Ahead of print DOI: 10.2478/hukin-2021-0068

Post-eccentric flywheel underwater undulatory swimming potentiation in competitive swimmers

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Acknowledgements

This work was supported by the Spanish Research Agency and European Regional Development Fund (ERDF) under Grant: DEP 2014-59707-P "SWIM: Specific Water Innovative Measurements applied to the development of International Swimmers in Short Swimming Events (50 and 100M)" and under Grant: PGC2018-102116-B-I00 "SWIM II: Specific Water Innovative Measurements: applied to the improvement in performance".

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Abstract

Underwater undulatory swimming (UUS) influences overall swimming performance, therefore swimmers should try to maximize it. This research aimed to: 1) assess the effects of an activation protocol based on post-activation performance enhancements upon UUS; and 2) evaluate the differences between males and females. Seventeen competitive swimmers (male = 10; female = 7) participated in a cross-sectional study designed to test performance in UUS at 10 m after a traditional swimming warm-up (TRA) and after adding to the TRA 4 maximal half-squat repetitions on an inertial flywheel device (PAPE). A speedometer and an electronic timing system were used to obtain kinematic variables such as time, frequency and velocity at 10-m, which were processed with MATLAB®. A paired sample *t* test was applied to determine the differences of the kinematic variables between the TRA and PAPE. An independent sample *t* test was used to determine the effects of the PAPE in males and females. Participants reduced the time to cover 10 m after PAPE compared to the TRA (males: 5.77 ± 0.44 to 5.64 ± 0.46; females 6.34 ± 0.80 to 6.09 ± 0.66; $p < 0.05$). In addition, trends towards improvements in UUS velocity were obtained for males and females. However, push-off velocity and frequency showed a different tendency between genders ($p < 0.05$). In conclusion, the warm-up including repetitions on the flywheel device improved UUS performance. Some differences were obtained between

genders after PAPE. Further research should confirm if the benefits obtained after the eccentric overload would depend either on gender or on other components such as fiber type composition.
Key words: Performance, strength, resistance, testing, training.

Introduction

The use of high-intensity resisted voluntary conditioning exercises during the warm-up has been reported in recent literature as post-activation performance enhancement (PAPE) (Cuenca-Fernández et al., 2017). This method has shown to exhibit short-term potentiation on performance as long as it ensures activation over fatigue (Seitz and Haff, 2016). Some studies have tried to explain mechanisms that influence PAPE by examining post-conditioning activity rest intervals offering varied and conflicting results (Blazevich and Babault, 2019). To date, while some suggest that potentiation responses after short recovery periods (< 5 min) are regulated by the myosin head phosphorylation (Boullosa et al., 2020; Vandenboom, 2011), some others report that the PAPE effects after moderate recovery periods (5-12 min) could be a consequence of the enhanced cross-bridge cycling rates obtained after elevating muscle temperature (González-Alonso et al., 2000; Seitz et al., 2016). Some of the effects have been reported after an extensive recovery period (10-18 min), what could be explained by reductions in the pre-synaptic inhibition or increases in motoneuron excitability that may persist to that length of time after voluntary muscle contractions (Blazevich and Babault, 2019).

Competitive athletes may offer highly different responses influenced by some intrinsic characteristics, such as the fiber-type distribution, muscular strength or training background (Seitz and Haff, 2016; Wilson et al., 2013). In this regard, it has been reported that the PAPE phenomenon lacks optimal standards for both volume and intensity (Kobal et al., 2019). For instance, speed-power athletes (e.g. sprinters and jumpers) could benefit more from brief, high-intensity conditioning activities, while endurance athletes (e.g. marathon runners and triathletes) would benefit more from submaximal prolonged conditioning activities due to an optimized balance between fatigue and potentiation (Boullosa et al., 2020). In addition, while some authors reported that PAPE effects do not differ significantly between genders (De Renne, 2010; Timon et al., 2019; Wilson et al., 2013), some others have shown increases in performance solely in men (Arabatzi et al., 2014; Krzysztofik et al., 2020; Sarramian et al., 2015), or a trend towards improvements more pronounced in women (Jensen and Ebben, 2010). Therefore, a question arises whether PAPE effects may be particularly regulated by sex.

