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Cardiorespiratory Responses to a 20-Minute Shallow Water Tabata-Style Workout

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The purpose of this study was to examine physiological responses to a 20-min Tabata-style shallow water exercise workout (TS-SWE). Volunteers ($n = 9$, females) had recently participated in an experiment (Experiment I) that measured, in part, peak oxygen uptake and heart rate (VO_2 and HR) during SWE (D'Acquisto, Miller, D'Acquisto, Roemer, & Fisher, 2015). Peak VO_2 and HR were used in the current study to compute relative physiological responses (e.g., % VO_2 and %HR peak) to TS-SWE. VO_2 , HR, rating of perceived exertion (RPE; Borg 6–20 scale), and blood lactate were measured during a TS-SWE. TS-SWE consisted of 4×4 min bouts (20-s maximal efforts followed by 10 s of rest for each bout; 1 min rest between bouts). TS-SWE elicited cardiorespiratory and psychophysical responses (RPE) classified as vigorous to “near-maximal to maximal intensity” according to the American College of Sports Medicine’s guidelines for exercise prescription, suggesting that a TS-SWE workout imposes a substantial physiological load on the human body.

Keywords: Tabata-style exercise, intervals, shallow water exercise, oxygen uptake, heart rate, rating of perceived exertion, water immersion

Aquatic exercise continues to grow in popularity as an addition to, or alternative to, land-based training (Kruel, Posser, Alberton, Pinto, & Oliveira, 2009; Nagle et al., 2013; Nikolai, Novotny, Bohnen, Schleis, & Dalleck, 2009). Recreational exercisers, athletes of varying levels, and the elderly use aquatic exercise as part of their training regimen (Campbell, D'Acquisto, D'Acquisto, & Cline, 2003; Cook, Scarneo, & McAvoy, 2013; Kruel et al., 2009; Sanders, Takeshima, Rogers, Colado, & Borreani, 2013). Shallow water exercise (SWE) is performed in water with participants typically immersed anywhere from waist to axillary level (Barbosa, Garrido, & Bragada, 2007; Cook et al., 2013; Kruel et al., 2009; Nagle et al., 2013; Nikolai et al., 2009). Because of its greater density and dynamic

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viscosity, water offers more resistance to movement compared with an air medium (Becker, 2009; Schrepfer, 2012; Thein & Brody, 1998; Torres-Ronda & Alcázar, 2014). Furthermore, the buoyancy effect of water reduces impact forces on joints (Schrepfer, 2012). The unique properties offered by water require that certain instructional (i.e., verbal cues) and movement tactics be employed to modulate physical exertion during aquatic exercise. For example, participants can change intensity during SWE by manipulating speed, body surface area, force application, range of motion, and planes of movement (Sanders, Takeshima, Rogers, Colado, & Borreani, 2013). Employing any one or a combination of these movement strategies will dramatically change the magnitude of resistance to motion and impact physical exertion and energy expenditure during a continuous or intermittent SWE workout.

High-intensity interval training (HIIT) is intermittent in nature because it involves alternating periods of relatively intense work efforts with recovery periods. HIIT has a long history of being appreciated and used by athletes (e.g., in track, cycling, and swimming) in preparation for competition (Nicolò et al., 2014; Tabata et al., 1997; Zuniga et al., 2011) and has become an emerging trend in the general fitness community (Kilpatrick, Jung, & Little, 2014). Because of its high-intensity, low-volume nature, HIIT is being promoted as a time-efficient tactic for enhancing aerobic and anaerobic metabolic power (Emberts, Porcari, Doberstein, & Foster, 2013; Freese, Gist, & Cureton, 2013; Gist, Freese, & Cureton, 2014; Nicolò et al., 2014).

A term often used synonymously with HIIT is “Tabata training.” Tabata and colleagues (1997) found that 6 weeks of HIIT comprised of multiple 4-min sets of 20-s cycle ergometry work intervals (170% VO_2 max), 10-s rest, increased both VO_2 max (~14%) and maximal accumulated oxygen deficit (~28%) ($p < .05$). Investigators also discovered that HIIT improved VO_2 max to a similar degree as a moderate intensity training (MIT) regimen (70% VO_2 max) that involved substantially more training time. In addition, MIT did not result in any improvement in maximal accumulated oxygen deficit. Findings by Tabata and colleagues highlight that short, intensive interval training is a time-efficient approach to enhancing both aerobic power and anaerobic capacity.

High-intensity, exhaustive interval exercise which consist of a single 4-min bout, alternating 20-s all-out exercise with 10-s rest, may be regarded as a classic Tabata workout. Tabata-style workouts have emerged in which duration varies from between 8 and 20 min, involving multiple 4-min bouts performed at ~74–95% VO_2 max with a 1-min recovery following each 4-min bout (Olson, 2014). Recent studies of physiological responses to various land-based HIIT protocols have reported that Tabata-style training is a successful alternate to more traditional aerobic-based training regimens despite a substantially reduced time commitment and lower training volume (Burgomaster, Cermak, Phillips, Benton, & Gibala, 2007; Burgomaster, Heighenhauser & Gibala, 2006; Bugomaster, Hughes, Heighenhauser, Branwell, & Gibala, 2005; Gibala et al., 2006).

