©Journal of Sports Science and Medicine (2023) **22**, 329-337
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.329

Research article

The Effects of Incorporating Dry-land Short Intervals to Long Aerobic-dominant In-Water Swimming Training on Physiological Parameters, Hormonal Factors, and Performance: A Randomized-Controlled Intervention Study

Huan Liu [1] and Jue Wang [2]✉
[1] Woosuk University, 443, Samnye-ro, Samnye-eup, Wanju-gun, Jeollabuk-do, 55338, South Korea
[2] Kookmin University, 77 Jeongeung-ro, Seongbuk-gu, Seoul, 02707, South Korea

Abstract

This study investigated the impact of a 4-week dry-land short sprint interval program (sSIT) on a swim ergometer, when incorporated into long aerobic-dominant in-water swimming training, on the physiological parameters, hormonal factors, and swimming performance of well-trained swimmers. Sixteen participants (age = 25 ± 6 years, height = 183 ± 6 cm, weight 78 ± 6 kg, body fat = 10.6 ± 3.1%) were randomized to either a long aerobic-dominant in-pool training plus three sessions/week of sSIT or a control group (CON) who didn't engage in SIT. sSIT consisted of 3 sets of 10 × 4 s, 10 × 6 s, and 10 × 8 s *all-out* sprints interspersed by 15, 60, and 40 s recovery between each sprint, respectively. Pre- and post-training assessments included peak oxygen uptake ($\dot{V}O_2peak$), O_2pulse ($\dot{V}O_2/HR$), ventilation at $\dot{V}O_2peak$ ($\dot{V}_E@\dot{V}O_2peak$), peak and average power output, and freestyle swim performance at 50, 100, and 200-m distances, stroke rate, as well as testosterone and cortisol. sSIT resulted in significant improvements in $\dot{V}O_2peak$ (5.8%), O_2pulse (4.7%), $\dot{V}_E@\dot{V}O_2peak$ (7.1%), peak and average power output (6.7% and 13.8%, respectively), total testosterone (20%), testosterone to cortisol ratio (16.1%), and 50, 100, and 200-m freestyle swimming performance (-2.2%, -1.2%, and -1.1%, respectively). Furthermore, the observed alterations in the physiological, biochemical, and performance adaptations were significantly more substantial in the sSIT group than the CON group ($p \le 0.05$), demonstrating no modifications during the 4-week long aerobic-dominant in-water swimming without sSIT. The current research effectively established that supplementing standard long aerobic-dominant in-water swim training with three weekly dry-land sSIT sessions triggers adaptive mechanisms that foster enhancements in the aerobic and anaerobic capacity and swimming performance in well-trained swimmers.

Key words: Oxygen consumption, power output, hormonal response, athletic performance, conditioning, swim ergometer

Introduction

Physical conditioning is a critical component of training strategies aimed at enhancing the fitness levels of swimmers (Kwok et al., 2021). Conditioning programs are designed with specific interventions tailored to the characteristics of the discipline in which the athlete competes (Laursen and Buchheit, 2019). Swimming competitions are characterized by varying durations, ranging from approximately 21 s (50 meters) to 15 min (1500 meters) [International Swimming Federation (Fina)]. The energy demands of a swim competition vary according to the distance, with differing proportions of anaerobic and aerobic pathways supplying the required energy (Almeida et al., 2020; Capelli et al., 1998). Relative to the total energy expenditure, estimates indicate that the aerobic pathway, lactic, and alactic anaerobic systems contribute 15.3%, 58.9%, and 25.8%, respectively, for a 45.7-meter swim; 33.3%, 47.2%, and 19.6%, respectively, for a 91.4-meter swim; and 61.5%, 24.7%, and 13.8%, respectively, for a 182.9-meter swim (Capelli et al., 1998). Given these findings, enhancing both anaerobic and aerobic metabolic pathways is crucial for improving short to middle-distance swimming performances and should be of practical interest.

Swimmers usually undergo long aerobic-dominant training at low to moderate intensity levels (Sharp, 2000). However, expert coaches suggest that superior performances are achieved through emphasizing the training efficiency (quality), rather than high volumes (quantity), leading to better performances. They believe senior swimmers often benefit more from high-quality training programs (Marinho et al., 2020; Nugent et al., 2017). To achieve this objective, swimmers periodically incorporate low-volume high-intensity interval training (HIIT) into their training regimen to increase the efficiency of their training in terms of physiological and performance adaptations. Sprint interval training (SIT) is a widely used modality of HIIT to improve physiological adaptations and functional exercise capacity by swimmers (Pinos et al., 2021a and 2021b; Williamson et al., 2020; Bielec et al., 2016). The potency of SIT in promoting power output as well as central and peripheral adaptations associated with aerobic fitness is well-established (Boullosa et al., 2022; Vollaard et al., 2017; Bayati et al., 2011). A standard SIT regimen typically comprises 4 to 12 bouts of approximately 10 to 30 s, with rest intervals adjusted to target specific adaptive responses sought by the athlete (Kabasakalis et al., 2020). However, recent research indicates that protocols involving shorter sprints (≤ 10 s) may be more time-efficient than traditional SIT approaches (Vollaard et al., 2017).

Short sprint interval training (sSIT), characterized by ≤ 10 s efforts, has been proposed as an alternative to traditional SIT due to its ability to elicit similar adaptive responses while improving enjoyment and reducing the rate of perceived exertion (Benítez-Flores et al., 2018; McKie et al., 2018). The use of sSIT has been shown to elicit higher mechanical responses and lower peripheral fatigue due to reliance on the ATP-PCR pathway and reduced glycolytic activity (Boullosa et al., 2022). While some studies have investigated the acute physiological re-

Received: 08 March 2023 / Accepted: 21 May 2023 / Published (online): 01 June 2023

sponse to sSIT interventions in swimmers, few have examined the cardiorespiratory system, biochemical, and performance adaptations to dry-land sSIT (Pinos et al., 2021a; 2021b; Bielec et al., 2016). However, this is unclear if incorporating this intervention into long aerobic-dominant swim training would result in enhancing adaptive response and randomized-controlled intervention studies investigating the addition of a sport-specific dry-land sSIT to in-water long aerobic-dominant swim training, with outcome measures on physiological parameters and swimming performance, are scarce. Accordingly, this experiment aimed to investigate the efficacy of incorporating a discipline-specific dry-land sSIT to in-water long aerobic-dominant swim training over four weeks on aerobic and anaerobic power and short and middle-distance freestyle swimming performance in well-trained swimmers. We hypothesized that this approach would sufficiently stimulate adaptive mechanisms, improving these athletes' physiological parameters, hormonal factors, and swimming performance in short and middle-distance events.

Methods

Participants

Sixteen male swimmers experienced in freestyle short and middle-distance events gave informed consent and volunteered to participate. On average, they were 25 ± 6 years old, 183 ± 6 cm tall, weighed 78 ± 6 kg and had a body fat percentage of 10.6 ± 3.1%. Additionally, the swimmers had an average of 12 ± 5 years of experience. The participants in this study had a minimum training frequency of eight sessions per week and had consistently taken part in national-level competitive events for at least five years. According to the classification established by McKay et al. (2022), these athletes were categorized as well-trained. Before starting the study, all participants were medically screened to ensure they had no underlying health conditions that would put them at risk during intensive exercise. They were then randomized into two sSIT and control (CON) groups. Each group consisted of eight participants. The study received the approval of the ethical committee of Kookmin University and followed the guidelines of the Declaration of Helsinki.