On the other hand, previous studies stated that the higher the specificity of the stimulus provided by the conditioning exercise (CE), the larger the PAPE benefits (Wilson et al., 2013). This has led many researchers to test dry-land resistance exercises simulating sporting activities (Seitz and Haff, 2016). However, the main regulatory PAPE responses have been recently unrelated to the localized effects caused by post-activation potentiation (PAP) (Blazevich and Babault, 2019; Cuenca-Fernández et al., 2017), a muscle response mechanism originated from the localized contraction-induced effects in the muscle-myosin head phosphorylation (Vandenboom, 2011). Thus, there is no evidence supporting the need to achieve full simulation of the real movement during conditioning protocols to induce PAPE, but rather evidence in favor of sufficient stimulation of the muscular system to achieve those responses (Beato et al., 2019; Boullosa et al., 2020; Cuenca-Fernández et al., 2020).

Explosive modalities such as jumping and throwing have always obtained better outcomes than others related with endurance or cyclic sports after brief bouts of high-resistance protocols (Kobal et al., 2019; Krzysztofik et al., 2020; Seitz and Haff, 2016; Timon et al., 2019; Wilson et al., 2013). Specifically in swimming, the most significant results have been frequently obtained in the kinetic and kinematic variables collected from the swimming start performance (Cuenca-Fernández et al., 2015; Kilduff et al., 2011), with remarkable effects reported after eccentric overload protocols conducted on flywheel devices. In this regard, although applying this type of the activation protocol seems unfeasible in competition (a specific piece of equipment is required while athletes are waiting in the call-room); the superior influence of these procedures in stimulating the lower limbs musculature has been demonstrated under experimental conditions (Beato et al., 2019; Maroto-Izquierdo et al., 2017; Timon et al., 2019). In any case, other warm-up interventions have also attempted acute short-term enhancements in different components of the swimming race such as: the swimming stroke kinematics (Neiva et al., 2014; Sarramian et al., 2015), the stroke kinetics (Barbosa et al., 2020; Cuenca-

Fernández et al., 2020; Neiva et al., 2011), and the leg-kicking thrust (Ng et al., 2020), revealing the warm-up's importance in stimulating the physiological and biomechanical adjustments intended for the race (Neiva et al., 2014).

However, to date little or no concern has been given to the study of the specific effects provided by PAPE protocols on underwater undulatory swimming (UUS), the swimming technique used to propel forward following the starting dive and during the underwater phases at the start and turns (Atkison et al., 2014; Connaboy et al., 2009). Possibly, as swimming start performance is an explosive extension movement intended to propel the swimmer forward through the air (Cuenca-Fernández et al., 2015), this has gathered major interest for the PAPE protocols. However, it is well known that no matter what the obtained performance outcome is in 15 m after the start, it may not only be attributed to the gains in power and impulse generated by the potentiation protocols on the block, but also to performance displayed during UUS. In fact, the highest velocities reached by swimmers in the water are achieved through UUS by adopting a streamlined position with arms outstretched and held together over the head while performing body undulations (Collard et al., 2013). In addition, considering that it is a leg-dominated exercise and legs have a greater propulsive surface and stronger musculature than the arms (Connaboy et al., 2016), UUS has the potential to produce lower resistance and higher thrust than free swimming on the surface (Vennel et al., 2006). Thus, this highlights the importance of UUS on overall swimming performance.

