

ORIGINAL PAPER **OPEN ACCESS**

# Effect of Underwater Swimming on Physiological and Perceptual Parameters in Competitive Swimmers: A Comparison With Surface Swimming

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**Received:** 26 September 2025 | **Revised:** 2 April 2026 | **Accepted:** 16 April 2026

**Keywords:** apnea training | metabolic response | swimming performance | underwater maximal effort

## ABSTRACT

In competition, swimmers alternate between swimming on the surface and underwater; they therefore train in apnea to improve their tolerance to lack of oxygen during exercise, even though research in this area remains limited. The aim of the study was to investigate the impact of underwater swimming on physiological and perceptual responses of competitive swimmers. Eighteen national level swimmers ( $700.25 \pm 53.42$  AQUA points) performed  $6 \times 25\text{m}$  maximal swimming efforts from a push start with 3 minutes rest in three different conditions: underwater (without breathing), surface (with normal breathing pattern) and competitive (composed of an underwater plus a surface swimming segment) swimming. Swimming performance (T25), gases exchange, heart rate (HR), arterial oxygen saturation ( $\text{SpO}_2$ ), blood parameters, rating of perceived exertion (RPE) and subjective feeling (FS) were measured. The underwater condition produced a greater increase in blood lactate (Lac) ( $p < 0.05$ ;  $\eta^2 = 0.67$ ) and potassium ( $p < 0.05$ ;  $\eta^2 = 0.35$ ) than the surface and competitive conditions. No significant differences ( $p > 0.05$ ) were observed in HR,  $\text{SpO}_2$  or RPE, whereas FS values were lower (more unpleasant) in the underwater swimming condition. However, oxygen uptake ( $\text{VO}_2$ ) was significantly lower ( $p < 0.003$ ;  $\eta^2 = 0.09$ ) in underwater than in competitive swimming. This study shows that a set of 25m underwater swimming efforts at maximum intensity generates an intense muscular, perceptive and metabolic demand in competitive swimmers, well tolerated by young trained competitive swimmers.

## 1 | Introduction

During aquatic sport disciplines, athletes must manage periods of time when they voluntarily hold their breath due to aquatic constraint while performing vigorous physical task related to the specific sport discipline goal. Breath holding is also known as apnea (Fitz-Clarke 2018). It has been reported that artistic swimming athletes spend half the time of their technical routines (between 2 and 4 min) in apnea (Homma 1994) with

immersions of up to 20 s (Rodríguez-Zamora et al. 2013). In swimming, competitive pool swimmers in front-crawl events spend over 30% of the total race time swimming underwater on the start and turn segments (Pla et al. 2021).

Breath-holding in human body is characterized by a cardiovascular response, the so-called diving response, where the oxygen body reserves are mobilized toward the heart and brain (Lindholm and Lundgren 2009) to prevent hypoxia-related

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## Highlights

The findings of this study provide new insights into the physiological and perceptual effects of maximal underwater swimming efforts in competitive swimmers. Unlike previous research, which focused primarily on apnea-related constraints during surface swimming (Guimard et al., 2017, 2018), our results highlight the intense metabolic and muscular demands induced by underwater swimming. However, this training method is well tolerated by the swimmers under the specific experimental conditions of this study. Given the increasing emphasis on optimizing underwater phases in competitive swimming, these results could have direct implications for training strategies aimed at improving underwater efficiency without compromising swimmers' tolerance.

damage (Alboni et al. 2011). Bradycardia and peripheral vasoconstriction are the main mechanisms to prevent this damage (Asmussen and Kristiansson 1968; Sterba and Lundgren 1988). In addition, a rise in blood pressure, reduced cardiac output and an increase in sympathetic activity are also noted (Ferrigno et al. 1997; Leuenberger et al. 2001). Moreover, apnea induces hypercapnia (elevated partial pressure of CO<sub>2</sub> in the blood), which impacts tissue oxygenation, Lac levels (Graham et al. 1980; Graham et al. 1986) and discomfort (headaches and higher pressure of cerebrospinal fluid) (West and Luks 2017). Lastly, hemoglobin and hematocrit values increase due to splenic contraction (Hurford et al. 1990; Schagatay et al. 2007). However, when breath-holding is combined with physical exercise, the O<sub>2</sub> conservation mechanisms conflict with the body's response to exercise such as increased HR (Alboni et al. 2011) hampering the recognition of physiological patterns related to exercise performance in apnea.