Experimental design

The order and methodology of the tests utilized in this study are presented in Figure 1. To assess the training program's impact, the participants completed a progressive incremental exercise test to determine their aerobic power and related physiological parameters before and after the intervention. They also undertook an *all-out* 6 s and 30 s test using a swim ergometer (VASA, Essex Junction, VT, USA) to measure their peak power output [PPO (6 s)] and average power output [APO (30 s)]. Additionally, separate days were allocated for assessing their freestyle swimming performances in 50, 100, and 200-m distances. A bioimpedance analyzer was employed to analyze the participant's body composition (Inbody 270, Biospace Co, Ltd., Korea). The incremental exercise test and freestyle swimming performance test were carried out in an indoor swimming pool that measured 25 meters in length, and the water temperature was maintained at approximately 27.5ºC. To ensure adequate recovery time, there was a gap of 48 h between each physiological and performance test. The participants were advised to avoid strenuous physical activity and alcohol ingestion for at least 24 h before each testing session. They were also instructed to maintain a consistent diet for two days before the baseline testing and again before the post-training test session (Barzegar et al. 2021). After finishing the training program, all participants underwent the same set of tests they had taken before the training. The tests were conducted under comparable conditions and in the same sequence 48 h after their final training session.

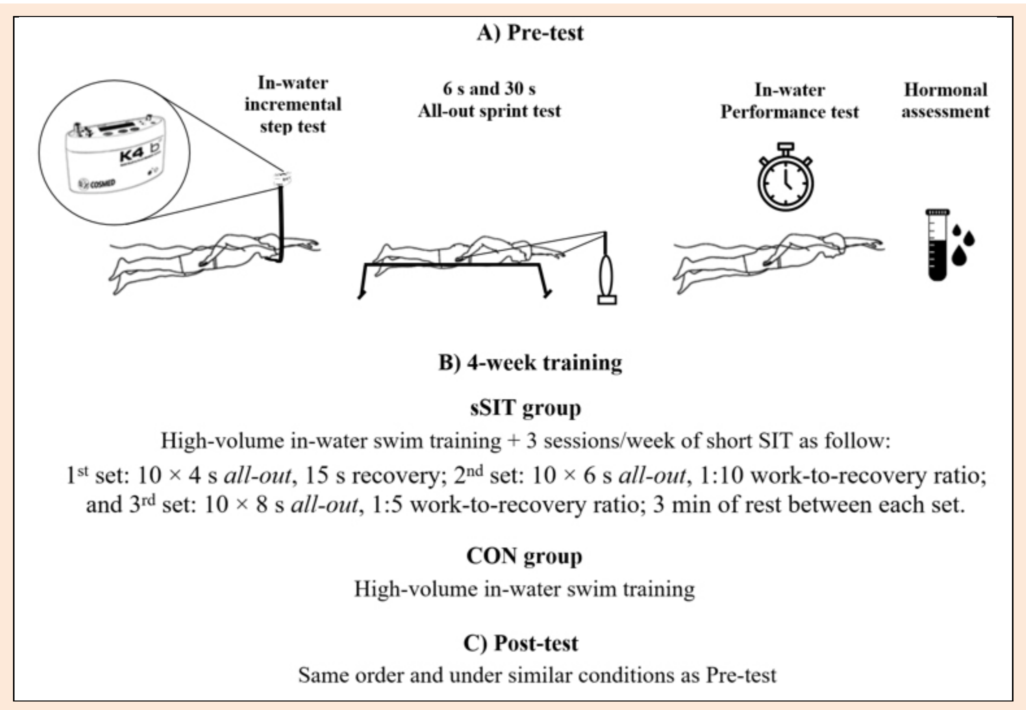

Figure 1. Overview of experimental protocol.

Incremental exercise test

A discontinuous incremental step test was performed to assess participants' physiological parameters. Each participant in the study underwent a personalized intermittent total protocol. The speed was increased by 0.05 m s^{-1} during seven 200-m stages, including 30 s intervals between each stage until the point of exhaustion was reached. The initial phase's speed was pre-determined based on the athlete's 400-meter best time in front crawl, subtracted by seven increments of velocity. The participants were assessed by starting in the water and involving open turns that did not include gliding beneath the surface. The continuous measurement of physiological parameters was carried out using a telemetric portable breath-by-breath gas collection system (K4b^2, Cosmed, Rome, Italy) connected the swimmer using a respiratory snorkel with low hydrodynamic resistance and a valve system (AquaTrainer®, Rome, Italy). The gas analyzer was calibrated per the manufacturer's guidelines before each test and accompanied the swimmers throughout the trial. Previous research has validated the use of swimming snorkels for collecting $\dot{V}O_2$ data, showing that they do not significantly affect the swimmer's $\dot{V}O_2$ response (Baldari et al., 2013). Blood lactate [La^-] levels were analyzed by collecting blood samples from the earlobe before and during the 30 s intervals between the stages. The participants were evaluated based on primary and secondary traditional criteria to decide whether or not they had reached their $\dot{V}O_2$peak. These criteria included a leveling off in $\dot{V}O_2$ despite elevation in swimming intensity, blood lactate acid concentrations reaching eight mmol l^{-1} or higher, an elevated RER > 1:1, a peak heart rate that was at least 90% of the maximum predicted for the athlete's age, and clear signs of exhaustion (Neto et al., 2022; Menz et al., 2019; Fereshtian et al., 2017). The speed at which $\dot{V}O_2$peak was achieved during the exercise was referred to as v$\dot{V}O_2$peak. A submerged visual indicator featuring flashing lights (TAR.1.1, GBK electronics, Aveiro, Portugal) at the pool's base was utilized to control the pace of the intervals.

Swim ergometer test

Two maximal ergometer tests were completed on a stationary swim ergometer, adequately calibrated per the manufacturer's guidelines. Previous studies have shown a strong correlation between anaerobic power measured using a swim bench and in-water swimming performance (Pinos et al., 2021a; Johnson et al., 1993), which served as the basis for the current testing protocol. The tests aimed to assess the PPO and APO, which are determined based on the power output generated during a 6 s sprint at maximum effort and the power output produced during a 30 s maximal effort, respectively. Before the tests, participants completed a standardized warm-up consisting of ten incremental pulls that progressively increased in intensity from light to submaximal levels (Pinos et al. 2021a). The 6 s and 30 s maximal sprints were performed at zero resistance to ensure that participants could exert maximal power throughout the test (Pinos et al., 2021b).

Freestyle swimming performance

In separate testing sessions 48 h apart and under swimming competition conditions, participants performed short-course freestyle swimming at distances of 50, 100, and 200-m. Before the test, participants underwent a standardized warm-up procedure as described by Neiva et al. (2014). An audio signal was given to commence the test, and the athlete began with a dive start. The duration of each trial was measured by two proficient timekeepers using a stopwatch (SEIKO S120-4030, Tokyo, Japan), and the average value of both measurements were documented for each trial. The stroke rate was measured over the middle 10-m of the pool by timing three complete stroke cycles with a stopwatch and expressed in cycles per minute. The same testing conditions were maintained before and after the training period.

Blood sampling and hormonal assessment

Swimmers attend the laboratory in the morning after fasting for at least 8 h overnight. They were asked to avoid intense physical activity and alcohol consumption 24 h before the blood test. A 10-milliliter sample was collected using venipuncture. The sample was spun at 3,000 rpm for 15 min at 4ºC, and 7 milliliters of plasma were stored at -80ºC until cortisol and total testosterone analysis. Three milliliters of the venous blood sample were used to analyze the complete blood cell count with an automated cell counter (LUNA-II™ Automated Cell Counter, Anyang, South Korea). The cortisol and testosterone levels in the serum were assessed by utilizing enzyme-linked immunosorbent assay kits (CD creative diagnostics, NY, USA) with an intra-assay CV of 9.32% for cortisol and 3% for testosterone.