Some of the aforementioned studies have pointed out several kinematic variables based on different manifestations of velocity and frequency over time which have shown to be valid to assess the propulsion and efficiency developed during UUS (Atkison et al., 2014; Connaboy et al., 2016). However, only one peer-reviewed approach has focused on conducting a mid to long-term experimental program in order to improve the technical aspects and performance on such variables (Collard et al., 2013). Therefore, it seems that UUS performance has shown to be measurable, but it is still needed to determine if UUS is also sensitive to changes provided by specific training protocols. In this regard, if we consider the significant responses reported on lower limbs in the literature after eccentric overload exercises (Beato et al., 2019; Maroto-Izquierdo et al., 2017) and the combined nature of shortening and lengthening cyclic-explosive movements that UUS is characterized for (i.e., from the downbeat to the upbeat of the kicking undulation), it is intriguing to see whether some acute short-term enhancements may be found after a voluntary conditioning exercise based on high-resistance eccentric/concentric transition through flywheel devices (Timon et al., 2019).

For such reasons, the first aim of this study was to assess the effects of a post-eccentric flywheel squatting protocol upon UUS performance and kinematic variables. Our hypothesis was that a specific activation protocol combining high-resistance eccentric and concentric repetitions would improve UUS performance as a consequence of stimulating the muscular system of the lower limbs. As a secondary aim, the differences in the PAPE responses were explored between males and females. Given that the evidence suggests that PAPE responses are elicited as long as sufficient stimulation of the muscles is achieved, our hypothesis was that the activation protocol would improve performance in both genders.

Methods

Participants

Seventeen competitive swimmers, (> 5 years of training experience) volunteered to participate in the study. Swimmers under the age of 18 were asked to provide parental consent. The main physical characteristics of male (n = 10) and female (n = 7) swimmers were (mean ± SD): 16.60 ± 2.01 and 15.42 ± 1.81 years old, 76.61 ± 9.12 and 59.43 ± 8.23 kg of body mass, 1.81 ± 0.03 and 1.62 ± 0.05 m of body height, respectively. The competitive swimmers background was for males: 29.64 ± 2.46 s; FINA points: 402 ± 120, and for females: 31.36 ± 1.93 s; FINA points: 483 ± 102 (long course 50-m freestyle personal best). Before the commencement of the study, swimmers received information about the experimental procedures and possible associated risks. All of the procedures were performed in accordance with the Declaration of Helsinki with respect to human research, and the study was approved by the University ethics committee.

Measures

Velocity data were recorded by a speedometer during the UUS maximal efforts, A-D converted (Signal Frame MF020, Sportmetrics, Spain) and analyzed in MATLAB 2013a (MathWorks Inc., Natick, Mass., USA). The encoder voltage was recorded at 200 Hz. A fourth order Butterworth low pass digital filter, with a cut off frequency of 6 Hz, was used to smooth the velocity-time curves. Swimmers were asked to start kicking immediately after leaving the wall, but the first two kicks were discarded to avoid the effects of the pushing.

Therefore, analysis comprised from the third to the sixth kick performed. The following variables were calculated for every UUS effort in MATLAB 2013a (Figure 1):

- - Push-off velocity ($m \cdot s^{-1}$): highest value obtained from the individual velocity-time curve.
- - Average underwater velocity (Uavg) ($m \cdot s^{-1}$): mean of velocity values recorded using the speedometer during 4 selected mid kicks.
- - Average underwater peak velocity (Upeak) ($m \cdot s^{-1}$): mean of velocity peaks recorded using the speedometer during 4 selected mid kicks.
- - Average underwater minimum velocity (Umin) ($m \cdot s^{-1}$): mean of minimum velocity recorded using the speedometer during 4 selected mid kicks.
- - Kick frequency (Hz): the 4 selected kicks divided by the time spent to perform them.
- - Time to cover 10 m (s) (Ttime): time spent to reach the final touchpad.