Few studies have examined the physiological responses to high-intensity, intermittent SWE. Nagle et al. (2013) reported an overall energy expenditure of ~6.4 $\text{Kcal}\cdot\text{min}^{-1}$ and an HR response ranging from 61 to 79% of predicted HR max for young adult females performing a 40-min SWE workout consisting, in part, of high-intensity intermittent exercise exertions. The workout consisted of self-regulated moderate-intensity work intervals (“aerobic” phase) and intermittent 15 s of hard/very hard whole body exercise efforts interspersed with active rest periods. The

body of the workout yielded an overall OMNI-RPE of ~6 (somewhat hard; 0–10 perceived exertion scale). Interestingly, Nagle and colleagues also found that the aerobic portion of the workout yielded a rate of energy expenditure that was nearly double compared with the high-intensity interval component (8.0 vs. 4.2 Kcal \cdot min $^{-1}$). Cook et al. (2013) compared blood lactate concentration and RPE between sprinting on land and in shallow water. They found that sprint running in shallow water (10 \times 9.1 m, 100% maximum effort, 30-s rest between intervals) elicited a greater blood lactate concentration (8.0 \pm 2.0 vs. 4.1 \pm 2.0 millimolars [mM], $p < .001$) and RPE (15 \pm 2 vs. 11 \pm 2, 6–20 Borg [1998] scale, $p < .01$) when compared with the same workout performed on land. The SWE and land 9.1-m interval sprints took ~15 and 1.8 s, respectively. Cook and colleagues' results highlight the dramatic impact of water drag on velocity of movement and the added metabolic demand when compared with land when performing high-intensity, relatively short work intervals.

Kruel et al. (2009) examined physiological responses to an SWE interval workout in which female volunteers self-regulated intensity with the use of Borg's 6–20 RPE scale. Subjects participated in a 32-min workout consisting of 8 \times 2 min at RPE-17 alternating with 2-min active recovery at RPE-9 (very light). Kruel et al. presumably choose an RPE-17 (very hard) to elicit a strenuous physiological load during the work interval. Average VO_2 for the interval workout was 0.92 \pm 0.18 l \cdot min $^{-1}$ (15.5 \pm 2.8 mlO $_2$ \cdot kg $^{-1}$ \cdot min $^{-1}$), while average peak VO_2 during the work intervals (excluding rest intervals) ranged from ~0.9–1.5 l \cdot min $^{-1}$ (~17–24 ml \cdot kg $^{-1}$ \cdot min $^{-1}$) (estimated from Figure 1, Kruel et al., 2009). Unfortunately, peak aerobic

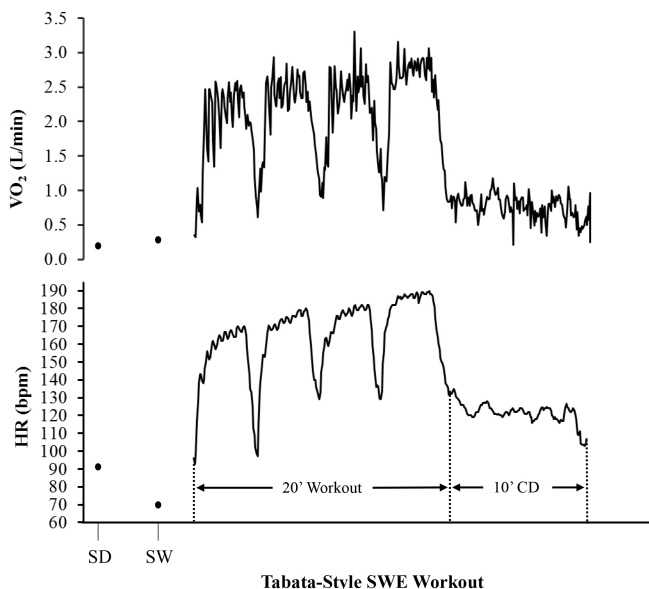


Figure 1 — Typical VO_2 and heart rate (HR) response for one participant while standing on deck (SD) and in water (SW, axillary level), during the 20-min Tabata-style workout and 10-min cooldown (CD). *Note:* SD and SW values represent averages from a 5-min collection period during each condition.

power was not reported in this paper, and thus relative measures of physiological load for the above work efforts are not known. Although Nagle et al. (2013), Cook et al. (2013), and Krueger et al. (2009) provide important insight into the physiology of intermittent work efforts during SWE, there is still a general lack of knowledge regarding the absolute and relative physiological responses of high-intensity SWE interval workouts.

The primary aim of this study was to describe the physiological strain and psychophysical responses to a Tabata-style, high-intensity interval SWE workout (TS-SWE). Providing such information is not only important in expanding our scientific knowledge about the physiology of SWE but relevant for aquatic fitness instructors who may wish to incorporate high-intensity interval workouts as part of the overall training regimen. It was hypothesized that a TS-SWE would result in an exercise intensity categorized as vigorous to maximal according to American College of Sports Medicine (ACSM) guidelines (ACSM, 2014). It was also hypothesized that physiological responses would vary among the executed TS-SWE bouts. A unique aspect of this study was the quantification of relative SWE physiological intensity (%VO₂ peak, %HR peak, %VO₂ R, and HR reserve [%VO₂ R, %HRR]) utilizing resting and peak measurements of VO₂ and HR obtained in water.