The inclusion of periods of voluntary apnea during physical activity has become an usual practice during training regimes to improve physical performance (Lemaître et al. 2010). It has been suggested that this method could increase tolerance to the lack of oxygen during exercise, in a similar way to natural hypoxia methods (Shah et al. 2020), although the information available on the effect of different apnea training methods is scarce (De Asís-Fernández et al. 2022). Apnea training could reduce blood acidosis, oxidative stress, while improving muscle buffer capacity and muscle oxidative and glycolytic metabolism (Joulia et al. 2002; Joulia et al. 2023; Woorons et al. 2008). Lastly, the interactions between mechanical, psychological and chemical factors defined the duration of the apnea (Hentsch and Ulmer 1984; Schagatay 2009), which suggests that exercise in apnea needs to be viewed using an integrative approach, combining physiological, psychological (and perceptual) parameters.

Previous studies on the physiological effect of apnea in swimming have mainly focused on the breathing patterns during surface swimming. A decrease in arterial O<sub>2</sub> saturation was found when swimming with the greatest apnea constraint (Guimard et al. 2014, 2017, 2018), but performance and HR remain unchanged (Guimard et al. 2018) or decreased (Guimard et al. 2014, 2017). The only study that examined the effect of underwater swimming segments (Veiga et al. 2022) showed no

changes in performance and HR but an increase in perceived effort. Although Veiga et al. (2022) found a tendency for lactatemia to increase, other studies focusing on apnea in surface swimming found no significant differences (Guimard et al. 2014, 2018). Consequently, there is a lack of evidence on underwater swimming, although this is an important section of competitive swimming that represents the longest apnea periods during races (Pla et al. 2021).

To investigate the effect of underwater swimming on the physiological and perceptual parameters of competitive swimmers, the present study compared maximal swimming efforts under different underwater and surface swimming conditions. We hypothesized that underwater swimming, because of the type of apnea exercise it involves, would lead to more changes in physiological and perceptual parameters than surface swimming.

## 2 | Methods

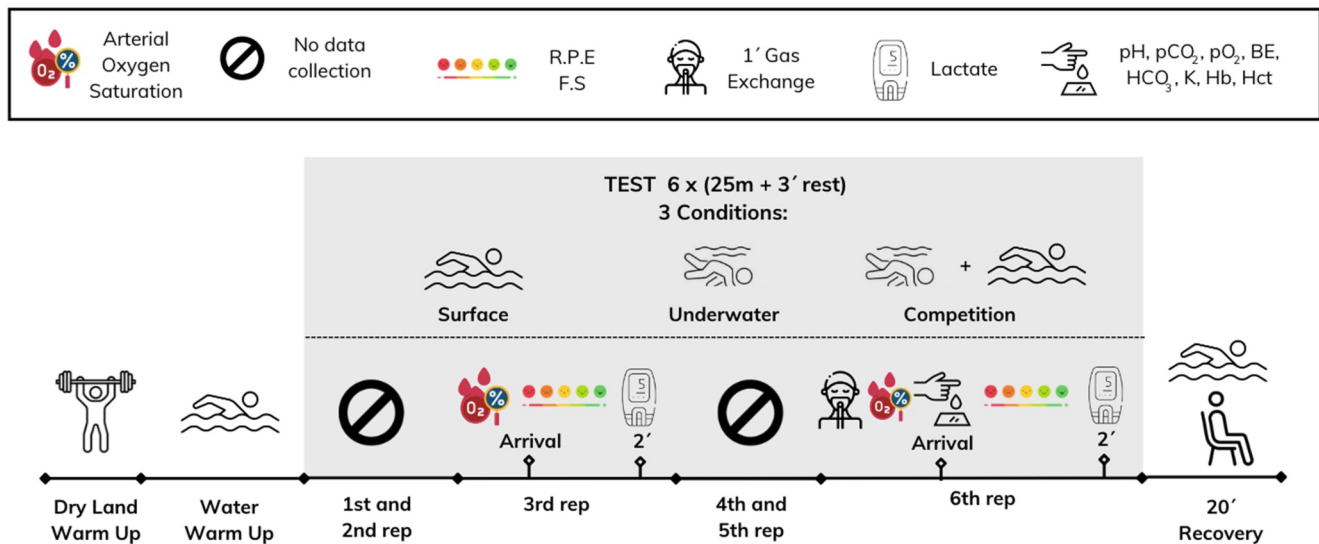
### 2.1 | Participants

Eighteen (9 males and 9 females) competitive swimmers (16.72 ± 0.73 years old; 65.32 ± 7.10 kg; 175.17 ± 6.82 cm) were recruited to participate in the present study. None of them had been trained in apnea and all of them belonged to a specialized training center, with an average weekly training frequency of nine in-water sessions and three out-of-water session. Their personal best times represented an average of 700.25 ± 53.42 points according to the World Aquatics Points Table, which fall within the range of the Level 3 (national) standardised performance level (Ruiz Navarro et al. 2022). The parents or legal tutors of all participants gave written consent for the experiment, and all procedures were designed according to the declaration of Helsinki and approved by the Technical University of Madrid (N° 2022–092)