Design and Procedures

A cross sectional design was used to compare UUS performance after a traditional warm-up (TRA) and a PAPE-based warm up (PAPE). To avoid the "fatigue/learning" effect swimmers were counterbalanced and randomly assigned to 2 groups. On the first testing day, the first group performed TRA before being tested in a maximal UUS effort, while the second group performed PAPE. Both protocols allowed 5 min rest intervals between the CE and the test. On the second testing day, the group order was reversed (the first group performed PAPE and the second group performed TRA) and the tests were repeated.

The week prior to testing swimmers underwent two familiarization sessions consisting of several half-squat repetitions on an inertial flywheel device and several 10 m UUS efforts attached to a speedometer cable (linear transducer, Heidenhain, D83301, Traunreut, Germany) by a belt. One of the UUS efforts was registered and the time was used to split and counterbalance the group participants. The experimental setting was a 12.5 x 5.94 m swimming pool (water temperature = 27º, humidity = 58%). Swimmers arrived at the pool within their regular evening training schedule, after having refrained from alcohol, caffeine, or any stimulants, and strenuous exercise for the previous 24 hours. First, both groups performed a stretching routine (Cuenca-Fernández, et al., 2015), which consisted of general flexibility exercises. After that, a certified swimming coach designed and overviewed an in-water warm-up which consisted of: 400 m easy swim, 4 x 25 m strong, 50 m ventral kick increasing the speed, and 3 x 10 m UUS with progressive speed. Despite the fact that the warm-up procedures seem to play a major role in swimming distances above 200 m, the procedure of dynamic stretching followed by the in-water warm-up was designed according to the fundamentals reported by Neiva et al. (2014).

Hence, the first group rested for 5 min (TRA) until performing a maximal 10 m UUS trial, while the second group performed 4 maximum half squat repetitions on an inertial flywheel nHANCE™ Squat Ultimate (PAPE) and then rested for 5 min before performing the maximal 10 m UUS trial. The load inertia of the flywheel was the highest provided by the device (0.05 kg) and participants were asked to perform maximal effort (Maroto-Izquierdo et al., 2017). Subsequently, swimmers entered into the water and on command, they pushed off from the starting wall to a vertical barrier fixed to a platform located 10 m from the wall. Touchpads from an electronic timing system (ALGE-TIMING, TP1890C Anschlagplatte, Lustenau, Austria) were secured to the starting wall and the vertical barrier to measure the time taken to cover 10 m in the UUS efforts. On the second testing day, the test was carried out in the reverse order. The first group performed PAPE, while the second group performed TRA. Two independent researchers monitored the entire stretching routine to ensure that the exercises were performed properly and at the right pace. They also supervised the in-water warm-up and provided swimmers with device harnesses and belts during the PAPE exercise and UUS trials.

Statistical analyses

Descriptive statistics were expressed as the mean ± SD and confidence intervals (95%CI). Shapiro-Wilk testing showed normality for the whole sample; however, when differentiating by sex, Upeak in male and Kick frequency in female athletes were not parametric. For analytical purposes, normal scores of Upeak in male and Kick frequency in female swimmers were calculated using the Blom formula reported in Vehtari et al. (2020). A paired sample *t* test was applied for the two protocols to determine differences in the kinematic variables. An independent sample t test was applied to determine the effects of PAPE in males and females by comparing the differences between TRA and PAPE. The relative changes (%Δ) were calculated as the percentage difference between conditions. The effect sizes (d) of the obtained differences were calculated and categorized (small if $0 \leq |d| \leq 0.5$, medium if $0.5<|d|\leq 0.8$, and large if $|d|>0.8$) (Cohen, 1988). All statistical procedures were performed using SPSS 23.0 (IBM, Chicago, IL, USA) and the level of statistical significance was set at $p < 0.05$.

Results

When comparing the effects of the two protocols in the whole sample Ttime was significantly lower after PAPE compared to TRA ($p < 0.001$, mean difference: -0.18; 95% CI: −0.26, -0.09; $d = 1.07$); however, push-off velocity, Uavg, Upeak, Umin, and kick frequency did not significantly improve ($p > 0.05$). Data concerning UUS performance variables for males and females are presented in Tables 1 and 2, respectively.