Method

Participants

Nine healthy, physically active females (26 ± 6 years; 168.2 ± 2.9 cm; 66.1 ± 6.2 kg) volunteered for this investigation. Subjects were familiar with the protocol (D'Acquisto, Miller, D'Acquisto, Roemer, & Fisher, 2015). The investigation was approved by the Human Subjects Review Council, and participants signed an informed consent document before participation. Subjects were screened with a health history questionnaire and excluded from the investigation if they self-reported an injury within the last 2 months, hydrophobia, allergies to chlorine, or were pregnant. Results from a physical activity questionnaire highlighted volunteers who were engaged in exercise for at least the last 10 weeks, 4.0 ± 0.8 sessions·wk⁻¹, and averaging 52.5 ± 13.8 min·session⁻¹.

Design

The study consisted of a within-subjects experimental design. Participants had recently (48 hr to 2 weeks) completed Experiment I of this larger scale investigation (D'Acquisto et al., 2015). In brief, Experiment I included familiarization and performance of self-regulated submaximal and maximal SWE efforts based on prescribed RPEs while cardiorespiratory parameters were measured. Peak VO₂ and HR measured during Experiment I were used in the current study for computing relative physiological intensity (%VO₂ and %HR peak, %VO₂ R, and %HRR) associated with the TS-SWE workout. Equations for computation of %VO₂ R and %HRR in the current study can be found in D'Acquisto et al. (2015). In addition, individual linear regression equations of VO₂ regressed on RPE (9, 11, 13, 15, 17) derived from Experiment I were applied to the current study to estimate individual VO₂ associated with the warm-up component of the TS-SWE workout. Participants

were asked to arrive to the laboratory 4 hr postprandial, having refrained from strenuous physical activity during the prior 24 hr and abstained from caffeine products for at least 12 hr before testing, and to arrive in a hydrated state. All testing was conducted during morning hours and during times when no other aquatic activities were scheduled in the pool. Thus, only the research team, participants, and lifeguard were present during times of testing.

Measurements

Following weight and height measurements, participants were fitted with an HR monitor (Polar Electro CE0537, Lake Success, NY, USA). Experiment I revealed that standing resting HR in water (axillary level) was, on average, 24 bpm lower (28%) compared with standing on deck (D'Acquisto et al., 2015). This comparison was repeated with the addition of measuring HR while seated. We were curious to examine resting state in the current study to determine whether participants were initiating exercise in the water at a similar metabolic state as in Experiment I, and to obtain SW baseline VO_2 and HR to use in the computation of $\% \text{VO}_2 \text{ R}$ and $\% \text{HRR}$ during TS-SWE. Participants were asked to sit quietly for 10–12 min. Participants were reminded that the Tabata-style phase of the workout would involve 4 times 4-min bouts, each consisting of eight rounds of 20-s all-out, maximal work intervals, and that each 20-s work interval would be followed by 10 s of rest in a ready stance. They were also reminded that 1 min of rest would be provided between each 4-min work bout. Refer to Table 1 for sequence of movements for the Tabata-style phase of the workout. The sequence of movements is representative of base moves in aquatic choreography (Aquatic Exercise Association [AEA], 2010; AEA *Aquatic Fitness Professional Manual*, Tables 9.1 and 9.2 and Appendix A). Distinct movement patterns were associated with each 4-min TS—SWE bout. Descriptions of each movement pattern performed by the participants included the following: Bout 1: Tuck Jumps With Scoop—start with knees slightly flexed, jump, both knees to chest as arms draw water from the sides of body bringing it toward chest, hands cupped; Bout 2: Cross-Country Ski (X-C Ski)—start in X-C Ski stance, alternate legs and move arms in opposition, pushing and pulling the water; Bout 3: Deep Split Jump Lunge—start staggered stance, knees flexed, jump, alternating stance simultaneously swinging arms back and forth in tandem, elbows flexed, hands fisted then spread wide while breaking surface of water; Bout 4: Alternating Long Leg

Table 1 Movements Performed During the 20-Min Tabata-Style Shallow Water Exercise Workout

Bout	Time (min)	Work:rest (s)	Movement	Gloved hands/arms
1	4	20:10	Tuck jumps	Open hands and scoop
2	4	20:10	X-C Ski	Push/pulls
3	4	20:10	Deep split jump lunge	Push/fist
4	4	20:10	Alternating long leg kicks	Extended and submerged

Note. A 1-min passive recovery period followed each 4-min bout. Thus, total time for the TS-SWE phase of the workout equaled 20 min.

Kicks—alternate forward straight leg kicks toward water surface with opposing hand reaching toward foot with wrist extended, fingers spread, hand fully submerged.

Baseline HR (radiotelemetry, Polar Electro CE0537) was monitored while participants were seated for 5 min between Minutes 3 and 8. HR values were averaged to yield a representative seated resting HR. Following this, participants put on webbed gloves (Hydro-Fit Wave Web Pros, Eugene, OR, USA) with digit sleeves vented (2-cm slit), thereby allowing access to digits for finger pricks. Subsequently, participants were fitted with a two-way breathing valve, assumed an up-right stance, and rested quietly for a period of 7 to 8 min while metabolic (Parvo-Medics TrueOne 2400, Parvo-Medics Incorporated, Sandy, UT, USA) and HR responses were monitored. The Parvo-Medic metabolic cart was calibrated with standard gases (16.0% O₂, 4.0% CO₂) while the pneumotach was calibrated with a standard volume of air (3-L syringe) before each test according to manufacturer's standards. A finger stick was performed and ~30 microliters (μL) of blood collected into a capillary tube and analyzed for whole blood lactate (Analox, Analox Instruments Ltd., The Vale, London) immediately following standing on deck. This measurement was defined as "resting" lactate concentration. The Analox analyzer was calibrated with an 8-mM standard immediately before each participant and throughout each test session according to manufacturing standards.

