Does jumping conducted before the swimming start elicit underwater enhancement?

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Abstract

The effects of pre-activation exercises on undulatory underwater swimming (UUS) have not been studied. This research aimed to: 1) assess the effects of a jumping-exercise strategy upon UUS performance and kinematics variables; 2) test the different effects on males and females, and; 3) to explore if stronger participants exhibit greater post-activation performance enhancement (PAPE). Ninety-two age-group national level swimmers randomly assigned into control (17 males and 18 females) and experimental groups (27 males and 30 females) took part in a cross-sectional study designed to test two maximal 15-m UUS performance efforts. The experimental group performed four maximal tuck jumps before the first or the second UUS effort. Performance and kinematics variables were analyzed using instantaneous velocity data via speedometer. Maximal lower-limbs force was obtained during a countermovement jump through a linear-encoder. Two-way repeated measures ANOVA test and linear regression analysis were used to explore variable interactions between baseline and PAPE, and the association between the PAPE response and strength of the swimmers, respectively. Despite trends toward improvements in push-off velocity (Δ=1.33%; d=0.12), the results did not show enhancements nor deterioration in UUS performance and kinematics after the tuck jumps. No specific PAPE responses modulated by sex or by the strength level of the swimmers were observed for this age-group ($p < 0.05$). Four tuck jump repetitions executed prior to diving could be insufficient to acutely enhance UUS performance. The fact that the exercise performed during warm-up was a body-weight based exercise, was possibly not enough to evoke PAPE.

Keywords: Coaching, competition, dolphin kick, exercise, gender.

INTRODUCTION

Not all sporting competitions offer athletes a smooth transition in time from warm-up to the sporting event. This is evident in competitive swimming, as during the minutes leading up to an elite international swimming event, it is common to observe competitors standing quietly in the marshalling area. Maybe for that reason, just before the start of the race, some swimmers perform series of ballistic exercises such as jumps, limb swings or flicks with the aim to re-activate and acutely enhance neuromuscular performance[1].

Active warm-up has been considered the standard for enhancing physiological mechanisms prior to competitive swimming at various distances and strokes[2]. These mechanisms include an increase in oxygen supply to the muscles, anaerobic metabolism and nerve conduction rate, all of which have been attributed to an increase in body temperature[3]. Specifically, the short-term effects of specifics warm-up over performance have been demonstrated largely on the swimming start, decreasing the swimming time during the first meters of a race[4, 5]. However, it is known that the same warm-up protocol can result in different responses among participants because of the interaction between fatigue and potentiation[6, 7, 8], ranging from a positive effect (responders), no effect (non-responders), or even adverse effects[6]. The phenomena by which an enhancement of voluntary force production is obtained several minutes after high intensity muscle contractions has been referred as post-activation performance enhancement (PAPE)[7]. The factors underlying PAPE are thought to be the increase in muscle temperature, muscle fiber water content and muscle activation (including motivation)[6]. These elements depend on intrinsic features such as muscular strength, fiber-type distribution and the training experience[9, 10]; and are modulated by the numerous forms of conditioning exercise (CE) used and by the load, number of repetitions and resting time provided[11].

Frequently, a larger PAPE effect has been reported in the athletes with higher levels of strength, and this has been attributed to the fact that an increased level of strength may make an individual more resistant to fatigue following a conditioning activity, thus responding more favorably than weaker athletes[4, 11]. Furthermore, as females and/or young participants usually exhibit considerably lower strength levels than adult males[12], these characteristics might also be the cause of the conflicting results regarding participants' sex and/or age; given that it is not clear if performance enhancement may be equally yielded both in male and female participants. Some authors have shown performance improvements in jumping and swimming solely in males[13, 14], while others found a trend towards jump improvements in females[12]. However, an analysis of the PAPE reviews shows that these conclusions may not be sufficiently substantiated as females and/or young participants represent a minority share of the experimental studies (~17%)[7, 9]. In addition, such analysis shows little consensus on the number of repetitions required to elicit performance improvements, with a wide variety of strategies[7, 9]. Specifically in swimming, some particular aspects of the muscular mechanics of swimming, which are related to the hydrodynamic reaction forces created underwater, have possibly conditioned the effects of the potentiation methods carried out in dry land conditions[15], to which must be added the difficulty of carrying out some of these CEs on the pool-side. Therefore, this controversy requires more knowledge that may contribute to solve it.