When comparing the effects of PAPE with regard to the differences between males and females, push-off velocity differed in 6.7% (male increased 3.0% + female decreased 3.7%) presenting significant differences between genders ($p = 0.017$, 95%CI = -0.29, -0.03). No significant effects were shown between males and females for Uavg, Upeak, Umin and dv ($p > 0.05$), with differences of 0.6, 1.8, 2.4 and 1.9%, respectively.

Discussion

The first aim of this research was to assess the effects of an activation protocol based on PAPE upon UUS kinematic variables and the results showed a significant difference in the Ttime after the experimental warm-up, which meant that maximal repetitions on a flywheel may be beneficial to improve UUS performance. To the author's knowledge, this is the first study to date to test a PAPE protocol on UUS. On the other hand, this study also aimed to measure the differences of the PAPE effects when comparing males and females. The push-off velocity showed a different outcome between genders after PAPE. Nevertheless, the improvement in Ttime was obtained for the whole group and although no significant changes were obtained in Uavg, Upeak, Umin, and Kick frequency, this trend was similar for both genders. Therefore, these results would be in agreement with those obtained by previous authors (De Renne, 2010; Wilson et al., 2013), since the effects of PAPE do not seem to differ significantly between genders.

The use of the flywheel device as a CE to induce PAPE on the lower limbs is not new in the literature (Beato et al., 2019; Maroto-Izquierdo et al., 2017; Timon et al., 2019). The athlete must resist the inertial force of the flywheel by developing a maximal voluntary braking action (i.e., eccentric leg contraction), which is characterized by a higher solicitation of type II fibers and a greater cortical activity (Maroto-Izquierdo et al., 2017; Timon et al., 2019). Some interventions have attempted the stimulation of the type II fibers by lifting heavy loads in strength tests within a percentage margin of load-intensity capable of ensuring 3-5 repetitions (Blazevich and Babault, 2019; Kobal et al., 2019; Krzysztofik et al., 2020; Seitz and Haff, 2016). However, some CEs are stiff or do not provide the fluency and speed that the flywheel device is able to provide on the targeted joint kinetics (Beato et al., 2019; Maroto-Izquierdo et al., 2017). In addition, during prolonged testing protocols, subjects may vary their load-percentage due to either deterioration or an improvement in their skills or even because the strength test was not adequate for such a specific task. This does not happen with the flywheel, given that the maximal load (i.e., through eccentric overload) can be achieved regardless of a subject's condition on the day of the test (Cuenca-Fernández et al., 2015).

When comparing two aquatic warm-up protocols of similar volume, the one with the eccentric stimulation on the flywheel gave better results (Tables 1 and 2). Therefore, this procedure provided higher stimulation to the lower limbs, allowing for significant power and muscle activation compared with a standard warm-up (Beato et al., 2019; Maroto-Izquierdo et al., 2017). Although an improvement was found in Ttime for the whole group, no significant differences were obtained in any of the velocity manifestations collected from UUS (Uavg, Upeak, Umin). These results were incongruent given that less time was necessary to complete the same space. A possible reason behind this enhancement may be explained by the sum of all non-significant improvements that are shown in these variables. In fact, a trend towards improvements in Uavg came in tandem with a trend of increases in Upeak and Umin, which showed that the trend towards improvements offered symmetry (Atkinson et al., 2014). Another possible reason behind this low effect size may reside on the fact that only four kicks were analyzed from the third kick onwards, which may have masked the possible enhancements in performance obtained from the very beginning. Actually, it is worthy of review that beyond the statistical significance, the reduction in Ttime for males came with an increase in the velocity of the impulse on the wall (push-off velocity) (Table 1); meanwhile, the reduction in Ttime detected for females seemed to be a consequence of increasing the kicking frequency (Table 2). The changes in these variables after PAPE, although non-significant, showed a different trend depending on the gender.

