (COM) and untrained (UNT) adult male swimmers. A control condition was also evaluated. Measurements included the Competitive State Anxiety Inventory, rate of perceived exertion, lower limbs muscle oxygenation, exercise heart rate, vertical jumping ability, 3 different split times and total time-trial performance during an all-out 50-m swim test executed using the breaststroke technique. In addition, total swim strokes and the optimal individual response after the potentiation activity were measured. No significant differences among the two testing conditions were found for all psychological, physiological and performance-related parameters ($p > .05$) with the exception of total performance time in the UNT group after the PAP condition (41.5 ± 5.3 vs. 41.9 ± 5.5 s; $p = .023$; ES = 0.6). As expected, the COM group showed enhanced swimming performance during all split times and total time, compared to the UNT group. These results suggest that (i) independently of the training level, psychological responses during sports-related tasks are probably not evident under non-competitive situations and, (ii) competitive level athletes may need more challenging activation stimulus, compared to their less competitive counterparts, to induce the desirable adaptations on the subsequent main activity.

1. Introduction

The enhancement of human performance during the execution of sports-related tasks is the main issue for athletes and coaches. Towards this direction, numerous training methods and techniques have been developed. For instance, a high-intensity muscle action may acutely increase performance during the subsequent strength or power activity. This phenomenon, usually referred as post activation potentiation (PAP) has been well studied in various sports [1,2], proposing a significant practical application. The underlying suggested physiological mechanisms responsible for the PAP during training or an actual competition have been described in detail [3], while it can be characterized as an individualized and multifaceted phenomenon [4], since training characteristics, gender and chronological age, among others, can affect the magnitude of PAP response [5,6].

In competitive sprint swimming, a sports discipline characterized by high rates of force production by the muscles aiming to *overcome the hydrodynamic resistance* [7], PAP may have an important practical application. Indeed, previous studies highlighted the acute positive effects of a PAP stimulus on the subsequent front-crawl sprint performance during the 50 and the 100-m events [8–13]. In most of these cases, different dry-land potentiation protocols have been used as a complementary activity to the traditional in-water warm- up, mainly focusing on the upper extremity and examining specific physiological variables, namely, exercise heart rate, core temperature, and blood lactate concentration. Apart from the above-mentioned variables, near-infrared spectroscopy device has been recently used as a field performance evaluation tool in swimming, enabling the measurement of muscle oxygenation [14,15]. This procedure is proposed as an attractive alternative to evaluate exercise intensity in swimmers, to the "traditional" blood lactate measurement [16].

Psychological factors play a significant role in sport-related performance [17]. These factors' positive contribution may be overlooked as their *detection* may *seem obscure, comparing to the tangible results of the more "simplistic" physiological factors* [18]. Performance anxiety, for instance, is considered to be a common psychological factor, usually

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manifested as a situation-specific or "state" anxiety [19]. This factor includes both cognitive and somatic components, frequently measured using specific inventories, such as the Competitive State Anxiety Inventory-2 (CSAI-2) [20]. Despite some criticism, CSAI-2 is considered a simple, reliable and valid tool to assess competitive state anxiety [21]. Although it is generally experienced as an "unpleasant condition", at certain levels, pre-competitive anxiety can be beneficial during sports situations, by increasing the readiness state of athletes [22]. Moreover, cognitive anxiety has been identified as a significant predictor of swimming performance [23].

Both PAP response and performance-state- anxiety seems to be influenced by the athletes' competitive level. More analytically, higher level athletes, in terms of resistance training experience, can realize greater performance improvements after a PAP activity compared to the less experienced counterparts [24], whereas athletes involved in power-type sports exhibited greater potentiation effect that the recreational-type athletes [25]. Likewise, a stronger negative relationship between anxiety and performance was presented in lower level athletes according to an older meta-analysis [26]. In the line of the above, it would be interesting to examine the possible short-term adaptations following a PAP protocol in two groups of athletes categorized according to their competitive level, analyzed from both physiological and psychological perspectives. Thus, the aim of the present study was to investigate the effects of a potentiation activity focused on activating the lower-body muscles on specific psychophysiological parameters and sprint *breaststroke* swimming performance in trained and untrained swimmers. Based on previous observations, our hypothesis was that the trained individuals would exhibit more profound short-term adaptations after the potentiation activity.