With headgear-breathing apparatus still secured and interfaced to metabolic cart, participants transitioned into the pool and assumed a standing position immersed to axillary level ($75 \pm 2\%$ of stature; transition time, 90–120 s). They were asked to rest quietly for 7 to 8 min in this posture. Metabolic and HR responses over the final 5 min of standing on deck and in water were separately averaged and defined as representing "resting" state for each respective condition. Following standing measurements, the breathing apparatus was removed, participants drank water, and participants subsequently engaged in an instructor-guided warm-up for 6 min. The warm-up consisted of the same exercises that would be performed during the TS-SWE workout. Immediately after the warm-up, subjects were asked to report their overall RPE for the warm-up while looking at a poster of Borg's 6–20 RPE scale. VO₂ for the warm-up was predicted by entering the reported RPE into the participant's individual regression equation of VO₂ regressed on RPE, $VO_2 = a + b$ (RPE), derived from Experiment I (D'Acquisto et al., 2015). Individual correlation coefficients for all participants exceeded .94.

Subjects were then fitted with a two-way breathing valve, which was interfaced to the Parvo-Medic metabolic cart located at poolside. Participants then moved into their exercise area (axillary level) and were reminded about the specific exercise to be performed for the subsequent 4-min TS-SWE bout. At the end of each 4-min bout, participants moved to poolside and reported their overall RPE for the bout by pointing to a number on a board illustrating Borg's RPE 6–20 scale. Subjects would then expose a finger through a vented sleeve for a finger-prick blood sample for lactate analysis (~30-μL capillary sample). In addition, a capillary blood sample was collected 60–80 s after the last 4-min bout and was analyzed for lactate (defined as peak blood lactate). Subsequently, participants performed a 10-min cooldown. Upon completion of the cooldown participants were asked to report their overall RPE for the cooldown. A finger stick was then performed, and a capillary sample of blood (~30 μL) was collected for lactate analysis. Metabolic and HR responses were measured throughout the entire TS-SWE phase and cooldown.

Statistical Analysis

All data were tested for normality using the Shapiro–Wilk test and presented as means and standard deviations. Calculation of sample size was determined using power of .8 (SPSS, Version 22.0). Accordingly, one-way analysis of variance with repeated measures or Friedman’s test was employed to test for a main effect of the TS-SWE workout (4 × 4 min bouts) for select metabolic parameters, HR and RPE. All data analyses were conducted using SPSS Version 22.0, and level of significance was set at $p \leq .05$. Significance levels for the pairwise comparisons were Bonferroni adjusted.

Results

HR while seated (S), standing on deck (SD), and in water (SW) was 76 ± 13 , 87 ± 13 , and 63 ± 12 bpm, respectively ($p < .0001$, all comparisons). VO_2 for SD and SW was 0.24 ± 0.04 and $0.26 \pm 0.04 \text{ l}\cdot\text{min}^{-1}$ ($p = .07$) with values similar to those reported in a recent experiment on the same individuals (HR: SD, 89 ± 19 ; SW, 66 ± 14 bpm; VO_2 : SD, 0.25 ± 0.04 ; SW, $0.28 \pm 0.07 \text{ l}\cdot\text{min}^{-1}$; D’Acquisto et al., 2015). Typical VO_2 and HR responses are illustrated in Figure 1 for one participant during SD, SW, 20-min TS-SWE, and cooldown. The increasing and decreasing VO_2 and HR responses illustrates the distinctive stimulus imposed by the work (20 s) to rest (10 s within and 1 min between bouts) intervals during TS-SWE. Select absolute and relative physiological responses to the overall 20-min TS-SWE workout are shown in Table 2.

Results of absolute and relative physiological responses for each 4-min bout are shown in Table 3. VO_2 ($\text{l}\cdot\text{min}^{-1}$) was different between Bouts 1 and 4, 2 and 4, and 3 and 4 ($p < .0001$, $p < .0001$, and $p = .021$, respectively). VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was different between Bouts 1 and 4, 2 and 4, and 3 and 4 ($p < .0001$, $p = .001$, and $p = .032$, respectively). Respiratory exchange ratio (RER) was different between Bouts 1 and 3, 2 and 3, and 3 and 4 ($p < .0001$, $p = .021$, and $p = .021$, respectively). V_E ($\text{l}\cdot\text{min}^{-1}$) was different between Bouts 1 and 4, 2 and 4, and 3 and 4 ($p < .0001$ for all), while HR (bpm) differed between Bouts 2 and 4, 3 and 4, 1 and 4, and 2 and 3 ($p < .0001$, $p = .003$, $p = .001$, and $p = .001$, respectively).