Training program

Participants in the study began their exercise training programs about 48 h after baseline measurements were taken. The sSIT and CON groups received the same long aerobic-dominant in-water swimming training, consisting of five weekly sessions lasting between 90 - 100 min. The training program consisted of moderate intensity sets with short recovery time in front crawl and technical training in the medley. Each session included a total training volume of 5000 ± 500 meters. In addition, both groups participated in one day per week of Fartlek training and two sessions per week of resistance training. The resistance training involved 3 × 8-12 repetitions at 65 - 75% of one repetition maximum using various exercises such as horizontal leg presses, lat pull-downs, bench presses, triceps rope, elbow extensions, and bent arm flys.

In addition to in-water swim training, the sSIT group engaged in three sessions of ergometer-based sSIT protocol a week, but not the CON group. Our protocol consisted of 30 sprints, including three sets of 10 × 4 s, 10 × 6 s, and 10 × 8 s, with a 3 min rest between sets. In the first set, recovery time between sprints was set at 15 s to elicit a greater percentage of $\dot{V}O_2$peak (Satiroglu et al., 2021). In the second and third sets, the work-to-recovery ratio was set at 1:10 for maintenance of power generation (Vardarli et al., 2021) and 1:5 to maximally engage glycolytic systems (Price and Moss, 2007) and aerobic power (Satiroglu et al., 2021). Participants recovered passively between sprints. The swimmer used both arms to pull during each stroke to achieve maximum power generation and minimize the possibility of shoulder injury caused by excessive internal rotation of the glenohumeral joint (Pinos et al., 2021a).

Because utilizing an ergometer with zero resistance allows swimmers to achieve maximum anaerobic power (Pinos et al., 2021a) quickly and perform trials at maximal intensity, we chose to utilize an ergometer.

Statistical analyses

SPSS software (version 25.0; IBM Analytics, Armonk, NY), and G*Power software [Version 3.1; Christian-Albrechts-Universität Kiel, Kiel, Germany (Faul et al., 2007)] were recruited to run statistical analyses and to establish sample size, respectively. With an effect size of 0.8, an alpha error of 0.05, and β of 0.08, the initial estimation for the sample size was a minimum of six participants in each group. However, to account for potential participant dropout during data collection, the sample size was subsequently increased to eight participants per group. Results were presented as mean ± standard deviation. Levene's and Shapiro-Wilk's tests checked the data's homogeneity and the variances' normality, respectively. A 2 × 2 [time (pre- and post-training) × group (sSIT and CON)] mixed ANOVA analyzed the difference between changes in groups. Eta squared (η^2) was reported as the estimate of effect size for ANOVA and interpreted as: (i) minimum if $0.04 < \eta^2 \leq 0.25$; (ii) moderate if $0.25 < \eta^2 < 0.64$; and (iii) strong if $\eta^2 > 0.64$ (Ferguson, 2009). Pearson product-moment correlations assessed the relationship between the variables, and α level of 0.05 was established for the statistical analysis.

Results

Change in gas exchange variables

Table 1 displays the participants' average values of physiological variables before and after training, whereas Figure 2 shows the alterations in $\dot{V}O_2$peak over time. A significant time-regimen interaction ($p \leq 0.05$) was detected in the physiological variables after four weeks of the training program. The change in $\dot{V}O_2$peak, v$\dot{V}O_2$peak, $\dot{V}O_2$/HR, ventilation at $\dot{V}O_2$peak ($\dot{V}_E$@$\dot{V}O_2$peak), and respiratory frequency at $\dot{V}O_2$peak (R_f@$\dot{V}O_2$peak) in response to sSIT was greater when compared to the CON group ($p = 0.001$, $\eta^2 = 0.44$; $p = 0.01$, $\eta^2 = 0.29$; $p = 0.03$, $\eta^2 = 0.29$; $p = 0.002$, $\eta^2 = 0.32$; and $p = 0.009$, $\eta^2 = 0.36$, respectively). sSIT resulted in significant (except as shown) increases compared to the pretest in $\dot{V}O_2$peak ($p = 0.0003$), v$\dot{V}O_2$peak ($p = 0.008$), heart rate at $\dot{V}O_2$peak (HR@$\dot{V}O_2$peak) ($p = 0.8$), $\dot{V}O_2$/HR ($p = 0.01$), $\dot{V}_E$@$\dot{V}O_2$peak ($p = 0.002$), tidal volume at $\dot{V}O_2$peak ($\dot{V}_T$@$\dot{V}O_2$peak) ($p = 0.8$), and R_f@$\dot{V}O_2$peak ($p = 0.01$). No difference in the abovementioned variables was found between the sSIT and CON groups before training.

Anaerobic power

Table 1 displays the mean values of PPO and APO before and after the training program. Following the training, the sSIT group significantly enhanced PPO ($p = 0.001$) and APO ($p = 0.003$). Moreover, the increase in PPO and APO in response to sSIT was significantly greater than that of the CON group ($p = 0.007$; $\eta^2 = 0.39$ and $p = 0.001$; $\eta^2 = 0.23$, respectively).

Hormonal and hematological changes

Table 2 displays the changes in hormonal concentrations and hematological parameters following four weeks of training. The changes in total testosterone (TT) and the ratio of testosterone to cortisol (T/C) over time are presented in Figure 3. Before training, no significant differences were detected between groups for these parameters. However, a time-regimen interaction ($p \leq 0.05$) was observed in serum TT levels after the training program. The change in serum TT in response to sSIT was significantly greater than that of the CON group ($p = 0.001$, $\eta^2 = 0.36$). Serum TT was significantly increased in the sSIT group ($p = 0.007$) over time. The T/C ration significantly increased from pre-training to post-training in the sSIT group ($p = 0.02$) and remained unchanged in the CON group ($p = 0.6$). The training program didn't alter cortisol, hemoglobin, red blood cell, and hematocrit levels.

Change in freestyle swimming performance

Figures 4A and 4B depict changes in swimming performance in terms of time and stroke rate, respectively, for 50, 100, and 200-m distances over time. A time-regimen interaction ($p \leq 0.05$) was detected in swimming performance for all three distances. The change in swimming performance in response to sSIT was greater than that of the CON group in 50-m ($p = 0.01$, $\eta^2 = 0.11$), 100-m ($p = 0.001$, $\eta^2 = 0.17$), and 200-m ($p = 0.05$, $\eta^2 = 0.26$) distances.