The positive acute effects of specific warm-ups on swimming performance have been demonstrated largely in the kinematics variables collected from the swimming start, flutter kicking, and surface swimming[4, 5, 16-18], but no studies have explored the PAPE effects caused by jumping CEs in underwater undulatory swimming (USS). Apart from the start, the highest velocities in butterfly, backstroke, and front crawl events are obtained during the underwater phase, making this one as one of the most influential variables on swimming performance[19]. Since UUS is a leg-dominated exercise, some studies have tested surface electromyography (EMG) on the lower limbs during UUS, showing a high muscular activation in: rectus femoris and anterior tibialis during the downward kick; and biceps femoris and gastrocnemius during the upward kick[20, 21]. In addition, a muscular co-activation synergic activity has been detected along the undulation movement as a way to assist thrust force during the link between both propelling actions (i.e., the downward and upward kick), especially when increasing kicking frequency[20, 22]. However, it has been shown that UUS performance is favored and highly linked to the velocity that the swimmer enters the water[23, 24, 25]. Thus, if swimmers obtain improvements in the take-off speed, then this speed could be transferred to an improvement effect on UUS performance regardless of whether these improvements were obtained specifically in the neuromuscular mechanisms that enable UUS performance.

Therefore, it is unknown whether such conditioning activities may elicit PAPE responses solely on UUS performance. One study recently evidenced the potentiation effect of eccentric devices on UUS[26]. In this regard, although it has been stated that the PAPE effects are better when the CE is more similar to the sport task to be performed[6, 11], it is important to note that some of the experimental exercises reported on PAPE research are performed through practices or devices that do not always correspond to the pre-race routines performed in a real competition scenario. An example of a pre-activation routine is shown in the run-up to a swimming competition, where competitors are seen performing ballistic movements and/or powerful jumps prior to swimming starts. Indeed, a pre-race routine that instils confidence and motivation is essential for many swimmers to help themselves feel in control of the situation. Therefore, this research aimed: 1) to assess the effects of a pre-activation jumping protocol followed by swimmers upon UUS performance and kinematic variables; 2) to compare differences in the PAPE responses on UUS performance and kinematic variables in males and females, and; 3) to explore if stronger participants exhibit greater PAPE responses. It was hypothesized that swimmers would achieve better UUS performance after the pre-activation protocol. In that case, these changes would not depend on sex but on the strength level of the participants.

MATERIALS AND METHODS

Participants

Ninety-two age-group national level swimmers, with at least three years of competitive national experience, volunteered to participate in this study. Main physical and competitive background characteristics for male control and PAPE groups (n = 17 and 27, respectively) and female control and PAPE groups (n = 18 and 30) are displayed in Table 1. The swimmers were included after being selected for a monitoring programme based on the FINA points achieved at the last regional championships. They presented a weekly training volume of 12 to 15 hours, including regular dry land work. Before the beginning of testing, swimmers received limited information about the testing procedures to avoid bias. Since the swimmers were under 18 years, parental consent was also obtained. Swimmers were asked to refrain from caffeine, or any stimulant drink, and strenuous exercise for the previous 24 hours. All 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.

Design

A parallel study design was conducted to compare UUS performance and kinematics values after a traditional in-water warm-up (acting as the control), and an in-water warm-up followed by a PAPE protocol (Figure 1). Swimmers were assessed during a single session lasting up to two hours. The evaluation consisted of in-water tests (UUS) and maximal-force in unloaded countermovement jump (CMJ).

(Please insert Figure 1 near here)

First, dry-land tests were conducted to evaluate the swimmers' strength and power and after a 30 min break, swimmers arrived to the pool to conduct the in-water warm-up. Then, the sample was counterbalanced and randomly divided into two groups, control and PAPE, according to the FINA scores of each swimmer (www.fina.org). One group waited 10 min prior executing one maximal 15 m UUS effort. After 10 minutes of rest, swimmers repeated the maximal effort. The swimmers of the PAPE group were required to perform four tuck jumps right before the UUS maximal effort.

That group was randomly split into two groups to avoid the "fatigue/learning" effect; therefore, the jumps were performed either before the first or the second effort. We considered that the PAPE group should be larger than the control group to ensure a similar number of participants as the control group when splitting the sample into two sub-groups. With this strategy, we were able to detect with sufficient statistical power that there were no differences that could have occurred by performing the intervention before the first or second maximum UUS test[27]. Tuck jumps were chosen as CE because it was the most representative exercise performed by swimmers before the start in competition and movement-specific PAPE complexes appear to be more successful in producing a performance improvement[11]. The number of repetitions was intentionally low to replicate a normal routine that could be performed by the swimmer prior to the race. Due to swimmers' availability, both conditions were performed on the same day.