2. Material and methods

2.1. Design

In this study, a within-subject design was used to analyze the effect of a potentiation activity, targeting the lower body muscles, on a variety of psychological (cognitive and somatic anxiety, subjective rate of perceived exertion), physiological (exercise heart rate, muscle oxygenation), stroke cycle parameters (number of swim strokes completed), split times (10 m, 25 m and 50 m sectors) and 50-m breaststroke swimming performance in 2 groups of swimmers classified according to their level of competition.

2.2. Participants

Twenty-two male adult swimmers were equally divided into two groups, one consisting of competitive level swimmers (COM*:* $n = 11$; age: 20.3 ± 1.8 years; body height: 179.7 ± 6.9 cm; weight: 77.6 ± 6.6 kg; training experience: 14.4 ± 2.4 years; FINA 2018 scoring points: 629.3 ± 78.0) and one composed by previous trained swimmers (UNT*:* $n = 11$; age: 21.8 ± 0.8 years; body height: 179.8 ± 6.3 cm; weight: 80.3 ± 11.2 kg; training experience: age: 10.4 ± 3.6 years). Swimmers from the COM group were recruited from 2 different clubs and trained approximately 18.0 ± 2 h per week by the time that this study was conducted, specialized in various race distances and swim techniques. In addition, they were all placed within the top 8 national ranking in their respective events. On the other hand, participants from UNT group were nonactive athletes for a minimum time of 6 months prior to the beginning of the study, while they also reported a wide variety of swim training background. All participants were familiar with the potentiation activity applied in this study. Before any testing procedure, written informed consent was signed from all participants. Effort was made to maintain the same training volume and intensity, as well as their normal diet, the day before testing. The study was approved by the university's institutional review board and conducted in accordance with the Declaration of Helsinki.

2.3. Procedures

Participants were engaged in 3 testing sessions. In the 1st session, anthropometric (body height and weight) and training characteristics (years of experience, distance specialty, preferred swimming stroke and best swimming time) were recorded. As recovery time between a conditioning activity and the "target" exercise can affect the magnitude of a PAP response [24], the optimal individual time was also measured in this session (PAP OIT). Analytically, swimmers initiated their warm-up on a stationary cycle-ergometer (Bike xt, Technogym) with the pedaling cadence set at 50-60 rpm for 5 min. Following a routine composed by dynamic stretching and a set of vertical jumps, the PAP OIT was examined. In this procedure, each swimmer's best vertical jump height during an unloaded condition was measured. Afterward, they executed the PAP activity that included 5 loaded jumps, with a weighted vest, onto a 40 cm box. No arm movement was allowed. The external load used was *equivalent* to *10*% of each participant's body weight, with a self-selected depth [12]. Finally, to ensure an equal effort the distance between the box and the take-off point was adjusted according to each swimmer's lower limb length. Three different jumps were executed at the 4th, 8th and 12th minute after the PAP activity [10]. For this measurement, a portable photocell system (Optojump, Microgate, Bolzano, Italy) was employed. The minute that the highest score was achieved was used as a reference point between the PAP activity and the 50-m swim max test.

During the 2 subsequent swimming testing sessions, participants were randomly assigned to either the PAP or the control condition (CON). Each training session was separated by a 1-week period. All the procedures were conducted during the same period (May) and in the daytime (9:00–11:00 h), under the same water temperature (26–27 °C) in an outdoor 50-m swimming pool.

2.4. Swim testing sessions

The swim testing sessions began with an in-water warm-up, with the same structure (continuous swimming/arm and kick drills/short sprints/cool down), but of different total volume (1100 vs. 600 m for the COM and UNT groups, respectively). After completing the in-water warm-up, each swimmer was assigned to 1 of the 2 swim testing sessions; during the PAP condition, participants rested for 15 min before executing the 5 loaded jumps. Following, according to their PAP OIT previously measured, they performed the 50-m swim trial. In the CON condition, the swimmers remained seated throughout a 20-min transition phase (i.e., between the in-water warm-up and the 50-m swim trial).