Table 1. Pre-training vs. post-training values for gas exchange indices, power output, and stroke rate. Values are means ± SD.

	sSIT			CON		
	Pre	Post	% Change	Pre	Post	% Change
$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})	54.6 ± 3.6	* 57.8 ± 3.2	† +5.8	54.5 ± 3.5	55.2 ± 3.4	+1.3
v$\dot{V}O_2$peak (m·s^{-1})	1.29 ± 0.0	* 1.35 ± 0.0	† +4.7	1.2 ± 0.0	1.2 ± 0.0	+0.0
HR at $\dot{V}O_2$peak (%maximum)	89.1 ± 1.9	89.2 ± 2.4	+0.11	87.2 ± 3.2	87.7 ± 3.7	+0.5
$\dot{V}O_2$/HR (ml·beat^{-1}·min^{-1})	21.0 ± 2.6	* 22.0 ± 2.1	† +4.7	22.0 ± 2.0	22.0 ± 2.2	+0.0
$\dot{V}E$ at $\dot{V}O_2$peak (l·min^{-1})	131.9 ± 16.1	* 141.2 ± 16.3	† +7.1	138.9 ± 16.9	139.5 ± 16.1	+0.5
$\dot{V}T$ at $\dot{V}O_2$peak (l·b^{-1})	2.3 ± 0.2	2.3 ± 0.2	−0.2	2.3 ± 0.1	2.3 ± 0.1	−0.1
Rf at $\dot{V}O_2$peak (b·min^{-1})	56.3 ± 5.9	* 60.4 ± 6.2	† +7.4	59.7 ± 4.6	59.8 ± 4.5	+0.2
Peak power output (W)	218.0 ± 20.7	* 232.6 ± 21.6	† +6.7	222.1 ± 23.8	224.6 ± 20.7	+1.1
Average power output (W)	142.1 ± 10.6	* 161.7 ± 10.5	† +13.8	147.4 ± 10.7	149.4 ± 8.8	+1.3
Stroke rate 50-m (cycle·min^{-1})	55.1 ± 2.2	55.3 ± 2.7	+0.3	54.7 ± 2.4	54.5 ± 2.6	−0.3
Stroke rate 100-m (cycle·min^{-1})	51.6 ± 2.4	50.8 ± 2.9	−1.6	51.2 ± 2.9	51.1 ± 2.9	−0.1
Stroke rate 200-m (cycle·min^{-1})	45.2 ± 2.9	44.7 ± 2.5	−1.1	44.7 ± 3.8	44.5 ± 3.4	−0.4

HR, heart rate. * Significantly greater than pre-training value ($P < 0.05$). † Significantly different change compared with CON group ($p < 0.05$).

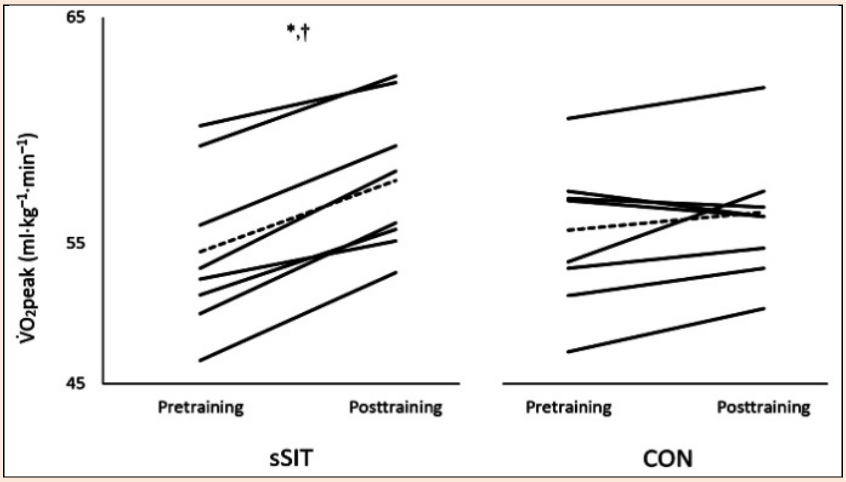

Figure 2. Effects of sSIT and CON on V̇O2peak. *N* = 8 for each group. Each line represents an individual participant and the dotted line represents the mean response. * Denotes significant difference *vs.* pre-training ($p \le 0.05$). † Denotes significant difference *vs.* CON group ($p \le 0.05$).

Table 2. Pre-training vs. post-training outcomes for biochemical indices. Values are means ± SD.

	sSIT			CON		
	Pre	Post	% Change	Pre	Post	% Change
TT (μg·dL^{-1})	0.60 ± 0.12	* 0.72 ± 0.08	† +20	0.59 ± 0.08	0.61 ± 0.09	+3.4
Cortisol (μg·dL^{-1})	20.16 ± 1.83	19.66 ± 2.03	–2.5	18.79 ± 4.89	18.48 ± 4.66	–1.6
T/C ratio	0.031 ± 0.01	* 0.036 ± 0.01	† +16.1	0.034 ± 0.01	0.035 ± 0.01	+2.9
RBC (Mill·mm^{-3})	5.51 ± 0.21	5.47 ± 0.29	−0.7	5.72 ± 0.44	5.72 ± 0.31	+0.0
Hb (g·dL^{-1})	15.75 ± 0.75	15.72 ± 0.81	−0.2	15.36 ± 1.44	15.36 ± 1.36	+0.0
Htc (%)	47.11 ± 1.53	46.26 ± 2.19	−1.8	45.96 ± 2.33	46.02 ± 2.58	+0.1

TT, total testosterone; T/C, testosterone/cortisol; RBC, red blood cell; Hb, hemoglobin; Hct, hematocrit.
* Significantly greater than pre-training value (P < 0.05). † Significantly different change compared with CON group (p < 0.05).

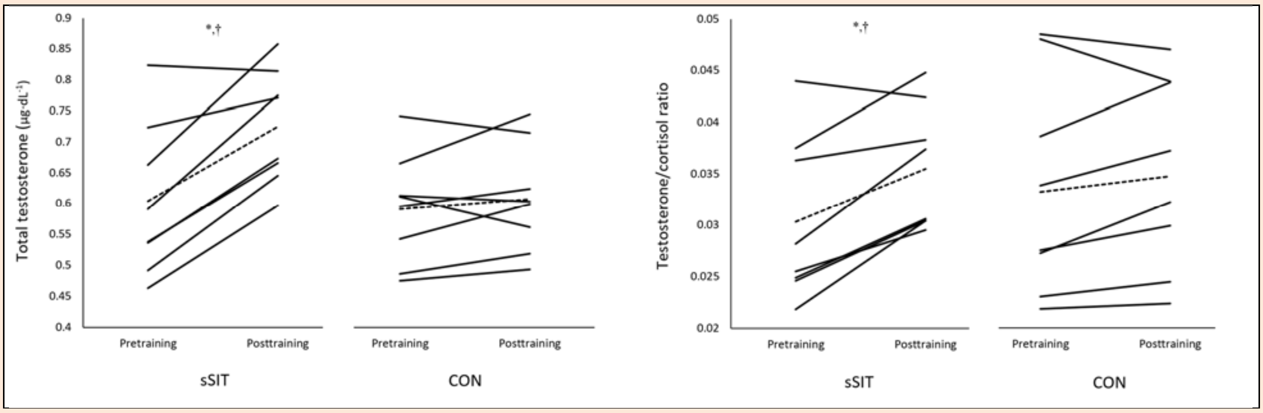

Figure 3. Effects of sSIT and CON on total testosterone and testosterone/cortisol ratio. *N* = 8 for each group. Each line represents an individual participant and the dotted line represents the mean response. * Denotes significant difference *vs.* pre-training ($p \le 0.05$). † Denotes significant difference *vs.* CON group ($p \le 0.05$).

After the training program, the sSIT group significantly decreased 50-m swim time (Pre: 25.96 ± 1.15 vs. Post: 25.40 ± 1.24 s; %change = -2.2, $p = 0.01$) but not the CON group (Pre: 25.43 ± 1.28 vs. Post: 25.40 ± 1.29 s; %change = -0.12, $p = 0.3$). Additionally, swim time in the 100-m distance significantly decreased in the sSIT group (Pre: 57.17 ± 1.58 vs. Post: 56.46 ± 1.49 s; %change = –1.2, $p = 0.003$) but not in the CON group (Pre: 53.1 ± 2.07 vs. Post: 53.0 ± 2.04 s; %change = -0.9, $p = 0.3$). Also, sSIT significantly decreased 200-m swim time pre- to post-training (Pre: 125.01 ± 3.41 vs. Post: 123.69 ± 3.77 s; %change = -1.1, $p = 0.01$) but this value remained unchanged in CON group (Pre: 121.79 ± 2.99 vs. Post: 121.52 ± 2.91 s; %change = -0.22, $p = 0.3$). sSIT and CON groups didn't alter stroke rate in 50, 100, and 200-m swimming performance over time ($p > 0.05$) (Table 1). The performance level of the 50, 100, and 200-m distances did not differ at the baseline.