Methodology

The tests were carried out on a 25 m x 16 m swimming pool (water and air temperature = 27 and 28.5ºC; humidity = 53%). Swimmers reported to the experimental setting to be assessed in anthropometrics and CMJ-Force through a linear encoder (T-Force; Ergotech, Murcia, Spain). Swimmers were required to perform two maximal CMJs with 30s rest in between with self-selected knees' flexion and holding an unweighted methacrylate bar on the shoulders. The cable of the encoder was connected to the methacrylate bar to ensure the linear displacement of the cable. The average of the maximal-force of the two CMJs was considered for further analysis. Since the CMJ force is very dependent on body-weight, the obtained values were normalized for each subject to highlight the swimmers that applied the biggest load during the test[4].

Subsequently (≥ 30 min) swimmers arrived to the pool. To account for differences in the type of warm-up affecting participants' responses[6], swimmers performed a standardized warm-up consisting of a dynamic stretching protocol on land followed by 400m of varied swimming for at least 20 min[1]. Following the in-water warm-up, the control group performed the first maximal 15 m UUS trial, then rested for 15 min and executed the second maximal 15 m UUS trial. Thus, "PRE" referred to the first trial and "POST" to the second trial". The two PAPE groups conducted four tuck jumps followed by a two min rest, either after the first or the second maximal 15 m UUS trial (Figure 1). Then, "PRE" referred to the UUS trial without performing tuck jumps and "POST" to the trial including the execution of tuck jumps. For a pure randomized control trial, the time elapsed from the cessation of the baseline measure, and the post-performance test, was similar in the control and the experimental trial[28] (i.e., 15 min in between).

One minute before the beginning of the UUS trial, swimmers entered the water and a speedometer cable (linear transducer, Heidenhain, D83301, Traunreut, Germany) was attached to their hips via a belt[26]. Swimmers were instructed to perform a maximal horizontal push-off at 1 m depth and maintain the depth throughout the 15 m to negate wave drag effects[23]. To evaluate the true effect of the PAPE protocol on UUS, horizontal wall push offs at 1.0m depth were utilized instead of a dive start to limit possible confounding of UUS kinematics by differences in entry angle and depth following dive starts. Two researchers monitored the in-water warm-up, the initial position, belt placement, and provided the starting signal of the UUS trials.

Data analysis and Kinematic measurements

Velocity data recorded at 200 Hz during the UUS 15 m maximal efforts by the speedometer were A-D converted (Signal Frame MF020, Sportmetrics, Spain) and exported to MATLAB 2013a (MathWorks Inc., Natick, Mass., USA). Velocity-time curves were smoothed using a second order Butterworth low pass digital filter, with a cut off frequency of 6 Hz. The push-off from the wall and six successive kicks, from the 3rd to the 9th kick, were analyzed. The first two kicks were discarded to avoid velocity attained during kicking being affected by the maximal horizontal wall push-off[24]. The kick cycles were identified and the following parameters were calculated as previously reported[29]:

- Push-off velocity ($m \cdot s^{-1}$): highest value obtained from the individual velocity-time curve during underwater gliding.
- Average underwater velocity (Uavg) ($m \cdot s^{-1}$): mean velocity from each of the six selected kicks recorded using the speedometer.
- Average underwater peak velocity (Upeak) ($m \cdot s^{-1}$): mean peak velocity from each of the six selected kicks recorded using the speedometer.
- Average underwater minimum velocity (Umin) ($m \cdot s^{-1}$): mean minimum velocity from each of the six selected kicks recorded using the speedometer.
- Kick frequency (Hz): The 6 selected kicks divided by the time spent to perform them.

Statistical analysis

The same experimental procedures for males and females were conducted, and results were split for sex. Descriptive statistics were expressed as the mean ± standard deviation (SD) and confidence intervals (95%CI). The relative changes [%Δ] was calculated as the percentage difference between Pre-Post conditions ([$Mean^{Post}$ – $Mean^{Pre}$/$Mean^{Pre}$] × 100). After Shapiro-wilk testing, parametric analysis was adopted. Since no assumptions were violated, two-way (factors: time [Pre-Post] × intervention [control or PAPE]) repeated-measures ANOVAs were used to compare variables (Note: although some of the swimmers in the PAPE group performed the tuck jumps before the first trial, this measurement was considered as Post). Independent sample student *t* test for anthropometric characteristic was applied to study the homogeneity between the control and PAPE groups. Paired sample *t* test was applied to determine differences on the kinematic variables between baseline and PAPE (or second trial for control group). An independent sample *t* test was applied to determine the effects of PAPE in males and females by comparing the aforementioned differences. To test if force-related CMJ values normalized by body weight affected PAPE responses, Pearson correlation coefficients (r) were applied between this parameter and the [%Δ] obtained on the UUS variables. Linear regression analysis was applied to explore the possible associations. Effect sizes (d) were calculated and categorized (small if $0 \leq |d| \leq 0.5$, medium if $0.5<|d|\leq 0.8$, and large if $|d|>0.8$)[29]. All statistical procedures were performed using SPSS 24.0 (IBM, Chicago, IL, USA). The level of statistical significance was set at $p<0.05$.