All swim tests were performed at a maximum effort. Two experienced researchers timed each swim trial individually with a commercial stopwatch (Seiko S141, Japan) and the mean value was used for further analysis. Swimmers were instructed to begin with an in-water push start and avoid underwater gliding [8]. Exercise heart rate (HR) was determined with a strap (Polar S610 Electro, Kempele, Finland) attached to the participant's chest immediately after the 50-m test.

Muscle oxygenation measurement was conducted before (served as baseline values) and immediately after each 50-m swim max trial. A Near-Infrared Spectroscopy (NIRS) portable apparatus (MOXY, Fortiori Design LLC, Hutchinson, Minnesota, USA) was used to monitor changes in two specific muscle oxygenation parameters, namely muscle oxygen saturation (SmO_2) (expressed in %) and total hemoglobin (tHb) in the rectus femoris muscle of the dominant leg of the participants. The apparatus was placed in the middle distance of the femoral condyle and the superior edge of the patella. The thigh skinfold of the dominant leg was assessed with a Lange skinfold caliper (Lange skinfold caliper (Cambridge Scientific Instruments, Cambridge, MD) to ensure that skinfold thickness was less than half the distance between the emitter and the detector in all swimmers (25 mm). SmO_2 expressed as a percentage (%) and tHb values are reported in micromolar centimeter units (μM cm^{-1}).

Regarding the psychological measures, rating of perceived exertion (RPE) (Borg scale 0–10) was recorded after the end of each swim test, while the CSAI-2 *was administered* to *participants* approximately 10 min before each 50-m swim trial [27].

A digital video camera (50 Hz, Nikon, L840, China) was placed in the middle 12.5-m of the pool, with reference marks set at 10 and 25-m, while the swimmers' head was used as the reference point. This design allowed swimming time to 10-m (t.10-m) and 25-m (t.25-m) to be calculated (split times). The final time (t.50-m) minus t.25-m was used to estimate the second half of the swim trial. In addition, total swim strokes were measured throughout each 50-m effort. The Kinovea software (version 0.8.24) was used for video analysis. No feedback related to swimming performance was given to participants until the completion of the swim tests [28].

2.5. Statistical analysis

Normal distribution of the data was tested using the Shapiro-Wilk test. Sphericity was verified by the Mauchly's test. When the assumption of sphericity was not met, the significance of *F*-ratios was adjusted according to the Greenhouse-Geisser procedure. Two-way analysis of variance with repeated measures on pool conditions factor (two-way ANOVA) was used to compare the psychological (somatic, cognitive anxiety and RPE), physiological (SmO_2, tHb, HR) and performance-related parameters (time splits: t.10-m, t.25-m, t.50-m, 50 m swimming time), as well as stroke cycle kinematics (total swim strokes) (2 groups (trained − untrained) × 2 pool conditions). To analyze the differences between trained and untrained swimmers, an independent sample *t*-test was applied, while in order to examine the differences between the 2 pool conditions separately on trained and untrained swimmers, a paired sample t-test was used. Cohen's d effect sizes (d = difference between means ÷ pooled SD) were calculated for the difference between means. The small, medium and large effects were reflected in values > 0.20, 0.50, 0.80, respectively [29]. All statistical tests were processed using the SPSS statistical package (v. 21; SPSS Inc.; Chicago, IL, USA). The level of significance was set at $p \leq .05$. Data are reported as mean ± *SD*.

3. Results

According to two-way Anova, a non- significant interaction between groups and pool conditions was revealed regarding the cognitive and somatic anxiety values ($p > .05$). Split performance (t.10-m, t.25-m, t.50-m) and 50-m maximum performance time also showed non-significant interaction ($p > .05$). Similar results were obtained for the total swim strokes, as well as SmO_2, tHb and HR values ($p > .05$). COM group demonstrated faster split and 50-m maximum performance time, compared to the UNT group ($p = .011$ to 0.028; $ES = -0.19$ to 0.47 [small to medium effect]). RPE and PAP OIT values were identical for the two groups. Paired sample *t*-test analysis revealed almost similar values between the different pool conditions within the two groups regarding all psychological, physiological, and performance-related parameters (Tables 1 and 2). As an exception, the UNT group achieved faster 50-m performance time after the PAP condition (Table 2). SmO_2 and tHb baseline values were no different between pool conditions in both groups.