The study results revealed negative correlations between V̇O2peak and 100-m ($r = -0.653$, $p = 0.002$) and 200-m performance ($r = -0.858$, $p = 0.006$). Also, a significant correlation was shown between PPO and 50-m ($r = -0.812$, $p = 0.0001$) and 100-m performance time ($r = -0.567$, $p = 0.02$, respectively). Additionally, APO was significantly correlated to 50-m ($r = -0.753$, $p = 0.001$), 100-m ($r = -0.631$, $p = 0.009$), and 200-m performances ($r = -0.566$, $p = 0.02$).

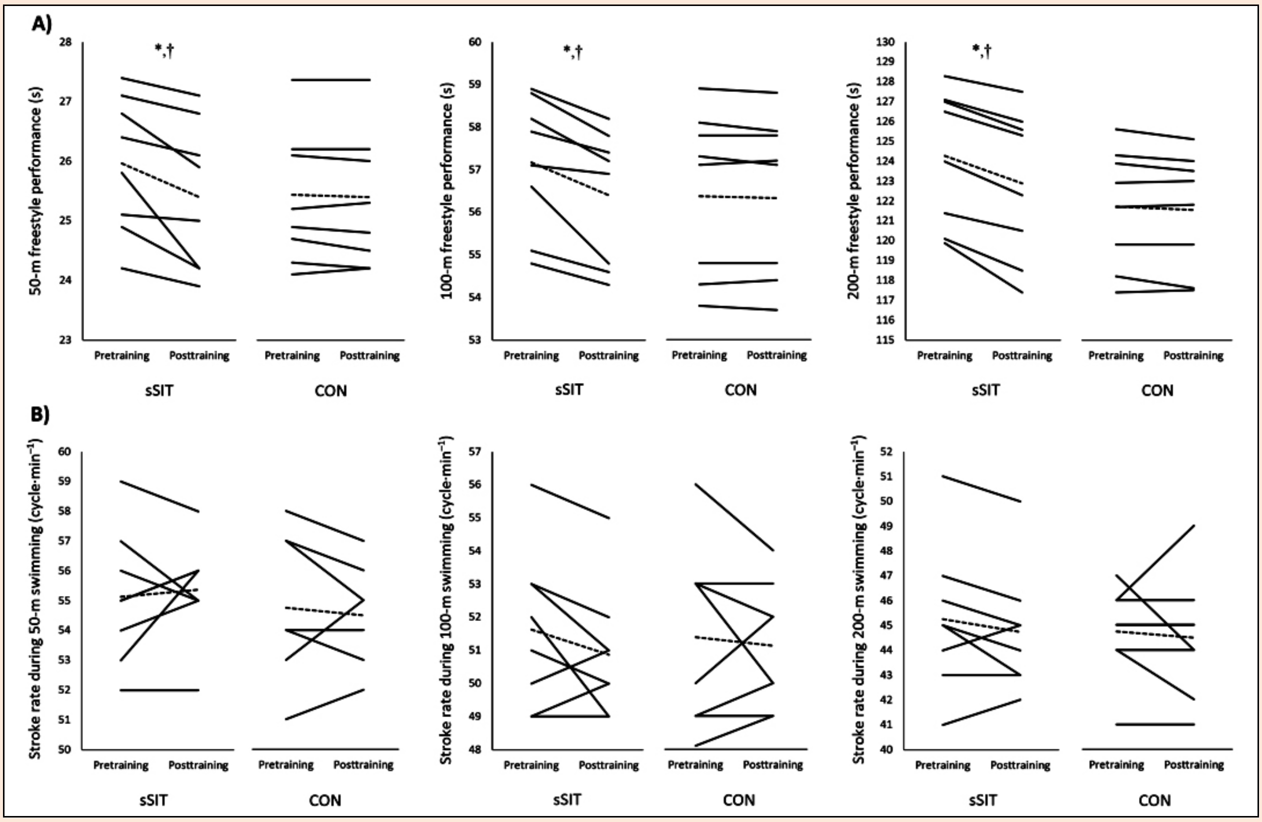

Figure 4. Effects of sSIT and CON on time and stroke rate in 50, 100, and 200-m freestyle swimming performance. ***N*** **= 8 for each group. Each line represents an individual participant and the dotted line represents the mean response.** * Denotes significant difference *vs.* pre-training ($p \leq 0.05$). † Denotes significant difference *vs.* CON group ($p \leq 0.05$).

Discussion

This study investigated if incorporating a dry-land short sprint interval program (sSIT) into in-water swimming training affects physiological parameters and exercise performance. The results demonstrated that the addition of only approximately 36 min of high-intensity sSIT to long aerobic-dominant in-water swimming training improved various parameters, including $\dot{V}O_2$peak, $\dot{V}O_2$/HR, $\dot{V}_E$@$\dot{V}O_2$peak, peak and average power output, as well as 50, 100, and 200-m performance in well-trained swimmers.

Previous research has identified $\dot{V}O_2$peak as a robust predictor of swimming performance over short and middle distances, corroborated by our findings of a negative correlation between $\dot{V}O_2$peak and 100 and 200-m swimming performance. Our findings agree with previous studies investigating the impact of cycling, running, and paddling sSIT on maximal oxygen uptake, indicating that our participants exhibited a notable increase in $\dot{V}O_2$peak after the training intervention. However, Bielec and colleagues (2016) study reported no improvements in $\dot{V}O_2$max of collegiate male swimmers after two weeks of sSIT consisting of a 12 × 25-m front crawl with maximal intensity. Sheykhlouvand and colleagues (2018a) observed a 7.6% increase in $\dot{V}O_2$peak after four weeks of sSIT that involved 3-6 series of 5 × 5 s *all-out* efforts with 10 s passive relief between sprints. Similarly, Satiroglu and colleagues (2021) found that 30 bouts per session of 4 s cycling at an *all-out* intensity with 15 s passive recovery between efforts (i.e., 2 min of exercise per session) performed over eight weeks led to a 13.2% increase in $\dot{V}O_2$peak. Their study demonstrated significantly greater improvements in $\dot{V}O_2$peak (13.2%) compared to the change observed in our participants (5.8%), which may be attributed to the extended period of their training regimen.

The significant increase in $\dot{V}O_2$peak observed in our participants may be partly due to improved cardiac function or $\dot{V}O_2$/HR (O_2pulse). $\dot{V}O_2$/HR is a reliable way of assessing stroke volume indirectly in trained individuals (Bernardi et al., 2020; Gharaat et al., 2020). Our results showed that O_2pulse increased by 5.3% in response to sSIT, which is in agreement with previous research indicating significant improvements of 7.7% (Sheykhlouvand et al., 2018a) or 7.9% (Farzad et al., 2011) in O_2pulse after four weeks of short *all-out* SIT (<10 s). However, the precise mechanisms underlying the improvement of $\dot{V}O_2$peak are complex, and previous studies suggest that SIT can also elicit various peripheral adaptations that may enhance $\dot{V}O_2$peak. As proposed by classical theories, increased enzymatic activities of the energy pathways and regulated mitochondrial content in response to short SIT could be possible mechanisms to improve maximal aerobic capacity (Russell et al., 2003; Rodas et al., 2000).