RESULTS

There was no time x protocol interaction for Umax ($F_{1,90}$ = 0.016; p = 0.9), Uavg ($F_{1,90}$ = 0.060; p = 0.8), Upeak ($F_{1,90}$ = 2.371; p = 0.12); Umin ($F_{1,90}$ = 0.034; p = 0.85), and kick frequency ($F_{1,90}$ = 0.208; p = 0.65). Table 1 shows the homogeneity of the sample clustered by sex, in both control and PAPE groups. Neither males nor females presented significant differences between the groups in age, height, body of mass, and arm span (p>0.05). Regarding the control group, there were no differences between first and second effort (Table 2). After PAPE, neither male nor female performance and kinematics were significantly affected (Table 2). The effect of PAPE on performance and kinematic variables was not significantly different regarding sex (Table 3). There were weak to moderate correlations between the CMJ-force normalized to body weight and [%Δ] in Upeak, only in the control group (females: [r = 0.47; p = 0.05]; males: Upeak [r = -0.48, p = 0.04]). The regression analysis showed that the [%Δ] in UUS variables after PAPE interventions was not explained by the level of strength of the participants (Figure 2).

(Please insert Table 1 near here)

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DISCUSSION

This research aimed to assess the effects of a PAPE protocol followed by swimmers before a competitive swimming race upon UUS performance and kinematic variables. The PAPE warm-up protocol did not show any significant effect on UUS performance or kinematics, although no deterioration was detected either, thus its implementation was not counterproductive. Furthermore, this study aimed to test the possible different PAPE responses that could be modulated either by sex and/or the strength level of the participants, showing no differences as a consequence of any of them.

Although no significant improvements were achieved, the tuck jumps seemed a suitable choice to perform prior to diving. Usually, the exercises tested in PAPE research consisted of high-intensity or high-loaded exercise-based warm-ups, trying to stimulate the muscles involved in the action tested[1, 5, 13, 17]. However, this represents an issue since some specific dry-land equipment is not commonly available in competition[26]. For that reason, the execution of plyometric exercises and the number of repetitions needed to prompt performance enhancements have been stated as key modulating factors of PAPE responses[9, 11, 13, 30]. In the current study, this number was considerably lower than previous studies conducting unloaded plyometric exercises. Tobin and Delahunt [30] achieved CMJ performance enhancement after performing a total of 40 plyometric repetitions at one, three, and five min before the movement test, whereas, Ng et al., [18] conducted two sets of five CMJ repetitions achieving higher kick velocity and thrust five min after. Thus, it is therefore possible that when lower intensity exercise as tuck jumps is conducted, the number of repetitions required to yield PAPE responses might be higher to stimulate the muscle system[4, 13].

The rest time provided in this study was intentionally low to simulate those activities that are performed just prior to the start of the race. Seitz and Haff [11], asserted that to optimize the potentiation effect rest periods should last from 0.3 to four minutes in length after plyometric exercises. When comparing one, three, and five min resting periods, Tobin and Delahunt [30], found performance enhancement in all three conditions, with a one min rest period the most efficient choice. A possible explanation behind this outcome may reside in the modulation of skeletal muscle contraction by myosin head phosphorylation, given that its effect are known to dissipate quickly, with a rapid decline in the first 28 seconds and only a small effect present by five min[31]. Therefore, although this phenomenon has been attributed to post-activation potentiation (PAP) but not PAPE[6, 7], it is not discarded that both response mechanisms acted simultaneously since no fatigue was observed after tuck exercise[32].