Considering the results found in males for push-off velocity, they seemed to produce higher reaction forces in the push from the wall in comparison with females. According to some authors, PAPE effects seem to be higher in maximal voluntary contractions depending on the maximal rate of force development rather than in cyclic movements (Seitz and Haff, 2016; Wilson et al., 2013). In addition, other approaches have shown that males are able to produce higher ground reaction forces and jump higher than females (Jensen and Ebben, 2003). In this regard, it is possible that the remarkable effect of the eccentric overload in stimulating the type II fibers could have prompted more significant effects in males than in females for the push-off velocity, due to the superior rate of type II fibers and/or greater muscle mass that are characteristic for males (Beato et al., 2019; Maroto-Izquierdo et al., 2017). Therefore, the results found in the present study revealed that the improvement found in Ttime for males was possibly influenced by the improvement of the push-off velocity. In the study of Cuenca-Fernández et al. (2015), the improvement detected in swimming start performance to 15 m was explained by the enhancements originated in the velocity and impulse generated to the block-start during the effort. Possibly, the effects of PAPE in UUS velocity variables (Uavg, Upeak, Umin) may have been enhanced in males by analyzing also the first two kicks after the push from the wall. However, given the high influence of the impulse in the first kicks (Connaboy et al., 2009), it was discarded in order to explore an actual effect of PAPE in the kinematic variables of UUS.

With regard to females, the push-off velocity was lower after PAPE; however, an increased, but non-significant, velocity and frequency of kicking produced a reduction in Ttime after all. This trend would be similar to what was obtained in a previous study (Jensen and Ebben, 2003). In addition, considering that kicking frequency is one of the most important factors to improve UUS velocity (Connaboy et al., 2009), the increase in frequency by 2.1% obtained in females after PAPE may have influenced the reduction obtained in Ttime. The reasons behind the neuromuscular mechanism by which PAPE led to an increase in the kicking frequency are uncertain. Nevertheless, eccentric actions activate elastic components in the muscle by the stretch-shortening cycle, increasing the production of force in subsequent actions (Timon et al., 2019). In any case, some other recent approaches have shown acute enhancements of the neuromuscular function (~2%) by improvements in the aquatic thrust obtained after dry-land warm-ups (Barbosa et al., 2020; Cuenca-Fernández et al., 2020; Ng et al., 2020). It should be noted that the aquatic thrust does not essentially represent the effective propulsive force generated by the body, but the increase in the force conveyed per stroke against the water (Barbosa et al., 2020). Thus, the potentiation responses obtained in the kicking frequency could reflect an increase in the lower limbs performance, but this may not be in line with an increase in the effective propulsive impulse of the swimmer (Cuenca-Fernández et al., 2020). Nevertheless, although the velocity achieved during UUS did not improve significantly, it is clear that there was no worsening either, therefore, the eccentric flywheel CE seemed to provide an additional stimulation of the neuromuscular system in comparison to the traditional warm-up (Maroto-Izquierdo et al., 2017; Timon et al., 2019).

On the other hand, the trend towards improvements may have been higher in both genders with an appropriate rest interval between the CE and the test. For instance, Krzysztofik et al. (2020) obtained potentiation responses in the upper limbs 4 min after a bench press protocol, while other studies have reported that 5 minutes would constitute sufficient time to recover from activation while potentiation from the myosin heads phosphorylation (dissipates < 5 min) still exists (Boullosa et al., 2020; Jensen and Ebben, 2003). Moreover, this gap of time may also benefit from a combination with other modulating mechanisms of PAPE only possible after several minutes (> 5 min), such as the vascular bed dilation/blood muscle perfusion, the increased muscle temperature and excitability in the spinal cord obtained after repetitive muscle contraction (Blazevich and Babault, 2019). In this regard, some studies have reported potentiation responses above 5 min (Cuenca-Fernández et al., 2015, 2017; Kilduff et al., 2011; Timon et al., 2019). Given that the moment to perform the task in the better potentiated conditions is an individually regulated response that depends on the nature of the participants muscle's fiber and the training experience (Kobal et al., 2019; Seitz and Haff, 2016), an individualized rest interval may have provided more significant results by enhancing the effects of PAPE (Cuenca-Fernández et al., 2020). In any case, future studies should replicate these procedures with a higher number of participants or with swimmers of a higher sports level.