### 2.2 | Experimental Procedures (Figure 1)

The experimental procedures were done in a 25m × 25m indoor swimming pool, with water temperature at 27°C. At their usual training schedule and after a standardized warm-up of approximately 15 min of dryland exercises and 1200m in-water, the swimmers performed six repetitions of 25m front-crawl swimming at maximum effort from push start (Trinidad et al. 2022). The 6 × 25m protocol was performed with 3 min of passive recovery between repetitions and repeated under three randomized conditions: Underwater (underwater undulatory kicking performed in ventral position), Surface (front-crawl swimming on the surface with a breathing pattern every four strokes and no underwater swimming segment), and Competitive (front-crawl swimming with the same breathing patterns and a free duration of the underwater swimming section after pushing off the starting wall) swimming. Each swimming condition was separated by a recovery period of 20 min, consisting of 5 min of passive recovery followed by 10 min of standardized active recovery and 5 min of passive recovery.

For each trial, the starting signal was provided by a custom trigger device (ORITIA & BOREAS, S.L., Spain) that emitted an acoustic signal for swimmers but also a visual signal by a LED light synchronized with the start command. One aerial video camera (Sony RX100 VII) filming at 30 Hz and with its optical



**FIGURE 1** | Experimental procedure of the study. Swimmers performed randomly  $6 \times 25$  m in three different conditions. For each day, trials were separated by a 20-min recovery. Measurements: Blood sample for lactate (Lactate), rating of perceived exertion (RPE), feeling scale (FS), partial pressure of carbon dioxide ( $p\text{CO}_2$ ), partial pressure of oxygen ( $p\text{O}_2$ ), base excess (BE), bicarbonate ( $\text{HCO}_3^-$ ), potassium (K), hemoglobin (Hb), hematocrit (Hct), arterial oxygen saturation and gas exchange.

axis perpendicular to the swimmers direction was situated at 1m from the finish wall and 2 m high and 5 m away from the water surface. The camera view captured the swimmers arrival to the finish wall and it was synchronized with the trials time code by capturing the LED light. 25-m swimming times (T25) on each repetition were computed to assess the trials performance.

During trials, swimmers wore a Polar Verity Sense (Polar Electro Inc., Bethpage, NY, USA) optical sensor to continuously register their HR. After the trials, the HR data for each swimmer were uploaded using Polar software (Polar Electro Inc., Bethpage, NY, USA). Arterial oxygen saturation ( $\text{SpO}_2$ ) was measured with a Portable Nellcor PM10 N (Nellcor, Pleasanton, CA, USA) device using an adhesive forehead sensor Max-Fast (Nellcor Pleasanton, CA, USA) at rest and during the first 30 s after the arrival of the third and sixth 25m repetition, in order to determine the lowest  $\text{SpO}_2$  ( $\text{SpO}_{2\text{min}}$ ). Capillary blood samples (100  $\mu\text{L}$ ) were taken at rest and immediately when finishing the sixth repetition of each 25m condition in order to measure pH, partial pressure of carbon dioxide ( $p\text{CO}_2$ ) and oxygen ( $p\text{O}_2$ ), base excess (BE), bicarbonate ( $\text{HCO}_3^-$ ), potassium (K), hematocrit (Hct) and concentration hemoglobin (Hb). These variables were evaluated by an i-STAT 1 handheld point-of-care clinical analyzer (Abbott, Princeton, USA) that it revealed reliable when testing maximal exercise (Dascombe et al. 2007). For the measurement of blood Lac (Lactate pro2, Arkay, Kyoto, Japan), 10  $\mu\text{L}$  of capillary blood was drawn from the fingertip at rest and 2 min after the end of the third and sixth 25 m repetitions of each condition. Gas exchanges were assessed before exercise and for 1 min immediately on arrival at the sixth repetition of 25m in each condition using a portable breath-by-breath gas exchange measurement system (K5, Cosmed, Rome, Italy). The rating of perceived exertion (RPE) scores and the subjective feeling (feeling of pleasure or displeasure) concerning the exercise performed (after the third and sixth 25m in each condition) were estimated by swimmers using the Borg CR-10 category-ratio scale (Borg 1982) and a Feeling Scale (FS) (Hardy and Rejeski 1989), respectively. The FS consists of 11 grades between  $-5$  and  $+5$ , combined with verbal information