The respiration process during exercise depends on the integrated function of the cardiovascular and respiratory systems (McConnell, 2013). Our study showed a significant increase in $\dot{V}_E$ after the sSIT training period. The rise in $\dot{V}_E$ was primarily due to an increase in R_f as $\dot{V}_T$ remained unchanged from pre- to post-training. This finding suggests that changes in breathing patterns resulting from respiratory muscle fatigue may have contributed to the increased R_f (Sheykhlouvand et al., 2018b). During high-intensity exercise, respiratory muscles play an essential role in meeting the high rates of ventilation required, and as a result, they may become fatigued. This fatigue can lead to an elevation in R_f through chemoreceptor changes and a plateau or decrease in $\dot{V}_T$ (McConnell, 2013).

Our research provides additional evidence to reinforce earlier studies that have emphasized the significance of "muscle power" in determining a swimmer's performance in short and middle-distance events (Pinos et al., 2021a; Loturco et al., 2016; Hawley et al., 1992). Our findings revealed a strong correlation between power output and performance in the 50, 100, and 200-m swimming events. Notably, recent work by Pinos et al. (2021a) demonstrated that using a swim ergometer for four weeks of SIT (10-12 × 6-15 s *all-out* sprints) could effectively increase power output and improve 50-m swimming performance. According to Morais et al. (2018), incorporating dry-land conditioning into in-water training is a successful approach for improving stroke biomechanics and enhancing swimming performance. In another study, these researchers suggested that the augmentation of strength and power through simultaneous dry-land and in-water training results in enhancements in swim kinematics and kinetics, and ultimately leads to improvements in performance (Morais et al., 2016). These findings suggest that improved anaerobic power and propulsive force through short-term sprint interval training using swim ergometer interventions can ultimately improve swimming performance (Pinos et al., 2021a).

Our study demonstrated that a short sSIT program increased TT and the T/C ratio levels without changes in serum cortisol. The T/C ratio is a commonly used marker for evaluating anabolic-catabolic balance and determining the actual physiological strain of training. Thus, the anabolic adaptations observed in response to sSIT may be indicated by the improvements in the T/C ratio. Farzad and colleagues (2011) also reported an increased T/C ratio following a running-based sSIT program that included 6 × 35-m maximal efforts with 10 s relief between sprints. The increased T/C ratio in our study can be attributed to elevated serum levels of TT since cortisol levels did not change over time.

Short SIT resulted in significant improvements in 50, 100, and 200-m swim performance. The decrease in 50-m swim time (%change = -2.2) was almost twice as much as that of 100, and 200-m distances (%change = -1.2 and –1.1, respectively). Contrary to 100, and 200-m swim times that were negatively correlated to both $\dot{V}O_2$peak and power output, 50-m swim time showed only a negative correlation with PPO and APO indicating that anaerobic power is the main contributing factor in improving 50-m swim time. The improved swimming performance may also be attributed to increased stroke length, stroke rate, or both. In response to sSIT and CON group, stroke rate decreased in some participants and some of whom showed an increased stroke rate over time. On average, no exercise-induced change in stroke rate was observed in response to sSIT and CON over time indicating that the change in stroke rate or combination of stroke rate and stroke length to maintain or enhance swimming velocity is highly individual (Morais et al., 2023; Pelayo et al., 1996). Improvement in the performance of the sSIT group could in part be attributed to increased power per stroke. In support of this, previous research (Morais et al., 2016; Gatta et al., 2014) have indicated positive effects of power development on the swim kinematics which have a direct effect on the performance. Therefore, it is plausible to suggest that maintaining power output is crucial for achieving optimal performance in short and middle-distance swimming events, and ergometer-based sSIT may be an effective strategy for improving power maintenance. However, additional research is necessary to verify the impact of short SIT protocols on longer swimming distances.

Limitation

A limitation of our experiment was that even though the sSIT group had a higher training workload in comparison to the CON group, the duration of very low-volume sSIT was relatively short, encompassing only around 36 min of highly intensive actual exercise time. Therefore, it seems improbable that this alone could have produced such notable physiological transformations. Consequently, it is plausible to suggest that some parameters related to the essence of sSIT (such as frequency, duration, and intensity of both the training and recovery phases) may have further contributed to these changes. However, the absence of a comparative group conducting in-water sSIT makes it challenging to determine whether the observed results are solely attributed to the specific characteristics of sSIT training or if they could be influenced by the additional work performed during sSIT compared to a control group. Future studies incorporating an in-water sSIT group would provide further insights into the distinct effects of sSIT training and help strengthen the interpretation of the results. Also, to gain a deeper understanding of the extent and positive outcomes of sSIT compared to long aerobic-dominant low-intensity training, further studies are warranted.

Conclusion

In summary, this study provides evidence that incorporating four weeks of dry-land sSIT intervention into long aerobic-dominant in-water swim training, consisting of repeated bouts of sprints during three sets of 10 maximal efforts with 3 min of relief between sets, three times weekly, is an effective method for eliciting adaptations that enhance both aerobic and anaerobic capacity as well as power in well-trained swimmers. Furthermore, the changes in hormonal responses suggest an anabolic adaptation to the sSIT intervention, indicating a favorable training response. Consequently, this protocol represents a practical, sport-specific approach to improve the aforementioned athletic qualities in well-trained swimmers under the experimental conditions employed in this study.

Acknowledgements

The authors state that they do not have any conflicts of interest that may

be perceived as potential commercial or financial relationships. This research was not funded by any specific sources from public, commercial, or not-for-profit sectors. The authors have committed to providing the raw data that supports the research findings without any hesitation. Additionally, the experiments conducted in this study adhere to the prevailing laws of the country where they were carried out.

References

Almeida, T.A.F., Filho, D.M.P., Espada, M.C., Reis, L.F., Sancassani, A., Massini, D.A., Santos, F.J. and Alves, F. B. (2021) Physiological Responses During High-Intensity Interval Training in Young Swimmers. *Frontiers in Physiology* **12**, 662029. https://doi.org/10.3389/fphys.2021.662029

Almeida, T.A.F., Pessôa Filho, D.M., Espada, M.A.C., Reis, J.F., Simionato, A.R., Siqueira, L.O.C. and Alves, F.B. (2020) $\dot{V}O_2$ kinetics and energy contribution in simulated maximal performance during short and middle distance-trials in swimming. *European Journal of Applied Physiology* **120**, 1097-1109. https://doi.org/10.1007/s00421-020-04348-y

Baldari, C., Fernandes, R., Meucci, M., Ribeiro, J., Vilas-Boas, J.P. and Guidetti, L. (2013) Is the new aquatrainer® snorkel valid for $\dot{V}O_2$ assessment in swimming? *International Journal of Sports Medicine* **34(04)**, 336-344. https://doi.org/10.1055/s-0032-1321804

Barzegar, H., Arazi, H., Mohsebbi, H., Sheykhlouvand, M. and Forbes, S.C. (2021) Caffeine co-ingested with carbohydrate on performance recovery in national level paddlers: a randomized, double-blind, crossover, placebo-controlled trial. *Journal of Sports Medicine and Physical Fitness* **62**, 337-342. https://doi.org/10.23736/S0022-4707.21.12125-5

Bayati, M., Farzad, B., Gharakhanlou, R. and Agha-Alinejad, H. (2011) A practical model of low-volume high-intensity interval training induces performance and metabolic adaptations that resemble ‘all-out’ sprint interval training. *Journal of Sports Science and Medicine* 10, 571-576. https://pubmed.ncbi.nlm.nih.gov/24150635/