Even though no significant effects were shown between male and female after PAPE (Table 3), this study demonstrated two aspects that deserve to be mentioned. One of them refers to the fact that males showed better records than females in all variables. Apparently, males presented higher Uavg, Umax, Upeak, Umin, and frequency values than females, proving the considerably higher level of force[33]. These differences with respect to sex may be explained by the differences in muscle strength and fiber type distribution that males are characterized of[12, 14, 34], therefore, this should be taken into account when applying a CE according to the athlete's characteristics. On the other hand, it has been stated that stronger or more trained individuals show great PAPE responses due to their greater capacity to resist and/or dissipate fatigue quicker, requiring shorter resting intervals after the activation exercise to exhibit performance enhancement[4, 11, 13]. The correlation analysis only showed that the stronger females obtained higher Pre-Post [%Δ] in Upeak on the control group ($r = 0.47$, $p = 0.05$). In this regard, it is not discarded that the first UUS pre-task may be entailed a stimulus strong enough to cause a potentiation effect on them for the subsequent UUS post-task[7]. However, even though the related-force CMJ values were normalized to the body-weight, these relations were not found for the PAPE group, neither for males nor females, meaning that the stronger participants did not show greater PAPE responses after intervention (Figure 2). A possible explanation for this was found in an earlier study; Arabatzi et al.,[13] tested PAPE responses in different age groups: pre-adolescents (10-12 years), adolescents (14-15 years) and adults (20-25 years) and found that PAPE responses were only revealed in adults. Therefore, it is possible that differences in both strength level and muscle fibre volume or type at this age are not yet relevant enough for PAPE protocols to have a significant impact on performance change.

Previous performance enhancement achieved with plyometric exercise were conducted on adult swimmers[18, 30]. Hence, the fact that the swimmers assessed in the current study were aged-group swimmers could have an effect on the lack of potentiation[13, 34]. Experimental studies of PAPE involving young participants are scarce[7,9], which means that possible age effects cannot yet be clearly described. In the present study, variation in participant ages (female SD = 1.56; male SD = 1.44) did not predict PAPE responses (nor Pre-Post responses in the control group). Although the sample was quite homogeneous (Table 1), an age difference of almost one year was detected between the female PAPE and control groups ($p = 0.06$), which could present maturational and strength development differences at these ages. Longitudinal analysis of age-group female swimmers has shown a plateau in swimming velocity at 13.6 ± 1.9 years[35], as maturation-related changes may not translate into significant technical stroke improvements at this age. Similarly, possible maturational differences between female participants in the PAPE and control groups may have been present but may not have translated into significant UUS improvements. On the other hand, it is important to mention that all participants had a more than acceptable level of fitness to recover from the possible fatigue generated by the CE; however, they were not previously familiarized with the tuck jumps and the PAPE responses could be the result of muscle memory mechanisms which seems to be more frequent when the exercise used to induce PAPE is practiced during daily training[36]. Therefore, future research should explore age differences with an appropriate maturational assessment such as the Tanner's scale, or be conducted with adult elite swimmers or after a period of practice, to corroborate or clarify the findings of the current research.

In conclusion, the PAPE-based warm up carried out in this study, which tried to replicate the jumping activities prior to swimming competitions, did not elicit significant performance and kinematics improvements in age-group swimmers. The low number of repetitions does not seem enough to elucidate potentiation, or to outperform the effects of the fatigue to enhance UUS performance and kinematics. Although other studies have shown positive effects of PAPE warm-ups on swimming performance through practices or devices that do not always correspond to the exercises performed in a real competition scenario, this study brought reality closer to science by studying a behavior that is commonly observed in swimming events, such as the activation routines performed by the swimmers just before starting the race. Furthermore, given that the mechanisms of warm-up and PAPE are very similar, it is difficult to isolate the two elements and correctly attribute performance improvement in pre-post study designs. For that reason, this study included a control trial that included warm-up and an experimental trial that included a warm-up followed by a conditioning activity, so that any performance improvements that might be observed could be attributed to the conditioning activity, rather than to the confounding variables[6]. Future studies should test a PAPE protocol with a greater number of repetitions or evaluate the effect of the same routine within daily practice to get the muscle system used to potentiation protocols. Methods to increase the intensity of the tuck jumps in a competition setting could be the use of weighted jackets[14], the application of blood-flow restriction in the lower limbs[37], or the addition of elastic resistance to the movement, as it has successfully shown to alter the mechanical loading and stress placed through the musculoskeletal system inducing a PAPE effect in dynamic activities involving the lower body[38]. Even though the execution of jumping exercises was based on previous findings, the fact that the exercise performed during competition was a body-weight based exercise, was possibly not enough to evoke PAPE. The aim to elicit improvements to start performance through this method should be addressed in the future.

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DECLARATION OF INTEREST STATAMENT

Authors have no conflict of interest into report.