Blood lactate (in millimolars) was different between Bouts 1 versus 4 and 2 versus 4 ($p = .001$ and $p = .021$). RPE differed between Bouts 1 and 4 and 3 and 4 ($p = .049$ and $p = .008$). $\% \text{VO}_2$ peak was different between Bouts 1 versus 4 and 2 versus 4 ($p < .0001$ and $p = .006$) with $\% \text{VO}_2 \text{ R}$ yielding the same statistical results. $\% \text{HR}$ peak was different between Bouts 1 and 4, 2 and 4, 3 and 4, and 2 and 3 ($p = .001$, $p < .0001$, $p = .004$, and $p = .008$, respectively), while $\% \text{HRR}$ differed between Bouts 1 and 4, 2 and 4, 3 and 4, and 2 and 3 ($p < .0001$, $p < .0001$, $p = .004$, and $p = .001$, respectively). Figure 2 illustrates $\% \text{VO}_2 \text{ R}$ and $\% \text{HRR}$ responses for the 4 × 4 min bouts in reference to exercise intensity classified as “vigorous” and “near-maximal to maximal” according to ACSM guidelines (ACSM, 2014).

Energy expenditure was $199.5 + 19.0$ Kcals during the 20-min TS-SWE (work plus recovery intervals). Participants expended 39.2 ± 5.1 , 40.8 ± 4.3 , 41.5 ± 3.7 , and 46.8 ± 4.9 Kcals during Bouts 1, 2, 3, and 4, respectively, collectively representing ~84% (168 Kcals) of the total energy expenditure for the 20-min period. It was estimated that subjects expended 26.8 ± 11.5 Kcals during the 6-min warm-up (RPE

Table 2 Absolute and Relative Physiological Responses to a 20-Min Tabata-Style Shallow Water Exercise Workout (Females, n = 9)

	VO ₂ STPD (l·min ⁻¹)	VO ₂ STPD (ml·kg ⁻¹ ·min ⁻¹)	RER	Total EE (Kcals)	V _E STPD (l/min)	HR (bpm)	BLa peak (mM)	RPE	%VO ₂ peak	%HR peak
Mean	1.98	29.86	1.05	199.5	60.48	156	9.18	18.53	72.6	86.0
SD	0.19	2.40	0.04	19.0	5.76	8	1.71	1.13	4.7	2.0

Note. Data presented as mean ± SD. VO₂ = rate of oxygen uptake; STPD = standard, temperature, pressure, dry; RER = respiratory exchange ratio; EE = energy expenditure; V_E = ventilation; HR = heart rate; BLa peak = peak blood lactate concentration in millimolars; RPE = rating of perceived exertion; %VO₂ peak = percent of peak oxygen uptake; %HR peak = percent of peak heart rate.

Table 3 Select Absolute and Relative Physiological Responses for Each 4-Min Bout During a Tabata-Style Shallow Water Exercise Workout (Females, n = 9)

Parameters	Bouts			
	1	2	3	4
VO ₂ STPD (l·min ⁻¹)	1.94 ± 0.25	2.02 ± 0.21	2.07 ± 0.18	2.32 ± 0.24
VO ₂ STPD (ml·kg ⁻¹ ·min ⁻¹)	29.42 ± 4.22	30.48 ± 2.38	31.28 ± 1.90	35.01 ± 3.25
RER	1.07 ± 0.06	1.06 ± 0.04	0.98 ± 0.04	1.05 ± 0.04
Total EE Kcals/4'	39.2 ± 5.1	40.8 ± 4.3	41.5 ± 3.7	46.8 ± 4.9
V _E STPD (l/min)	57.8 ± 6.4	63.1 ± 7.1	62.1 ± 6.9	73.9 ± 7.6
HR (bpm)	152 ± 8	157 ± 9	162 ± 9	171 ± 6
BLa (mM)	5.2 ± 1.6	6.0 ± 1.0	5.9 ± 1.2	8.4 ± 1.5
RPE	18.1 ± 1.5	18.6 ± 1.3	18 ± 1.2	19.4 ± 0.9
%VO ₂ peak	71.1 ± 5.7	74.1 ± 5.7	76.2 ± 6.9	85.1 ± 6.0
%VO ₂ R	68.1 ± 6.2	71.4 ± 6.4	73.7 ± 7.5	83.5 ± 6.6
%HR peak	84.1 ± 4.2	86.6 ± 2.5	89.2 ± 3.0	94.4 ± 1.9
%HRR	75.7 ± 5.8	79.3 ± 4.0	83.4 ± 4.8	91.2 ± 3.6

Note. Data presented as mean ± SD. VO₂ = rate of oxygen uptake; STPD = standard, temperature, pressure, dry; RER = respiratory exchange ratio; EE = energy expenditure; V_E = ventilation; HR = heart rate; BLa = blood lactate concentration in millimolars; RPE = rating of perceived exertion; %VO₂ peak = percent of peak oxygen uptake; %VO₂ R = percent of oxygen uptake reserve; %HR peak = percent of peak heart rate; %HRR = percent of heart rate reserve.

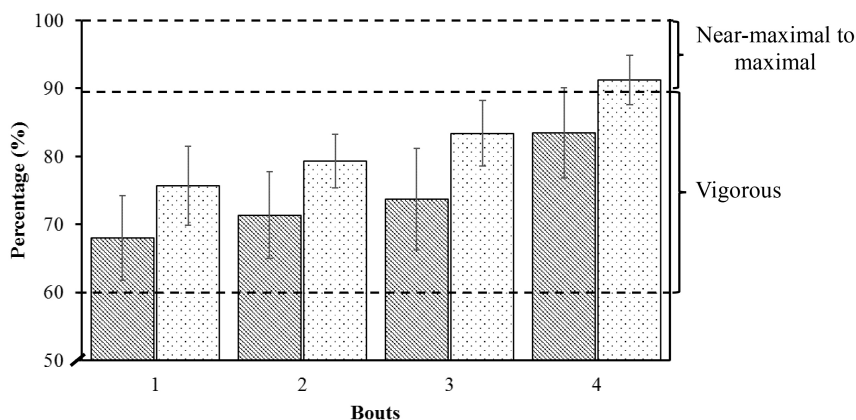


Figure 2 — Percentage VO₂ R and HRR during each 4-min bout of TS-SWE performed by apparently healthy young females (n = 9) in reference to vigorous and near maximal to maximal exercise intensity ranges according to ACSM guidelines (ACSM, 2014). Note: Percent VO₂ R = oxygen uptake reserve (diagonal line bar); percent HRR = heart rate reserve (dotted bar).