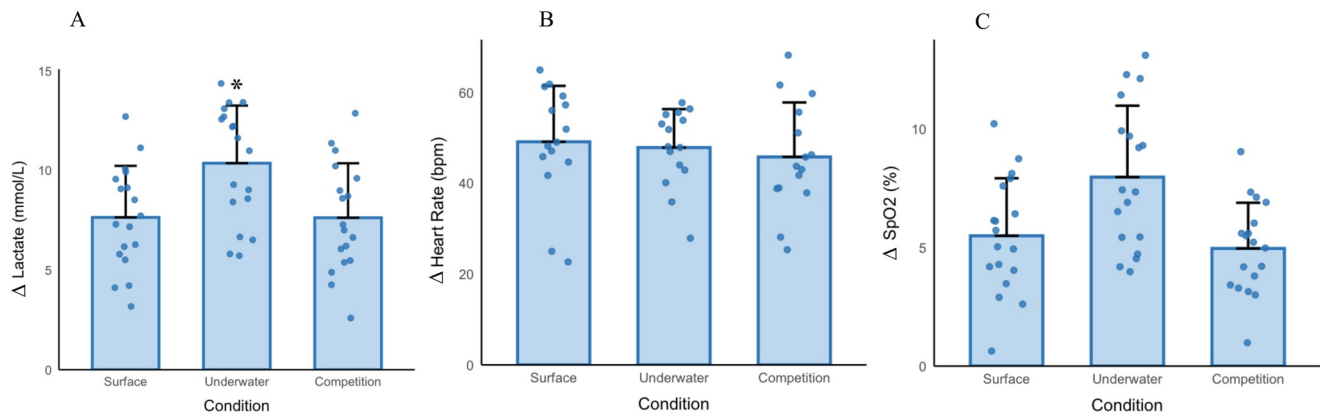
(ranging from “Very bad” for  $-5$  to “Very good” for  $+5$ ) and allows for the assessment of affective valence during exercise, reflecting the degree to which the experience is perceived as pleasant or unpleasant (Hardy and Rejeski 1989). All parameters, with the exception of T25, RPE and FS were expressed as changes by calculating the difference between pre- and post-exercise values.

### 2.3 | Statistical Analysis

Data are presented as mean values  $\pm$  standard deviation (SD). After screening for normality assumption (Kolmogorov-Smirnov normality test), analyses of variance (ANOVA) with repeated measures (condition: underwater, surface and competitive; and repetition: first to sixth, as intra-subject factors) were used to compare differences in Lac, FS, RPE, HR  $\text{SpO}_2$  and T25. For blood parameters and gas exchange, one-way repeated-measures ANOVA with condition as the within-subject factor was applied. In case of any statistical effect, a Bonferroni post-hoc test was used to locate the pairwise differences. The magnitude of statistical differences was presented as effect sizes, interpreted as partial  $\eta^2$  values. Threshold values for effect sizes were defined as small ( $\geq 0.01$ ), medium ( $\geq 0.06$ ), and large ( $\geq 0.14$ ) (Cohen 1988; Lakens 2013). The level of significance was  $p < 0.05$ .

### 3 | Results

Swimmers performed an underwater phase of  $7.11 \pm 1.54$  m from a push start, with an average duration of  $2.9 \pm 1.1$  s, during the competitive condition. Average T25 in the underwater condition were higher ( $p < 0.01$ ) than in surface and competitive swimming conditions. The exercise-induced increase Lac was greater in the underwater condition than in the other conditions. However, no differences between conditions were detected for HR or  $\text{SpO}_2$  values ( $p > 0.05$ ) (Figure 2). Despite a tendency toward a greater RPE during 25m efforts while underwater swimming, no statistical differences were detected between the three swimming



**FIGURE 2** | Changes in pre- and post-exercise in (A) blood lactate concentration (Lac), (B) heart rate (HR), and (C) arterial oxygen saturation (SpO<sub>2</sub>) following the 6 × 25 m protocol under underwater, surface, and competitive conditions. Data are presented as mean ± standard deviation (SD), with individual responses shown as dots. Changes were calculated by subtracting the pre-exercise values from the post-exercise values. \* indicates significant differences between underwater condition and the other conditions ( $p < 0.05$ ).

conditions. On the other hand, for the feeling scale, the values reported in the underwater condition were lower ( $p > 0.05$ ) than in the other conditions (Figure 3).