In fact, one of the limitations of this study resided in lack of the assessment of strength of the lower limbs of swimmers as we could not explore the possible relations with our results. In addition, the low age of some of the participants (males: 16.60 ± 2.01; females: 15.42 ± 1.81 years) could be a relevant point in the results since age and growth influence the strength level and therefore, the PAPE responses (Arabatzi et al., 2014; Blazevich and Babault, 2019; Seitz and Haff, 2016). A meta-analysis conducted by Wilson et al. (2013) stated that less trained participants not only demonstrated low performance increases after PAPE, but also a quicker potentiation dissipation; the difference between trained and elite athletes was that high competitive individuals were able to peak in performance at short (3-7 min) recovery periods, meanwhile trained ones would need a moderate (7-10 min) rest interval to benefit from PAPE responses. Although participants of this study were trained athletes with a certain amount of competitive experience (> 5 years), none of them reported a high competitive performance level (FINA points < 500) and that fact would explain why 5 min of rest was not sufficient to expect higher improvements in performance.

In conclusion, the warm-up protocol evaluated in this study, which included a specific PAPE application through a flywheel device, showed better results than the traditional warm-up, and it may be especially relevant in short sprints (50 – 100 m). In addition, no significant differences were obtained between genders after PAPE (with the exception of the push-off velocity), which may confirm that the benefits obtained after this method are subject-dependent and could depend on other components such as training experience or the fiber composition (Kobal et al., 2019). On the other hand, although applying this type of activation protocol seems unfeasible (a specialist piece of equipment is required while athletes are waiting in the call-room), the influence of PAPE on UUS kinematic variables has shown optimistic outcomes, at least under experimental conditions. Therefore, swimming coaches should experiment with the eccentric overload on the lower limbs before competition. At last, this manuscript used the novel taxonomy for the classification of potentiation in sport by encompassing the identification of the conditioning activity, verification test and athletic population, according to the formula provided by Boullosa et al. (2020).

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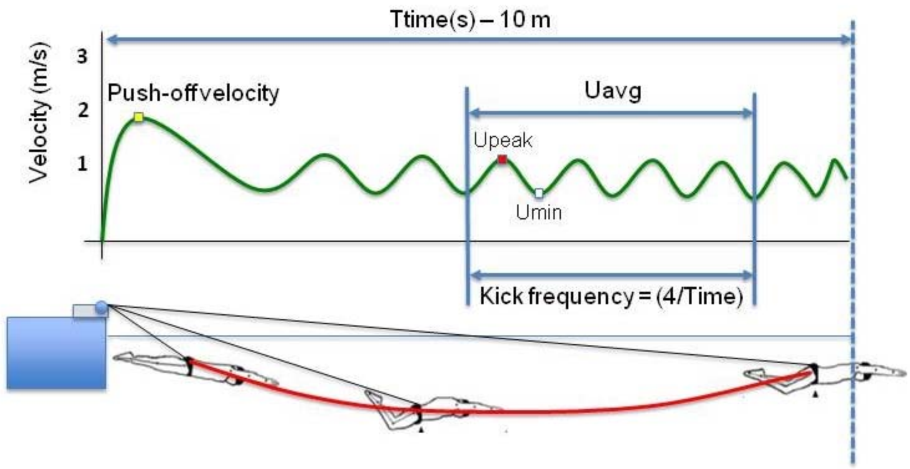

Figure 1.

Layout of the aquatic protocol and variables measured.