= 10.0 ± 2.0). During the 10-min cooldown subjects expended 41.6 ± 5.2 Kcals (RPE = 8.7 ± 1.4). For the 36-min session (6-min warm-up, 20-min TS-SWE, and 10-min cooldown) subjects expended 268.0 ± 11.9 Kcals. Blood lactate following the cooldown was 6.4 ± 1.4 mM.

Discussion

The unique feature of this experiment was the physiological assessment of a Tabata-style, high-intensity interval workout performed in shallow water (TS-SWE). VO_2 and HR respond to the influence of hydrostatic pressure, hydrodynamic resistance, water temperature, buoyancy, and level of immersion (Onodera et al., 2013; Torres-Ronda & Alcázar, 2014). Thus, performing resting and exercise measurements while all participants were immersed to axillary level, ~80% of body weight unloaded (Onodera et al., 2013), and at the same water temperature (28.6 ± 0.3 °C), was important from a design perspective. Furthermore, based on land and water resting VO_2 and HR measurements, participants initiated exercise in the current study in the same metabolic state as in Experiment I (D'Acquisto et al., 2015). Peak VO_2 (2.7 ± 0.3 l·min⁻¹) and HR (181 ± 8 bpm) values measured in the Experiment I were used in the current study for computing relative physiological reserve (e.g., % VO_2 R, %HRR). In addition, individual regression equations from Experiment I relating VO_2 to RPE were applied to this study for estimating VO_2 during the SWE warm-up phase. This allowed us to estimate caloric expenditure associated with the warm-up, thus providing a more accurate accounting of the total energy expenditure.

A primary finding of this experiment was that the physiological responses associated with the 20-min TS-SWE workout captured the mid to upper range of vigorous exercise intensity according to ACSM guidelines, a training intensity noted for improving cardiovascular fitness (ACSM, 2014). Overall, participants exercised at 73% (~2.0 l·min⁻¹) and 86% (~156 bpm) of their VO_2 peak and HR peak, and 74% and 82% of their VO_2 R and HRR, respectively. A peak blood lactate concentration of > 9.0 mM and respiratory exchange ratio of 1.05 provide further evidence of the intense metabolic load experienced by the participants during TS-SWE. Our hypothesis that a TS-SWE would elicit an overall physiological demand categorized as vigorous based on ACSM exercise intensity guidelines was supported.

During a 20–30 min land-based Tabata-style workout, investigators have found that participants can exercise vigorously or near-maximally to maximally reaching 80–96% of HR max and 74–88% of VO_2 peak (Emberts et al., 2013; Gist et al., 2014; Laurent, Vervaecke, Kutz, & Green, 2014; Skelly et al., 2014). As aquatic exercise continues to grow in popularity as an addition, or alternative, to land-based training, it is important for the aquatic instructor to realize that a TS-SWE workout can elicit a substantial metabolic load that is similar to land-based Tabata-style workouts. Furthermore, land-based, relatively brief HIIT results in time-efficient improvements in aerobic power and anaerobic capacity (Astorino, Allen, Roberson, & Jurancich, 2012; Gist et al., 2014; Laurent et al., 2014; Nicolò et al., 2014; Rozenek, Funato, Kubo, Hoshikawa, & Matsuo, 2007; Skelly et al., 2014; Tabata et al., 1997). Given the metabolic and cardiovascular load imposed by the TS-SWE in the current study, one may posit that HIIT performed in shallow water may result in comparable time-efficient metabolic adaptations as land-based HIIT.

The effects of TS-SWE training on metabolic adaptations and exercise capacity warrants further investigation.

Our second hypothesis that there would be a significant difference in physiological responses among the four TS-SWE bouts was supported. Pairwise comparisons indicated select differences in metabolic responses among the four bouts. Participants exercised vigorously during all four bouts as noted by measures of relative exercise intensity (%VO₂ peak, %VO₂ R, %HR peak, and %HRR) (Table 3 and Figure 2). Percent HR and %HRR increased in a step-wise fashion from Bout 1 to Bout 3 (~84–89% and 76–83%, respectively) and increased to near-maximally to maximally during the fourth bout (~94 and 91%, respectively) according to ACSM exercise intensity guidelines (ACSM, 2014). Percent VO₂ peak and %VO₂ R increased in a step-wise fashion with each successive bout with average values ranging from 71–76% and 68–74%, respectively, for Bouts 1 through 3, with the most noticeable increase occurring between Bouts 3 and 4 (Bout 4: 85 and 83.5 for %VO₂ peak and %VO₂ R, respectively). In addition, and as expected, the level of metabolic and HR response varied among participants within each bout. For example, %VO₂ R and %HRR for Bout 4 varied from 70–93% and 86–96, respectively. Collectively, the above findings support that energy-producing systems requiring oxygen, and supporting organ systems (e.g., pulmonary and cardiovascular) were substantially stressed and that the level in which participants taxed their physiological reserve varied considerably during the 20-min TS-SWE.