Table 1 shows no significant differences ( $p > 0.05$ ) in changes in pCO<sub>2</sub> and pO<sub>2</sub>, Hct, and Hb between the three conditions tested. The exercise-induced decrease in pH values tended to be greater in the underwater condition, although no significant difference was observed ( $p = 0.07$ ). The increase in potassium (K), and the decrease in bicarbonate (HCO<sub>3</sub><sup>-</sup>) and in base excess (BE) on exercise was greater in the underwater than in the surface and competitive conditions ( $p < 0.001$ ).

Table 2 shows no significant differences ( $p > 0.05$ ) in changes in VE and VCO<sub>2</sub> between underwater, surface and competitive conditions. However, the exercise-induced increase in VO<sub>2</sub> was significantly lower ( $p = 0.003$ ) in the underwater condition than in the competitive condition.

## 4 | Discussion

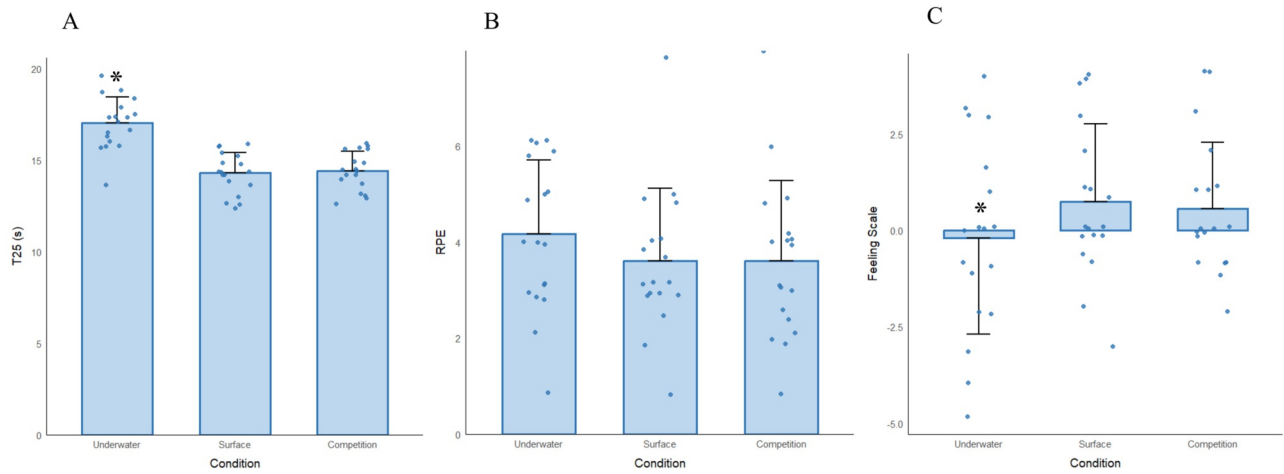
The aim of the study was to examine the impact of underwater swimming (and thus in apnea) on the physiological and perceptual parameters of competitive swimmers, compared to surface swimming (with normal breathing) and a mixed condition (competitive swimming alternating between apnea and normal breathing) during maximal efforts. The main finding is that underwater swimming over 25 m constitutes an intense muscular and metabolic demand while remaining well tolerated under the specific experimental conditions of the present study.

SpO<sub>2</sub> was not altered by the 25m underwater swim compared to the surface and competitive conditions. All swimmers had normal SpO<sub>2</sub> levels during exercise with none having SpO<sub>2</sub> levels below 95%, which would correspond to medically insufficient SpO<sub>2</sub> (Nunn 2017). (Guimard et al. 2014, 2018) reported a reduction in SpO<sub>2</sub> during surface swimming in apnea condition but these protocols included longer (50m) apnea distances (Guimard et al. 2018) or shorter recovery (25m every 30 s) between repetitions (Guimard et al. 2014). Indeed, (Fitz-Clarke 2018) showed that a decrease in SpO<sub>2</sub> is influenced by exercise duration and intensity. Although the intensity requested in our study was maximal, we can suggest that the 25m

sprint durations were too short (on average 17 s). This, combined with relatively long recovery periods, may have limited the development of cumulative hypoxic stress. Therefore, the absence of significant changes in SpO<sub>2</sub>, should be interpreted within the context of the experimental protocol and may reflect a protocol-specific effect rather than a general physiological response to underwater swimming. Consistently, no significant differences ( $p > 0.05$ ) were observed in changes in pO<sub>2</sub>, pCO<sub>2</sub>, as well as concerning Hct and Hb whatever the swimming condition.