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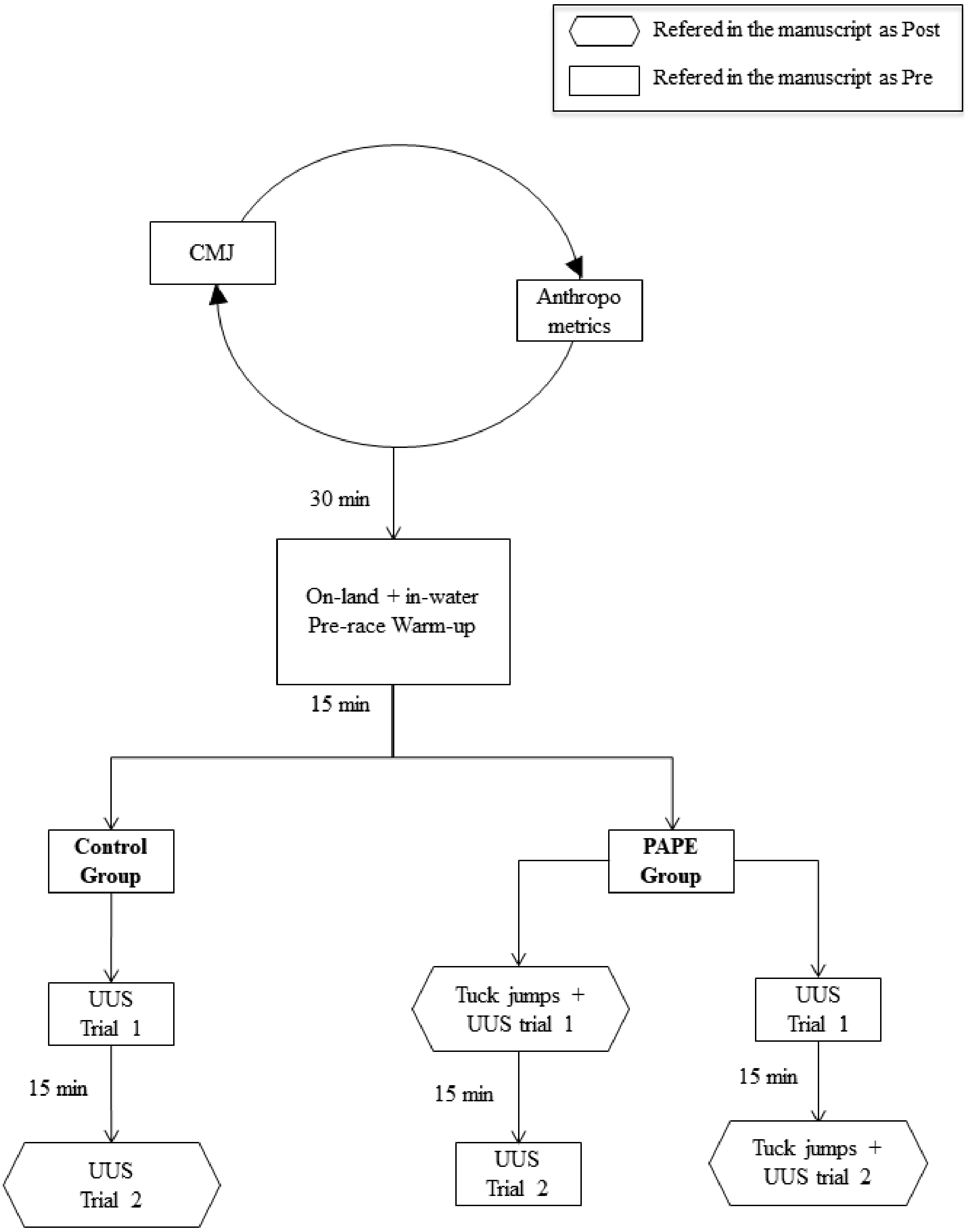
Figure 1. Layout of the experimental design.



CMJ, countermovement jump; UUS, undulatory underwater swimming; PAPE, post-activation performance enhancement.

Table 1. Descriptive statistics of the sample divided by sex.

	Variable	Control	PAPE	Difference [95%CI]	p-value
Male (n = 44)	Age (years)	14.96±1.28	15.52±1.61	0.56[-0.37, 1.49]	0.232
	Height (m)	1.75±0.06	1.73±0.07	-0.01[-0.05, 0.03]	0.611
	Body mass (kg)	65.17±7.83	64.21±10.81	-0.96[-6.81, 4.84]	0.741
	Arm span (m)	1.82±0.08	1.83±0.09	0.01[-0.04, 0.06]	0.648
	FINA points	592±58	602±65	10[-28, 50]	0.580
Female (n = 48)	Age (years)	13.99±1.51	14.88±1.62	-0.89[-0.05, 1.84]	0.065
	Height (m)	1.63±0.07	1.65±0.04	0.01[-0.02, 0.05]	0.341
	Body mass (kg)	55.11±9.62	57.58±6.25	-2.46[-2.14, 7.07]	0.287
	Arm span (m)	1.68±0.09	1.71±0.07	0.03[-0.01, 0.07]	0.204
	FINA points	602±77	623±61	20[-19,61]	0.306

Table 2. Differences between Pre and Post tuck jumps intervention for Control and PAPE groups (In case of the control group "PRE" refers to the first UUS trial and "POST" to the second UUS trial").