Before beginning the workout, participants were reminded to exercise “all-out” during each 20-s work interval, for each 4-min bout, and to be truthful in their rating of perceived exertion following each of the four bouts. Although relative physiological measures of intensity suggest that participants exercised at the mid to upper range of vigorous during each bout, RPE findings (>18 Bouts 1, 2, and 3, >19 Bout 4; > very, very hard on Borg 6–20 scale) support that an exercise intensity aligned with near-maximal to maximal was experienced (ACSM, 2014). As further evidence of the demanding nature of TS-SWE, blood lactate was ~5–6 mM for the first three bouts, and 8.4 ± 1.5 mM immediately following Bout 4. Perhaps more indicative of the overall intensity of the workout was a peak blood lactate concentration of 9.2 ± 1.7 mM, 10-fold above resting and 12% greater than measured following a maximal SWE performed by the same individuals in a recent study (8.1 ± 1.7 mM, D’Acquisto et al. 2015). Comparatively, peak blood lactate concentration recorded for land-based HIIT has been found to range from 7.0–13.1 mM (Embets et al., 2013; Gist et al., 2014; Laurent et al., 2014; Nicolò et al., 2014; Rozenek et al., 2007; Zuniga et al., 2011), whereas Cook et al. (2013) reported blood lactate values of 8.0 mM (RPE = 15, hard) in males following 10 × 9.1 m all-out running sprints in shallow water.

The accumulation of lactate during the TS-SWE workout suggests an anaerobic energy contribution (di Prampero & Ferretti, 1999; Margaria, Aghemo, & Sassi, 1971). Determining absolute and relative contribution of energy derived from anaerobic metabolism was beyond the scope of this study. The significant accumulation of blood lactate, however, suggests that energy derived from oxidative phosphorylation was not sufficient to cover the energy requirements of TS-SWE. This deficiency indicates that our participants most likely incurred an oxygen deficit. The involvement of anaerobic metabolism, as suggested by the accumulation of blood lactate (di Prampero & Ferretti, 1999; Margaria et al., 1971), coupled with

the great aerobic metabolic response, as evidenced by relative measures of exercise intensity (e.g., % VO_2R , %HRR), suggests that both central (cardiopulmonary) and peripheral (skeletal muscle) organ systems sustained a significant physiological load. Accordingly, participants' perception of exertion is aligned with near maximal to maximal intensity according to ACSM guidelines (ACSM, 2014).

Interestingly, participants did not reach 100% of their peak VO_2 and HR during TS-SWE. Furthermore, there was a gain in physiological output during the final bout compared with the first three bouts. As an example, % VO_2R increased from 74–84% (absolute increase of 14%) while blood lactate increased from 6 to 8.4 mM, (40%) between Bouts 3 and 4. Assuming that participants maintained reasonable technique and coordination, the increase in metabolic rate most likely reflects an increased rate of mechanical work. Participants were well aware of the all-out nature of the workout task, and it was the investigators' perception that participants were enthusiastic, determined, and focused throughout the entirety of the four TS-SWE bouts. This brings up the following question: What is the rationale for the participants' not utilizing a greater percentage of their physiological reserve throughout the TS-SWE?

One possible answer is that the work (20 s) to rest intervals (within [10 s] and between bouts [60 s]) were not conducive to achieving physiological responses that were closer to 100% of peak physiological capacity despite the fact that participants accumulated 640 s (10.7 min) of all-out SWE. One implication of this observation is that the length of the intermittent work interval (20 s) was perhaps not long enough to allow participants to more fully tax their physiological reserve during the exercise bouts. The idea of a Tabata-style workout is to perform relatively brief, high-intensity (all-out) exertions with reasonably short rest intervals. Another suggestion is that the 60-s recovery period between bouts allowed for too much recovery. Given the nature of the 4-min work task, at least a 60-s recovery was deemed necessary for the participant to effectively perform the next 4-min bout. Nonetheless, future studies should examine more carefully the work to rest time pattern of high-intensity, relatively brief interval workouts with the aim of maximizing physiological responses while exercising in water.

An intriguing perspective regarding the observation that physiological reserve was not fully taxed, especially during the first three bouts, is that participants may have used a pacing strategy throughout TS-SWE. It has been suggested that when individuals are aware of the heavy nature of an exercise task in addition to the end point, that the brain will formulate an unconscious plan to modulate spatial and temporal movements of the limbs, skeletal muscle force output, and metabolic rate (Ulmer, 1996). The model is based on a classic feedback control loop wherein efferent neural signals contain information regarding timing and coordination of intended limb movements, skeletal muscle power output, and metabolic rate, thus determining physiological load and exercise intensity. Afferent feedback from muscles and/or other organs (e.g., via chemoreceptors, mechanoreceptors) in addition to other factors such as training status, motivation, and familiarity with the work task are processed by the brain to modulate mechanical power output and metabolic rate accordingly throughout the workout (Lambert, St Clair Gibson, & Noakes, 2005; Noakes, 2012; Ulmer, 1996). The general idea is to arrive to the end point of a heavy exercise task before fatigue prematurely limits or ends performance (Lambert et al., 2005).