However, we did observe a trend toward a more marked exercise-induced decrease in pH values in the underwater swimming condition. This could suggest physiological changes between underwater and surface swimming, explained by the progressive accumulation of Lac in the blood (associated with H<sup>+</sup> ions) observed in the full apnea condition, accompanied by a depletion of buffer system reserves. Indeed, the underwater swimming led to a greater exercise-induced increase in Lac than in the other two conditions. During intense exercise, high blood Lac levels are generally due to a greater contribution of anaerobic metabolism to energy production. This might be explained by the involvement of a greater number of glycolytic muscle fibers with a faster glycolytic rate and associated Lac production during underwater kicking compared to front-crawl swimming at the surface (Tesch et al. 1978). On the other hand, a greater decrease in HCO<sub>3</sub><sup>-</sup> and BE was noted on exercise in the underwater than in the other two conditions. As VE is sensitive to capnia and pH (Ogoh et al. 2009), it is logical that VE was not altered under the conditions of our study, since these factors were not significantly different either. Unlike surface swimming, where gas exchange has been examined a number of times (Monteiro et al. 2022, 2023; Reis et al. 2010), the specific constraints of underwater swimming make it impossible to measure gas exchange while swimming underwater. Consequently, gas exchange variables were measured in the present study only during the immediate post-exercise period and not during the swimming effort itself, which limits the interpretation of ventilatory responses during underwater swimming.

The exercise-induced VO<sub>2</sub> values in the underwater swimming condition decreased significantly compared to the competitive condition. VO<sub>2</sub> was only measured immediately after the last



**FIGURE 3** | Performance and perceptual responses during the 6 × 25 m protocol under underwater, surface, and competitive conditions: (A) swimming time (T25), (B) rating of perceived exertion (RPE), and (C) feeling scale (FS). Data are presented as mean ± standard deviation (SD), with individual responses shown as dots. \* indicates significant differences between underwater condition and the other conditions ( $p < 0.05$ ).

**TABLE 1** | Changes in pre- and post-exercise in pH, partial pressure of carbon dioxide ( $pCO_2$ ) and oxygen ( $pO_2$ ), bicarbonate ( $HCO_3^-$ ), base excess (BE), potassium (K), hematocrit (Hct), and concentration hemoglobin (Hb) during 6 × 25 m swimming protocol in underwater, surface or competitive conditions.

|                    | Underwater                              | Surface                           | Competitive                       | <i>p</i> -value | ES   |
|--------------------|-----------------------------------------|-----------------------------------|-----------------------------------|-----------------|------|
| pH                 | $-0.12 \pm 0.01$                        | $-0.09 \pm 0.01$                  | $-0.10 \pm 0.01$                  | 0.07            | 0.15 |
| $pCO_2$ (mmHg)     | $-3.52 \pm 1.17$                        | $-2.22 \pm 1.17$                  | $-2.17 \pm 1.09$                  | 0.22            | 0.09 |
| $pO_2$ (mmHg)      | $-4.43 \pm 2.89$                        | $-6.71 \pm 3.24$                  | $-5.43 \pm 4.59$                  | 0.74            | 0.02 |
| $HCO_3^-$ (mmol/L) | $-6.99 \pm 0.48^{a,b}$ [−7.23 to −6.75] | $-5.38 \pm 0.53$ [−5.64 to −5.12] | $-5.63 \pm 0.55$ [−5.9 to −5.36]  | 0.001*          | 0.44 |
| BE (mmol/L)        | $-8.92 \pm 0.67^{a,b}$ [−9.25 to −8.59] | $-6.92 \pm 0.62$ [−7.23 to −6.61] | $-7.24 \pm 0.66$ [−7.57 to −6.91] | 0.001*          | 0.42 |
| K (mmol/L)         | $0.28 \pm 0.06^{a,b}$ [0.25–0.31]       | $0.11 \pm 0.06$ [0.08–0.14]       | $0.06 \pm 0.08$ [0.02–0.1]        | 0.001*          | 0.35 |
| Hct (%)            | $2.06 \pm 0.47$                         | $1.40 \pm 0.42$                   | $1.52 \pm 0.42$                   | 0.16            | 0.11 |
| Hb (g/dL)          | $0.70 \pm 0.16$                         | $0.47 \pm 0.14$                   | $0.51 \pm 0.14$                   | 0.13            | 0.12 |

Note: Values are presented as mean ± SD, with 95% confidence intervals [CI] shown in brackets. Changes were calculated by subtracting the pre-exercise values from the post-exercise values.