4. Discussion

This study has, for the first time, analyzed the acute effects of a potentiation activity on both psychological, and physiological parameters, as well as sport-related performance in 2 groups of adult male swimmers differentiated by their competitive level. As previous studies were limited to evaluating the potential effect of a conditioning activity on sprint swimming performance using the front-crawl technique, we

Table 1
Psychological, physiological and performance-related parameters in the 2 pool conditions for COM group.

	PAP	CON	Statistical analysis (*p* and [d])
Psychological parameters			
Somatic	14.8 ± 5.4	14.9 ± 5.7	.569 [0.23]
Cognitive	14.0 ± 3.6	13.9 ± 3.9	.322 [0.14]
RPE (0−10)	6–7	6–7	
Physiological parameters			
SmO_2 (%)	73.2 ± 11.2	69.5 ± 13.5	.870 [−0.28]
tHb (μM cm^{-1})	10.5 ± 1.1	10.3 ± 1.7	.360 [−0.14]
HR (bpm)	157.7 ± 13.2	156.6 ± 13.5	.630 [0.05]
Performance-related parameters			
t.10-m (s)	5.8 ± 0.4	5.9 ± 0.3	.561 [0.15]
t.25-m (s)	11.0 ± 1.0	11.2 ± 1.0	.069 [0.24]
t.50-m (s)	19.7 ± 1.6	19.8 ± 1.6	.530 [0.07]
50-m (s)	36.7 ± 2.5	36.7 ± 2.7	.949 [0.01]
Total swim strokes	28.6 ± 3.8	29.0 ± 3.1	.410 [0.13]
CMJ (cm)	37.7 ± 5.3		
PAP OIT (min)	8		

COM: competitive swimmers; UNT: previous trained swimmers; PAP: potentiation activity; CON; control condition; somatic: somatic anxiety measured by CSAI questionnaire; cognitive: cognitive anxiety measured by CSAI questionnaire; RPE: rate of perceived exertion; t.10-m: swimming time to 10-m; t.25-m: swimming time to 25-m; t.50-m: swimming time to 50-m; 50-m: 50-m maximum swimming time; total swim strokes: total breaststroke arm movements executed during the 50-m trial; CMJ: countermovement jump; PAP OIT: optimal individual time after the potentiation activity; SmO_2: muscle oxygen saturation at the end of the maximum 50-m test; tHb: total hemoglobin at the end of the maximum 50-m test; HR: exercise heart rate at the end of the maximum 50-m test; *p*: significance value; [d]: effect size.

Table 2
Psychological, physiological and performance-related parameters in the 2 pool conditions for UNT group.

	PAP	CON	Statistical analysis (*p* and [d])
Psychological parameters			
Somatic	13.1 ± 3.3	14.3 ± 3.3	.887 [0.34]
Cognitive	14.2 ± 4.0	15.1 ± 4.2	.211 [0.18]
RPE (0–10)	6–7	6–7	
Physiological parameters			
SmO_2 (%)	69.4 ± 14.4	71.9 ± 18.4	.104 [0.16]
tHb (μM cm^{-1})	10.8 ± 1.2	11.0 ± 1.6	.665 [0.14]
HR (bpm)	163.6 ± 9.0	161.5 ± 9.1	.268 [−0.22]
Performance-related parameters			
t.10-m (s)	6.3 ± 0.7	6.7 ± 1.0	.131[0.48]
t.25-m (s)	12.2 ± 1.6	12.6 ± 1.6	.117 [0.21]
t.50-m (s)	22.9 ± 3.4	22.6 ± 3.4	.414 [−0.10]
50-m (s)	41.5 ± 5.3	41.9 ± 5.5	.023* [0.06]
Total swim strokes	33.1 ± 6.6	32.7 ± 6.2	.307 [−0.06]
CMJ (cm)	34.2 ± 3.1		
PAP OIT (min)	8		