The presence of a metabolic “end spurt” noted in Bout 4 suggests that participants did not exhaust their physiological reserve during the workout, possibly to avoid overextending themselves to prevent premature fatigue and thus successfully complete the entire workout task (Lambert et al., 2005; Noakes, 2012). Interestingly, RPE was remarkably high for all bouts, >18 for the first three bouts and >19 for Bout 4 despite indications of a physiological reserve being present (e.g., %VO₂R and %HRR below peak capacity). The possible role of a central programmer in the brain setting a pacing strategy to presumably avoid premature exhaustion when performing highly intense intermittent exercise, like the workout model employed in this study, should not be ruled out. On a practical note, gaining a better understanding of those factors that potentially may impact pacing strategies during intense, intermittent water exercise (e.g., workout duration, work to rest pattern, training status, physiological capacity, familiarity with work task, participants’ confidence in performing the work task, and external feedback from aquatic instructor) may be useful in the design and prescription of high-intensity interval workouts.

Following the last TS-SWE bout, participants moved to poolside, where they were asked to rate their perception of effort for the last bout. A finger stick and capillary blood sample was collected 10–20 s and 60–80 s post Bout 4 and analyzed for blood lactate. Participants then moved back into position to begin a 10-min cooldown. The time elapsed between the end of Bout 4 and the beginning of the active cooldown was 100 ± 10 s, during which time VO₂, HR, and RER were 1.3 ± 0.2 l·min⁻¹ (0.9–1.5 l·min⁻¹), 140 ± 12 bpm (115–159 bpm), and 1.32 ± 0.09 (1.17–1.41), respectively. Collectively, the elevated metabolic rate and HR during this immediate postworkout time period punctuates the intense nature of TS-SWE. Furthermore, blood lactate concentration immediately following the cooldown was still considerably elevated at 8 times above resting (6.4 ± 1.4 vs. 0.8 ± 0.3 mM). VO₂, HR, and RER recorded over the final minute of the cooldown was 0.8 ± 0.1 l·min⁻¹ (3 times above rest), 113 ± 9 bpm (1.8 times above rest), and 0.81 ± 0.05 , respectively. Consideration regarding duration, types of exercises performed, and level of intensity during a cooldown following a TS-SWE deserves careful consideration on the part of the aquatic instructor and future studies on this topic.

The overall workout (warm-up, TS-SWE bouts, cooldown) lasted 36 min and resulted in an energy expenditure of nearly 270 Kcal (7.5 Kcal·min⁻¹) with 74% of the energy expended during the 20-min TS-SWE phase (200 Kcal; 10Kcal·min⁻¹). The 200-Kcal value is based on the metabolic response during 10.7 min of all-out work (32 × 20 s) in addition to the metabolic rate incurred during the recovery periods (9.3 min; 10 s within bout plus 1-min recovery periods). Variability in energy expenditure was notable and ranged from 177 (9 Kcal·min⁻¹) to 229 Kcal (11.5 Kcal·min⁻¹) during the 20-min TS-SWE. Specific to the 4-min bouts, rate of energy expenditure ranged from 9.8 to 10.4 Kcal·min⁻¹ (Bouts 1–3), and 11.7 Kcal·min⁻¹ for Bout 4. Kruegel et al. (2009) investigated a 32-min shallow water, self-regulated interval workout using a 2:2 min work (RPE = 17) to rest (RPE = 9) pattern and found that females expended 148.4 ± 28.4 Kcal, 26% lower than our 20-min TS-SWE workout. Nagle et al. (2013) used a 40-min SWE session. A high-intensity interval phase (15 s easy/moderate, 15 s hard/very hard, and 15 s easy) comprising 22 min of the session yielded an energy expenditure of 171 Kcal, 14% lower than our 20-min TS-SWE workout. Emberts et al. (2013) found that a 20-min intense Tabata land workout using a 20 (all-out):10-s model resulted in an estimated

energy expenditure of 240–360 Kcals for males and females combined. Our subjects were submerged to $75 \pm 2\%$ of stature, which meant that an estimated 80% of their body weight was unloaded (Onodera et al., 2013). Body weight unloading, due to buoyancy, coupled with water's high density and dynamic viscosity, changes the strategy of how one executes whole body movements to achieve a desired exercise intensity when compared with land-based physical activities (Onodera et al., 2013; Sanders et al., 2013; Torres-Ronda & Alcázar, 2014). Thus, caution is warranted when comparing physiological response and energy expenditure between water- and land-based physical activity. Furthermore, given that our participants were estimated to be about 80% body weight unloaded while performing a 20-min TS-SWE workout, where only 54% of time was spent exercising, our finding of a 200-Kcal energy expenditure is even more impressive.

To the best of the authors' knowledge, this is the first investigation regarding assessment of acute physiological responses to a TS-SWE workout utilizing multiple 4-min bouts ($\times 4$) while incorporating a classic 20:10-s work:rest ratio. TS-SWE elicited physiological and psychophysical responses that captured the mid to upper range of vigorous, and near maximal to maximal exercise intensity (ACSM, 2014). Understanding the acute physiological responses to a TS-SWE may be valuable to researchers who wish to pursue training studies employing brief, intense SWE work intervals. Furthermore, aquatic fitness professionals who are interested in incorporating brief, intense, intermittent SWE exertions in their classes may find results of this study interesting and useful. This study expands the scientific knowledge about the physiology and psychophysical aspects of SWE and provides relevant information not only for future research but for aquatic fitness instructors.

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