\*Statistical effect due to condition ( $p < 0.05$ ).

<sup>a</sup>Statistical differences ( $p < 0.05$ ) between underwater and surface condition.

<sup>b</sup>Statistical differences ( $p < 0.05$ ) between underwater and competitive condition.

**TABLE 2** | Changes in pre- and post-exercise in ventilation (VE), oxygen uptake ( $VO_2$ ), carbon dioxide production ( $VCO_2$ ) during 6 × 25 m swimming protocol in underwater, surface or competitive conditions.

|                  | Underwater                              | Surface                                 | Competitive                             | <i>p</i> -value | ES   |
|------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------|------|
| VE (L/min)       | $52.30 \pm 17.20$ [43.76–60.84]         | $50.1 \pm 17.14$ [41.58–58.62]          | $50.29 \pm 12.80$ [43.92–56.66]         | 0.685           | 0.09 |
| $VO_2$ (ML/min)  | $1970.22 \pm 438.76^a$<br>[1752–2188.4] | $2163.02 \pm 629.60$<br>[1849.9–2476.1] | $2332.91 \pm 598.82$<br>[2034.9–2630.9] | 0.003*          | 0.89 |
| $VCO_2$ (ML/min) | $1769.08 \pm 407.70$<br>[1566.3–1871.9] | $1779.64 \pm 541.42$<br>[1510.4–2048.8] | $1882.28 \pm 443.11$<br>[1661.8–2102.8] | 0.192           | 0.30 |

Note: Values are presented as mean ± SD, with 95% confidence intervals [CI] shown in brackets. Changes were calculated by subtracting the pre-exercise values from the post-exercise values.

\*Statistical effect due to condition ( $p < 0.05$ ).

<sup>a</sup>Statistical differences ( $p < 0.05$ ) between underwater and competitive condition.

repetition and therefore reflects early post-exercise recovery responses rather than the metabolic cost of the swimming effort itself. Consequently, these results should be interpreted with caution and cannot be considered a direct indicator of oxygen demand during underwater swimming. Several hypotheses can be put forward. Firstly, in contrast to land-based sports,

hydrostatic pressures make the respiratory muscles work harder in swimming (Ray et al. 2008). The absence of breathing movements during apnea could affect  $VO_2$  values, although this interpretation remains speculative, as respiratory muscle activity was not directly assessed in the present study. Secondly,  $O_2$  reserves (e.g., in blood or myoglobin in muscles) were sufficient. On

the basis of the results of the present study, it could be suggested that this type of training does not produce the adaptations that might be expected from lower oxygen availability, unless perhaps the 25m is repeated, the recovery time reduced or the underwater swimming distance/duration lengthened. This also means that coaches can use the selected interval set with maximum underwater swimming intensity, which is well tolerated in terms of SpO<sub>2</sub> for trained competitive swimmers.

No statistically significant differences in HR were found between the different conditions, but it is worth mentioning that there appears to be no (significant) effect of bradycardia during the underwater swimming condition. It is well established that the intensity of the diving response (and resulting bradycardia) is influenced not by diving depth but by apnea duration (Bosco et al. 2007; Schagatay 2009; Schagatay and Andersson 1998). Previous research has shown that the time required to reach the maximum bradycardic response averages only 34 s (Caspers et al. 2011), which is similar to the baroreceptor reflex (maximum feedback gain at around 10 s) and the chemoreceptor reflex (around 45 s). The duration of apnea during the test was perhaps too short, and the recovery time was sufficient to produce the convincing effects mentioned. In addition, participants were asked to perform the test at the maximum possible intensity, thereby increasing HR, which could counteract the effects of bradycardia. It has also been shown that swimmers with superior performance in 50-m front-crawl swim with restricted breaths exhibit a diminished diving reflex (Fujii et al. 2024). In addition, there is great individual variability in the response to apnea (Lindholm et al. 2002) and the decrease in HR can range from 15% to 40% (Alboni et al. 2011) which makes analysis of this variable even more difficult. Consequently, the results of the present study concerning HR appear to be in agreement with the existing literature, suggesting that 25m of apnea swimming does not result in bradycardia.

We noted an increase in blood K values in all three conditions, but this was significantly greater in underwater than in surface and competitive conditions, indicating stimulation by intense exercise and greater muscular suffering in this condition. Indeed, the main cause of increased rate and magnitude of net K release from contracting muscles is the electrical activity of exercising muscles (Wasserman et al. 1997) due to an increased recruitment motor units (and therefore muscle fibers) (Vøllestad and Blom 1985). Despite the electrical activity was not measured in our study, and considering swimmers used different swimming styles over the three trials, it could be suggested that underwater swimming requires the legs to exert much greater force during the dolphins kicking despite front-crawl swimming involving more muscle groups. Even if only the lower limbs are used, the muscle solicitation is higher.