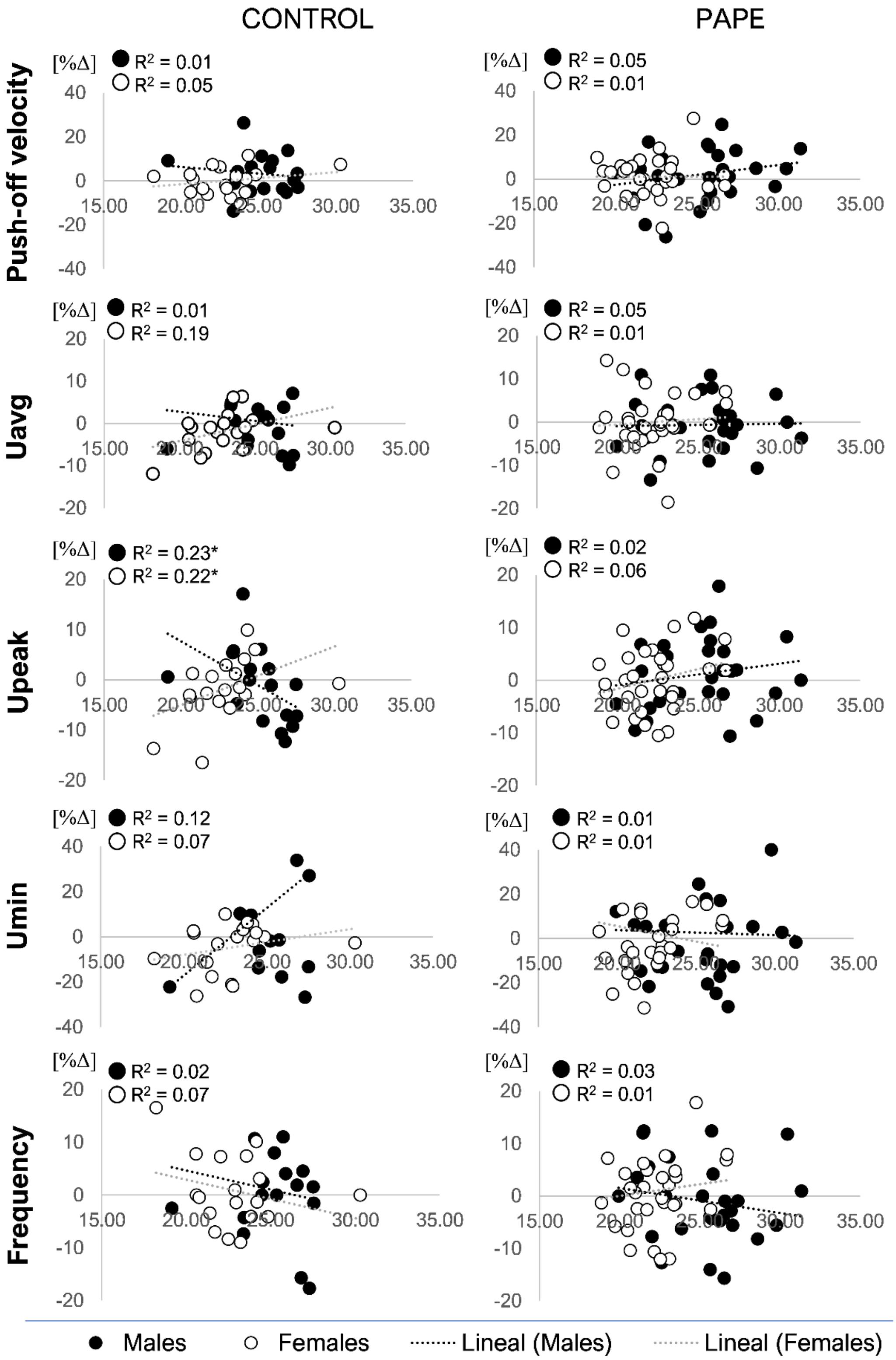
Group	Sex	Variable	PRE	POST	Difference [95%CI]; %Δ	p-value	Effect size
CONTROL GROUP	Male	Push-off velocity ($m \cdot s^{-1}$)	2.89±0.24	2.96±0.40	0.08[-0.22, 0.05]; 3.02%	0.199	0.32
		Uavg ($m \cdot s^{-1}$)	1.29±0.10	1.30±0.12	<-0.01[-0.05, 0.04]; 0.36%	0.848	0.04
		Upeak ($m \cdot s^{-1}$)	1.94±0.21	1.91±0.15	0.03[-0.04, 0.11]; -1.81%	0.355	0.23
		Umin ($m \cdot s^{-1}$)	0.59±0.16	0.65±0.19	-0.05[-0.13, 0.03]; 8.96%	0.205	0.32
		Frequency (Hz)	1.94 ±0.28	1.95±0.35	-0.01[-0.11, 0.08]; 0.81%	0.745	0.08
	Female	Push-off velocity ($m \cdot s^{-1}$)	2.43±0.34	2.43±0.32	<-0.01[-0.06, 0.07]; -0.16%	0.912	0.02
		Uavg ($m \cdot s^{-1}$)	1.16±0.19	1.14±0.20	0.02[-0.01, 0.04]; -1.75%	0.120	0.38
		Upeak ($m \cdot s^{-1}$)	1.60±0.21	1.56±0.24	0.03[-0.02, 0.07]; -1.49%	0.306	0.24
		Umin ($m \cdot s^{-1}$)	0.75±0.21	0.71±0.19	0.04[-0.01, 0.08]; -5.33%	0.082	0.43
		Frequency (Hz)	1.92±0.38	1.92±0.47	<-0.01 [-0.06, 0.05]; 0.34%	0.816	0.05
PAPE GROUP	Male	Push-off velocity ($m \cdot s^{-1}$)	2.96±0.33	3.00±0.43	-0.04[-0.18, 0.09]; 1.54%	0.499	0.13
		Uavg ($m \cdot s^{-1}$)	1.35±0.19	1.34±0.19	0.01[-0.02, 0.04]; -0.82%	0.469	0.14
		Upeak ($m \cdot s^{-1}$)	1.93±0.24	1.95±0.23	-0.01[-0.06, 0.03]; 0.87%	0.505	0.13
		Umin ($m \cdot s^{-1}$)	0.63±0.23	0.62±0.21	0.01[-0.04, 0.05]; -0.30%	0.937	0.01
		Frequency (Hz)	1.93±0.27	1.91±0.23	0.03[-0.03, 0.08]; -1.43%	0.320	0.19