Benítez-Flores, S., de Sousa, A.F.M., Totó, E.C, Rosa, T.S., Rosso, S.D., Foster, C. and Boullosa, D.A. (2018) Shorter sprints elicit greater cardiorespiratory and mechanical responses with less fatigue during time-matched sprint interval training (SIT) sessions. *Kinesiology* **50(2)**, 137-148. https://doi.org/10.26582/K.50.2.13

Bernardi, M., Guerra, E., Rodio, A., Dante, D., Castellani, V., Peluso, I., Schena, F. and Bhambhani, Y. (2020) Assessment of Exercise Stroke Volume and Its Prediction from Oxygen Pulse in Paralympic Athletes with Locomotor Impairments: Cardiac Long-Term Adaptations Are Possible. *Frontiers in Physiology* **10**, 1451. https://doi.org/10.3389/fphys.2019.01451

Bielec, G., Makar, P., Kujach, S. and Laskowski, R. (2016) Biomechanical and physiological effects of two-week sprint interval training in collegiate swimmers. *Science and Sports* **31(6)**, 189-192. https://doi.org/10.1016/j.scispo.2016.05.002

Boullosa, D., Dragutinovic, B., Feuerbacher, J.F., Benítez-Flores, S., Coyle, E.F. and Moritz, S. (2022) Effects of short sprint interval training on aerobic and anaerobic indices: A systematic review and meta-analysis. *Scandinavian Journal of Medicine and Science in Sports* **32(5)**, 810-820. https://doi.org/10.1111/sms.14133

Capelli, C., Pendergast, D., and Termin, B. (1998) Energetics of swimming at maximal speeds in humans. *European Journal of Applied Physiology* **78**, 385-393. https://doi.org/10.1007/s004210050435

Cohen, J. (1988) Statistical Power Analysis for the Behavioral Sciences. New York, NY: Routledge Academic.

Farzad, B., Gharakhanlou, R., Agha-Alinejad, H., Curby, D.G., Bayati, M., Bahraminejad, M. and Mäestu, J. (2011) Physiological and performance changes from the addition of a sprint interval program to wrestling training. *Journal of Strength and Conditioning Research* **25**, 2392-2399. https://doi.org/10.1519/JSC.0b013e3181fb4a33

Faul, F., Erdfelder, E., Lang, A.G. and Buchner, A. (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* **39(2)**, 175-191. https://doi.org/10.3758/bf03193146

Fereshtian, S., Sheykhlouvand, M., Forbes, S., Agha-Alinejad, H. and Gharaat, M. (2017) Physiological and performance responses to high-intensity interval training in female inline speed skaters. *Apunts Medicina de l'Esport* **52**, 131-138. https://doi.org/10.1016/j.apunts.2017.06.003

Ferguson, C.J. (2009) An effect size primer: A guide for clinicians and researchers. *Professional Psychology: Research and Practice* **40**, 532-538. https://doi.org/10.1037/a0015808

Gatta, G., Leban, B., Paderi, M., Padulo, J., Migliaccio, G.M., and Pau, M. (2015) The development of swimming power. *Muscles Ligaments Tendons Journal* **4(4)**, 438-45.

Gharaat, M.A., Sheykhlouvand, M. and Eidi, L.A. (2020) Performance and recovery: effects of caffeine on a 2000-m rowing ergometer. *Sport Sciences for Health* **16**, 531-542. https://doi.org/10.1007/s11332-020-00643-5

Hawley, J.A., Williams, M.M., Vickovic, M.M. and Handcock, P.J. (1992) Muscle power predicts freestyle swimming performance. *British Journal of Sports Medicine* **26(3)**, 151-155. https://doi.org/10.1136/bjsm.26.3.151

Johnson, R.E., Sharp, R.L. and Hedrick, C.E. (1993) Relationship of swimming power and dryland power to sprint freestyle performance. *Journal of Swimming Research* **9(1)**, 10-14.

Kabasakalis, A., Nikolaidis, S., Tsalis, G. and Mougios, V. (2020) Response of Blood Biomarkers to Sprint Interval Swimming. *International Journal of Sports Physiology and Performance* **15(10)**, 1442-1447. https://doi.org/10.1123/ijspp.2019-0747

Kwok, W.Y., Lung So, B.C., Ting Tse, D.H. and Mei Ng, S.S. (2021) A Systematic Review and Meta-Analysis: Biomechanical Evaluation of the Effectiveness of Strength and Conditioning Training Programs on Front Crawl Swimming Performance. *Journal of Sports Science and Medicine* **20**, 564-585. https://doi.org/10.52082/jssm.2021.564

Laursen, P.B. and Buchheit, M. (2019) in *Science and Application of High-Intensity Interval Training*, 1st Edn, Champaign: Human Kinetics. 325-344. https://doi.org/10.5040/9781492595830

Loturco, I., Barbosa, A.C., Nocentini, R.K., Pereira, L.A., Kobal, R., Kitamura, K., Abad, C. C.C., Figueiredo, P. and Nakamura, F. Y. (2016) A correlational analysis of tethered swimming, swim sprint performance and dry-land power assessments. *International Journal of Sports Medicine* **37(3)**, 211-218. https://doi.org/10.1055/s-0035-1559694

Marinho, D.A., Barbosa, T.M., Lopes, V.P., Forte, P., Toubekis, A.G. and Morais, J.E. (2020) The influence of the coaches’ demographics on young swimmers’ performance and technical determinants. *Frontiers in Psychology* **11**, 1968. https://doi.org/10.3389/fpsyg.2020.01968

McConnell, A. (2013) Respiratory Muscle Training; Theory and Practice, 1st Edn, Champaign, IL: Elsevier .37. https://doi.org/10.1016/B978-0-7020-5020-6.09997-0

McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., Sheppard, J. and Burke, L.M. (2022) Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance* **17(2)**, 317-331. https://doi.org/10.1123/ijspp.2021-0451

McKie, G.L., Islam, H., Townsend, L.K., Robertson-Wilson, J., Eys, M. and Hazell, T.J. (2018) Modified sprint interval training protocols: physiological and psychological responses to 4 weeks of training. *Applied Physiology Nutrition and Metabolism* **43(6)**, 595-601. https://doi.org/10.1139/ apnm-2017-0595

Menz, V., Marterer, M., Amin, S.B., Faulhaber, M., Hansen, A.B. and Lawley, J. (2019) Functional Vs. Running Low-Volume High-Intensity Interval Training: Effects on VO_2max and Muscular Endurance. *Journal of Sports Science and Medicine* **18**, 497-504. https://pubmed.ncbi.nlm.nih.gov/31427872/

Morais, J.E., Barbosa, T.M., Bragada, J.A., Nevill, A.M. and Marinho, A.A. (2023) Race Analysis and Determination of Stroke Frequency - Stroke Length Combinations during the 50-M Freestyle Event. *Journal of Sports Science and Medicine* **22**, 156-165. https://doi.org/10.52082/jssm.2023.156

Morais, J.E., Silva, J.A., Garrido, N.D., Marinho, D.A. and Barbosa, T.M. (2018) The transfer of strength and power into the stroke biomechanics of young swimmers over a 34-week period. *European Journal of Sport Science* **18**, 787-795. https://doi.org/10.1080/17461391.2018.1453869

Morais, J.E., Silva, A.J., Marinho, D.A., Marques, M.C. and Barbosa, T.M. (2016) Effect of a specific concurrent water and dry-land training over a season in young swimmers’ performance.