With regard to psychophysiological variables, a tendency toward a higher effort perception (RPE) was observed during 25m efforts in underwater swimming without reaching statistical significance. Previous studies had observed higher RPE values when swimming at the surface at a 400 m pace in apnea compared to normal breathing (Guimard et al. 2018) and when the swimmers have completed longer underwater turn sections during 200m race pace trials (Veiga et al. 2022). Given that the exercise in the present study was performed at maximum intensity in full apnea during the underwater swimming condition, we might have expected higher RPE values compared to

the other conditions. Yet apnea-induced hypercapnia is related to prolonged exercise duration (Woorons et al. 2008), which causes discomfort. In the present study, the duration of apnea during underwater swimming condition was short, and the recovery between repetition enabled isolated underwater swimming segments unlike race conditions. This could undoubtedly have affected the sensations perceived by the participants. Interestingly, there was a partial discrepancy between the RPE and FS results. The values recorded using the FS in the competitive were higher ( $p > 0.05$ ) than in the underwater condition. Swimmers felt “fairly good” in the competitive condition whereas they felt between “neutral” and “fairly good” in the underwater condition. This may be explained by the fact that the competitive condition allowed for a free distribution between underwater and surface swimming, in accordance with World Aquatics regulations. The RPE scale provides valuable information on a subjectively perceived effort, but it does not capture the affective experience associated with exercise in the same way that the FS does (Hardy and Rejeski 1989). Using it in combination with the FS offers a complementary approach that captures both perceived effort and affective valence during exercise. The same task at a given intensity may correspond to the same level of perceived exertion, but it may be experienced as more or less pleasant or unpleasant by the participant. In line with hedonic theory, individuals are more inclined to maintain activities that elicit positive affective responses and to avoid those associated with discomfort or displeasure (Higgins 1997). Integrating these two dimensions of athletes’ internal experience can improve the monitoring of training responses and support more informed coaching decisions. As such, the simultaneous assessment of RPE and FS represents a practical methodological advance in relation to underwater swimming.

Nevertheless, our study has limitations. Firstly, the depth at which swimmers effectively perform their underwater swimming does not allow us to measure gas exchange continuously during swimming. We therefore had to take measurements before and after each test swims. Secondly, the limited duration of apnea effort and extended recovery times between repetitions may have mitigated the cumulative effects of hypoxia and metabolic consequences, reducing the magnitude of the adaptations observed, such as bradycardia or a significant decrease in SpO<sub>2</sub>. In future research, an increase in distance and/or reduction in rest time could be investigated in competitive swimmers.

## 5 | Conclusions

Underwater swimming over 25m at maximum intensity generates greater muscular and metabolic demand with a greater perceived exertion compared to surface swimming with normal breathing or competitive conditions, while remaining well tolerated for trained swimmers. No significant differences were observed in HR or SpO<sub>2</sub>, suggesting that the duration of effort and recovery times were adequate to avoid desaturation or bradycardia. However, the underwater condition showed higher levels of Lac and K in the blood, as well as a tendency toward a more pronounced decrease in pH, reflecting high anaerobic exertion. The discrepancy between RPE and FS suggested that the subjective feeling of pleasure or discomfort may vary despite the physical demand of underwater swimming, and this may influence swimmers’ engagement and training adaptations.

These findings highlight that underwater swimming is a useful tool to stimulate metabolic and perceptive adaptations in competitive swimmers, while being effective for the population in this study within the parameters studied.

## Author Contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by all authors. Data treatment and data analysis were performed by C.S.S.B., A.G. and S.V. The first draft of the manuscript was written by S.V. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## Acknowledgments

We sincerely thank coaches and swimmers for their participation. We are grateful to the training facility M-86 for accommodating our measurements.

## Funding

The present study was funded within Project PID2021-124392NA-I00 by MCIN/AEI/10.13039/501100011033/FEDER, UE. CS was supported by a grant provided by Universidad Politécnica de Madrid and Banco Santander.

## Ethics Statement

The study complied with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments on human subjects and with the European Data Protection Regulation.

## Consent

Each participant provided written informed consent with the study approved by the Technical University of Madrid (N° 2022–092).

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

## Permission to Reproduce Material From Other Sources

The authors have nothing to report.

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