	Female	Push-off velocity ($m \cdot s^{-1}$)	2.53±0.29	2.55±0.33	-0.02[-0.09, 0.05]; 0.87%	0.553	0.11
		Uavg ($m \cdot s^{-1}$)	1.21±0.21	1.22±0.23	>-0.01[-0.02, 0.02]; 0.16%	0.884	0.02
		Upeak ($m \cdot s^{-1}$)	1.66±0.23	1.66±0.26	>-0.01[-0.03, 0.03]; 0.08%	0.938	0.01
		Umin ($m \cdot s^{-1}$)	0.76±0.25	0.77±0.27	>-0.01[-0.05, 0.05]; 0.22%	0.951	0.01
		Frequency (Hz)	1.99±0.35	2.01±0.39	-0.02[-0.07, 0.03]; 0.91%	0.487	0.12

Uavg, Average underwater velocity; Upeak, Average underwater peak velocity; Umin, Average underwater minimum velocity.

Table 3. Comparison of Post-Activation Performance Enhancement (PAPE) effect in male and female

Variable	Male	Female	Difference [95%CI]	p-value
Push-off velocity ($m\cdot s^{-1}$)	-0.04±0.34	-0.02±0.20	0.02 [-0.17, 0.13]	0.756
Uavg ($m\cdot s^{-1}$)	0.01±0.07	<-0.01±0.07	0.01 [-0.02, 0.05]	0.521
Upeak ($m\cdot s^{-1}$)	-0.01±0.13	<-0.01±09	-0.01 [-0.07, 0.04]	0.602
Umin ($m\cdot s^{-1}$)	<0.01±0.12	<-0.01±0.14	<-0.01[-0.06, 0.07]	0.922
Frequency (Hz)	0.02±0.14	0.01±0.14	0.04 [-0.02, 0.12]	0.228

Figure 2. Linear regression analysis between the CMJ-force normalized by body-weight and the relative change [%Δ] in performance after the interventions. * Statistical significance ($p < 0.05$).



Uavg, Average underwater velocity; Upeak, Average underwater peak velocity; Umin, Average underwater minimum velocity.