International Journal of Performance Analysis in Sport **16**, 760-775. https://doi.org/10.1080/24748668.2016.11868926

Neiva, H.P., Marques, M.C., Fernandes, R.J., Viana, J.L., Barbosa, T.M. and Marinho, D.A. (2014) Does warm-up have a beneficial effect on 100-m freestyle? *International Journal of Sports Physiology and Performance* **9**, 145-150. https://doi.org/10.1123/ijspp.2012-0345

Neto, V.H.G., Neves, L.N.S., Kalava-Filho, C.A., Schwingel, P.A., Leite R.D. and Carletti, L. (2022) Cardiopulmonary Exercise Testing with Elastic Resistance: A New Reproducible Proposal for Determination of Ventilatory Thresholds and Maximum Oxygen Consumption. *Journal of Sports Science and Medicine* **21**, 426-434. https://doi.org/10.52082/jssm.2022.426

Nugent, F.J., Comyns, T.M. and Warrington, G.D. (2017) Quality versus quantity debate in swimming: perceptions and training practices of expert swimming coaches. *Journal of Human Kinetics*, **57**, 147-158. https://doi.org/10.1515/hukin-2017-0056

Pelayo, P., Sidney, M., Kherif, T., Chollet, D. and Tourny, C. (1996) Stroking Characteristics in Freestyle Swimming and Relationships with Anthropometric Characteristics. *Journal of Applied Biomechanics* **12(2)**, 197-206. https://doi.org/10.1123/jab.12.2.197

Pinos, A.J., Bentley, D.J. and Logan-Sprenger, H.M. (2021a) The Effects of Anaerobic Swim Ergometer Training on Sprint Performance in Adolescent Swimmers. *International Journal of Sports Physiology and Performance* **16(8)**, 1169-1174. https://doi.org/10.1123/ijspp.2020-0591

Pinos, A.J., Fernandes, E.M., Viana, E., Logan-Sprenger, H.M. and Bentley, D.J. (2021b) Applicability of Maximal Ergometer Testing and Sprint Performance in Adolescent Endurance and Sprint Trained Swimmers. *Sports (Basel)* **9(5)**, 55. https://doi.org/10.3390/sports9050055

Price, M. and Moss, P. (2007) The effects of work: rest duration on physiological and perceptual responses during intermittent exercise and performance. *Journal of Sports Science* **25(14)**, 1613-1621. https://doi.org/10.1080/02640410701287248

Rodas, G., Ventura, J.L., Cadefau, J.A., Cusso´, R. and Parra, J. (2000) A short training programme for the rapid improvement of both aerobic and anaerobic metabolism. *European Journal of Applied Physiology* **82**, 480-486. https://doi.org/10.1007/s004210000223

Russell, A.P., Somm, E., Praz, M., Crettenand, A., Hartley, O., Melotti, A., Giacobino, J.P., Muzzin, P., Gobelet, C. and Dériaz, O. (2003) UCP3 Protein Regulation in Human Skeletal Muscle Fibre Types I, IIa and IIx is Dependent on Exercise Intensity. *Journal of Physiology* **550(3)**, 855-861. https://doi.org/10.1113/jphysiol.2003.040162

Satiroglu, R., Lalande , S., Hong, S., Nagel, M.J. and Coyle, E.F. (2021) Four-Second Power Cycling Training Increases Maximal Anaerobic Power, Peak Oxygen Consumption, and Total Blood Volume. *Medicine and Science in Sports and Exercise* **53(12)**, 2536-2542. https://doi.org/ 10.1249/MSS.0000000000002748

Sharp, R.L. (2000) *Physiology of* swimming. In: Garret WE Jr, Kirkendall DT (eds) Exercise and Sport Science. Lippincott Williams & Wilkins. 895-904

Sheykhlouvand, M., Arazi, H., Astorino, T.A. and Suzuki, K. (2022) Effects of a New Form of Resistance-Type High-Intensity Interval Training on Cardiac Structure, Hemodynamics, and Physiological and Performance Adaptations in Well-Trained Kayak Sprint Athletes. *Frontiers in Physiology* **13**, 850768. https://doi.org/10.3389/fphys.2022.850768

Sheykhlouvand, M., Khalili, E., Gharaat, M., Arazi, H., Khalafi, M. and Tarverdizadeh, B. (2018a) Practical model of low-volume paddling-based sprint interval training improves aerobic and anaerobic performances in professional female canoe polo athletes. *Journal of Strength and Conditioning Research* **32**, 2375-2382. https://doi.org/10.1519/JSC.0000000000002152

Sheykhlouvand, M., Gharaat, 5, Khalili, M., Agha-Alinejad, E., Rahmaninia, H. and Arazi, F. (2018b) Low-Volume High-intensity interval versus continuous endurance training: effects on hematological and cardiorespiratory system adaptations in professional canoe polo athletes. *Journal of Strength and Conditioning Research* **32**, 1852-1860. https://doi.org/10.1519/JSC.0000000000002112

Sheykhlouvand, M., Khalili, E., Agha-Alinejad, H. and Gharaat, M.A. (2016a) Hormonal and physiological adaptations to high-intensity interval training in professional male canoe polo athletes. *Journal of Strength and Conditioning Research* 30(3), 859-866. https://doi.org/10.1519/JSC.0000000000001161

Sheykhlouvand, M., Gharaat, M., Khalili, E. and Agha-Alinejad, H. (2016b) The effect of high-intensity interval training on ventilatory threshold and aerobic power in well-trained canoe polo athletes. *Science and Sports* **31**, 283-289. https://doi.org/10.1016/j.scispo.2016.02.007

Vardarli, E., Allen, J.R., Bjellquist-Ledger, R., Burton, H.M. and Coyle, E.F. (2021) Physiological responses to maximal 4-s sprint interval cycling using inertial loading: the influence of inter-sprint recovery duration. *European Journal of Applied Physiology* **121(5)**, 1996-2001. https://doi.org/10.1007/s00421-021-04677-6

Vollaard, N.B.J., Metcalfe, R.S. and Williams, S. (2017) Effect of Number of Sprints in an SIT Session on Change in V̇O2max: A Meta-analysis. *Medicine and Science in Sports and Exercise* **49(6)**, 1147-1156. https://doi.org/10.1249/MSS.0000000000001204

Williamson, D., McCarthy, E. and Ditroilo, M. (2020) Acute Physiological Responses to Ultra Short Race-Pace Training in Competitive Swimmers. *Journal of Human Kinetics* **75**, 95-102. https://doi.org/10.2478/hukin-2020-0040

Key points

- Incorporating dry-land sSIT into swimmers' typical long aerobic-dominant in-water swim training triggers adaptive mechanisms that foster enhancements in the aerobic and anaerobic capacity and swimming performance in well-trained swimmers.
- The changes in hormonal responses suggest an anabolic adaptation to such intervention indicating a favorable training response.
- The swim ergometer is a discipline-specific practical modality for SIT. Utilizing an ergometer allows swimmers to achieve maximum anaerobic power quickly and perform trials at maximal intensity.
- The integration of sSIT into long aerobic-dominant in-water swim training allows swimmers and their coaches to harness the potential of such programs to maximize the quality and efficiency of their training. This approach brings about positive physiological improvements and performance enhancements.

AUTHOR BIOGRAPHY

Huan LIU
Employment
Ph.D. student, Woosuk University, South Korea
Degree
MSc
Research interests
Exercise physiology, performance enhancement, cardiorespiratory response to exercise
E-mail: Lihuan4521@gmail.com

Jue WANG
Employment
Ph.D. Student, Kookmin University, South Korea
Degree
MSc
Research interests
Exercise physiology, performance enhancement, cardiorespiratory response to exercise
E-mail: Juewang8333@gmail.com

✉ **Jue WANG**
Kookmin University, 77 Jeongeung-ro, Seongbuk-gu, Seoul, 02707, South Korea