Table 1. Differences in male UUS performance and kinematics between the 2 different warm-up protocols: TRA and PAPE. Mean ± SD values with the respective level of probabilities (p), mean differences, 95% confidence intervals, relative changes (%Δ), and significant effect sizes.

Variable	TRA	PAPE	Difference [95%CI]; %Δ	p-value	Effect size (d)
Push-off velocity ($m \cdot s^{-1}$)	2.60 ± 0.21	2.68 ± 0.16	0.08 [0.03,0.12]; 3.0%	0.004**	1.20
Uavg ($m \cdot s^{-1}$)	1.18 ± 0.08	1.19 ± 0.12	0.01[-0.03,0.05]; 0.8%	0.575	0.18
Upeak ($m \cdot s^{-1}$)†	1.76 ± 0.19	1.76 ± 0.18	0.04[-0.53,0.62]; 0.1%	0.860	0.05
Umin ($m \cdot s^{-1}$)	0.54 ± 0.21	0.57 ± 0.30	0.02[-0.11,0.17]; 5.0%	0.673	0.13
Kick frequency (Hz)	2.18 ± 0.33	2.19 ± 0.38	0.01[-0.07,0.09]; -0.2%	0.875	0.05
Ttime ($m \cdot s^{-1}$)	5.77 ± 0.44	5.64 ± 0.46	0.13[0.03,0.12]; -2.2%	0.010*	1.03

*Uavg: average underwater velocity; Upeak: average underwater peak velocity; Umin: average underwater minimum velocity; dv: intra-cyclic velocity variation; Ttime: test time; TRA: traditional warm-up with 5 min rest intervals; PAPE: traditional warm-up followed by 4 maximal half-squat repetitions on an inertial flywheel nHANCE™ Squat Ultimate with 5 min rest intervals. *, ** and *** mean differences between suits for p < 0.05, 0.01 and 0.001.*
† The mean and SD data are without transformation, but the statistic results were calculated with the transformed data.

Table 2. Differences in females UUS performance and kinematics between the 2 different warm-up protocols: TRA and PAPE. Mean ± SD values with the respective level of probabilities (p), mean differences, 95% confidence intervals, relative changes (%Δ), and significant effect sizes.

Variable	TRA	PAPE	Difference [95%CI]; %Δ	p-value	Effect size (d)
Push-off velocity ($m \cdot s^{-1}$)	2.37 ± 0.20	2.29 ± 0.17	-0.08 [-0.21,0.03]; -3.7%	0.137	0.64
Uavg ($m \cdot s^{-1}$)	1.15 ± 0.11	1.17 ± 0.11	0.02[-0.04,0.07]; 1.4%	0.531	0.25
Upeak ($m \cdot s^{-1}$)	1.56 ± 0.07	1.54 ± 0.11	-0.02[-0.15,0.10]; -1.7%	0.630	0.19
Umin ($m \cdot s^{-1}$)	0.78 ± 0.19	0.84 ± 0.09	0.05[-0.09,0.20]; 7.4%	0.374	0.36
Kick frequency (Hz) †	149.24 ± 26.51	156.17 ± 28.22	-6.93[1.78,12.08]; 4.6%	0.276	-0.36
Ttime ($m \cdot s^{-1}$)	6.34 ± 0.80	6.09 ± 0.66	-0.25[0.44,-0.07]; -4.0%	0.016*	1.24

*Uavg: average underwater velocity; Upeak: average underwater peak velocity; Umin: average underwater minimum velocity; dv: intra-cyclic velocity variation; Ttime: test time; TRA traditional warm-up with 5 min rest intervals; PAPE: traditional warm-up followed by 4 maximal half-squat repetitions on an inertial flywheel nHANCE™ Squat Ultimate with 5 min rest intervals. *, ** and *** mean differences between suits for $p < 0.05$, 0.01 and 0.001.*

† The mean and SD data are without transformation, but the statistic results were calculated with the transformed data.