COM: competitive swimmers; UNT: previous trained swimmers; PAP: potentiation activity; CON; control condition; somatic: somatic anxiety measured by CSAI questionnaire; cognitive: cognitive anxiety measured by CSAI questionnaire; RPE: rate of perceived exertion; t.10-m: swimming time to 10-m; t.25-m: swimming time to 25-m; t.50-m: swimming time to 50-m; 50-m: 50-m maximum swimming time; total swim strokes: total breaststroke arm movements executed during the 50-m trial; CMJ: countermovement jump; PAP OIT: optimal individual time after the potentiation activity; SmO_2: muscle oxygen saturation at the end of the maximum 50-m test; tHb: total hemoglobin at the end of the maximum 50-m test; HR: exercise heart rate at the end of the maximum 50-m test; *p*: significance value; [d]: effect size.

* Significant at $p \leq .05$ value.

chose in this work to implement the breaststroke technique and, therefore, target on the lower limbs since their relative contribution to the horizontal propulsion is considerably higher, compared to the other 3 swimming techniques [30]. In addition, a 3-time point analysis during the maximum swim tests was performed. According to the results, the potentiation activity executed had no significant effect on any of the parameters tested, while in the UNT group it was only the 50-m performance time that was enhanced after the PAP activity. As expected, the COM group demonstrated higher performance values regarding all split- and 50-m performance times, compared to the UNT group.

4.1. Effect of the potentiation activity on psychological parameters

In most of the cases, previous studies examining psychological responses in athletes have either focused on the anxiolytic effects of exercise [31] or sport-related anxiety emphasizing on injury prevention and rehabilitation [17]. In specific cases, however, the competitive level was also analyzed presenting discrepancies between elite and non-elite athletes with reference to the intensity of anxiety symptoms [32] *or indicating competitive level as an important parameter towards the augmentation of the subsequent swimming performance, through positive interpretation of anxiety symptoms* [33]. Considering that the aforementioned studies were conducted under real competitive situations, we can speculate that the research setting followed in our study influenced the participant's anxiety perception, resulting in neutral results. In fact, this finding is previously confirmed in 2 groups of competitive tennis players, where real competitive environment resulted to more pronounced psychological responses [27].

4.2. Effect of the potentiation activity on performance-related parameters

Competitive level has been indicated as a factor affecting PAP responses in different sports [24]. However, in this study, the potentiation activity performed (5 jumps with 10% of individual's BW) was probably insufficient for eliciting acute positive responses in the COM group. Similar to the results of the current study Serramian et al. [13], involving the same experimental design concerning the potentiation activity in male National level swimmers, denoted a non-significant effect on participants' 50-m maximal front-crawl performance. In contrast, the UNT group achieved faster 50-m performance time after the PAP condition.

To our knowledge, this is the first study that analyzed 3 different split times after a potentiation activity during a 50-m all out swimming trial. This research design was put forth in order to identify any possible differences regarding acceleration (t.10-m), maximum speed (t.25-m) and maintenance phase (t.50-m). In agreement with previous results analyzing the effect of a high-intensity potentiation activity (1 set of 3 repetitions at 87% of each participant's 1 repetition maximum on the back-squat exercise) on the subsequent 15-m swimming performance time with a dive start [10], no differences were identified regarding t.10-m, as well as t.25-m and t.50-m splits in both groups.

In the present study an effort was made to control the components that can influence PAP responses (i.e., optimizing the time interval between the potentiation activity and the main activity, specifying the prior activity to the subsequent swimming test, limiting participation by male athletes only) it is likely that the relative low-intensity-high velocity conditioning activity applied here was the key factor explaining the absence of any positive effects, especially for the COM group. It should be noted here that both pool conditions were executed with equal intensity as indicated by HR values in both groups. Interestingly, no differences were observed between groups regarding the total swim strokes, the CMJ, and the PAP OIT values.

4.3. Effect of the potentiation activity on physiological parameters

Sensitivity of muscle O_2 during exercise and recovery kinetics on athletic performance and training-induced muscle adaptations have been previously demonstrated [34,35]. Since this is the first study that implemented muscle oxygenation measurement in swimmers' lower limbs, the NIRS apparatus was positioned on the rectus femoris muscle as previously applied during the evaluation of the breaststroke swimming kick, measured using the motion capture technique [36]. In agreement with the findings of other reports [34,37], no differences were found between the 2 groups regarding rectus femoris muscle oxygen kinetics. Although these results are relatively clear, the interpretation is somewhat difficult. Possible limitations to the interpretation of the NIRS signal have been also noted in the study of Ihsan et al. [34]. This can be possibly attributed to the large between-subject heterogeneity in photon scattering in the tissues, and to potential changes in tissue absorption and scattering that could not have been corrected with the present NIRS system; these limitations, however, are unlikely to dramatically affect the interpretation of our results.

The NIRS derived tHb signal is generally an accepted indicator of blood volume changes during exercise [38]. This variable has been previously shown to be sensitive to training-induced skeletal muscle adaptations [39] and has been used to investigate hemodynamic changes during exercise [40]. In the present study, no differences were found between the 2 groups for rectus femoris muscle tHb.

It is well recognized that the NIRS-derived tHb signal may also be influenced by the interaction of other factors such as microvessel vasodilation, intramuscular pressure changes and capillary recruitment [41,42]. The alterations in tHb values can partially be explained by the combined effect of increased intramuscular pressures, and probably by a possible time lag in the activation of local muscle vasodilatory factors [42,43]. Concerning the recovery phase, this may be facilitated by a reduced sympathetic outflow, increased muscle blood perfusion, capillary recruitment and activation of local vasodilatory factors [42–44]. Since these factors are all modified by exercise training [35], further investigation is required to examine their contribution. In any case, and despite the above-mentioned limitations, NIRS technology can be used as a noninvasive assessment tool for analyzing activation of specific muscle groups or monitoring training-induced changes during different training periods through field testing in swimming [38].

As earlier mentioned, PAP can be characterized as an individualized phenomenon. As such, further analysis of the data based on visual inspection revealed an intra-individual variability in all split times and 50-m swimming performance in both groups. Analytically for the COM group, 8 swimmers responded positively to the PAP condition, showing a mean 50-m performance improvement of 1.52%, while for the UNT group, 7 athletes swum faster after the PAP condition, with a respective mean 50-m performance improvement of 1.38%. This magnitude of improvement can be characterized as noteworthy since a seasonal 1.03% performance increase for the 50-m swimming event has been noted for male National-level swimmers [45]. For both groups, even no statistically significant, t.25-m was the time split that the largest performance enhancement was noticed after the PAP condition (1.98 and 1.66%, for COM and UNT groups, respectively). These observations should be taken into account by swimming coaches when designing potentiation protocols, while more considerations of the applicability of PAP protocols may include sex-related differences regarding the force-velocity characteristics and their separate evaluation during swimming [46].

An obvious limitation of the current study is the lack of an electronic time recording system regarding the 50-m maximum performance times. Even so, the 2 research collaborators that were recruited for the task were experienced and certified timekeepers, while caution was given in order to assess the same participants in each pool condition. Finally, it seems reasonable to suggest that the findings presented here are limited to sprint distance events employing the breaststroke swimming technique.

5. Conclusions

In summary, the current study indicates that the specific psychological and physiological parameters tested were not influenced by the different competitive level of the participants. Moreover, the potentiation activity executed was not sufficient enough to induce the desirable acute adaptations in the group composed by National- level male swimmers. Since no differences in muscle oxygenation variables were obtained, probably this procedure is not efficient to detect acute exercise-induced changes caused by one single set of loaded box-jumps. Finally, it is suggested that psychological responses should be measured under real competitive situations and individual responses should be taken into account by coaches to optimize potentiation-induced changes. The results reported in this study may contribute to a better understanding regarding the acute physiological responses after a PAP protocol in sprint swimming.

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Declarations of interest

None.

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