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Human Kinetics
ORIGINAL RESEARCH

Physiological and Psychophysical Aspects of Shallow Water Exercise

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This study investigated the cardiorespiratory responses to perceptually self-regulated shallow water exercise (SR-SWE) efforts. Females (26 ± 6 years) performed a series of SWE bouts prescribed at rating of perceived exertion (RPE) 9, 11, 13, 15, and 17 (Borg scale) and an incremental, SR-SWE bout to a max of RPE 20. Oxygen uptake (VO_2), heart rate (HR), and blood lactate (BLa) were monitored. VO_2, HR, and BLa ranged from 0.68 ± 0.13 $l{\cdot}min^{-1}$, 90 ± 16 bpm, 2.0 ± 0.7 mM (RPE 9) to 2.21 ± 0.21 $l{\cdot}min^{-1}$, 162 ± 11 bpm, and 3.9 ± 1.6 mM (RPE 17), respectively. Peak VO_2, HR, respiratory exchange ratio (RER), and BLa were 2.72 ± 0.33 $l{\cdot}min^{-1}$, 181 ± 7 bpm, 1.05 ± 0.05, and 8.1 ± 1.7 mM, respectively. The group linear regression equation was as follows: $VO_2 = -0.97 \pm 0.189$ (RPE), $R^2 = .89$ ($p < .0001$). The regression model predicted VO_2 peak of 2.81 ± 0.28 $l{\cdot}min^{-1}$ equivalent to the measured value of 2.72 ± 0.33 $l{\cdot}min^{-1}$ ($p = .33$). Findings suggest that self-regulation of intensity based on prescribed RPE is a viable way of regulating intensity while exercising in a shallow water medium.

Keywords: shallow water exercise, oxygen uptake, heart rate, perceptual regulation, rating of perceived exertion, water immersion

Movement strategies and physiological responses while exercising in an aquatic medium are impacted by the unique physical properties of water. The depth of immersion relative to one's height will influence the magnitude of hydrostatic pressure, buoyancy force, and body weight unloading, all factors which impact movement behavior and cardiorespiratory responses in water (Onodera et al., 2013; Torres-Ronda & Del Alcázar, 2014; Wilcock, Cronin, & Hing, 2006). Furthermore, the density and dynamic viscosity of water impose a significant resistance (drag force) to motion and influence fluid flow dynamics around an exercising body (Torres-Ronda & Del Alcázar, 2014; Toussaint, Hollander, Berg, & Vorontsov, 2000). Water also has a greater heat capacity when compared with a given volume

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of air (~1,000 times greater), and the human body has a lower capacity to store heat compared with water (0.83 vs. 1.00 kcal•kg °C) (Becker, 2009; Biewener, 2003; Torres-Ronda & Del Alcázar, 2014). Given these thermodynamic characteristics and in light of most public pool temperatures ranging from about 27–29 °C (Becker, 2009), some individuals performing water exercise may experience a cooling effect, especially if the rate of energy expenditure during exercise is low. Indeed, the aforementioned properties of water make it a unique and effective medium for manipulating intensity by incorporating a broad range of movement patterns.

Shallow water exercise (SWE) is performed in an upright posture with the participant immersed to about waist or axillary level with feet making contact with the pool floor (AEA, 2010). Thus, an individual performing SWE is about 40% (waist) to 80% (axillary) body weight unloaded (Onodera et al., 2013). Controlling exercise intensity while conducting biological measurements during SWE can be somewhat challenging and involved. This is particularly evident when one considers the unique properties of water, the distinctive and complex movement patterns associated with SWE to achieve a desired result and effort, and the fact that the human body is immersed in water while investigators attempt to measure physiological and/or mechanical responses. Investigators, however, have been successful in regulating SWE intensity while measuring the behavior of select physiological and mechanical parameters (e.g., oxygen uptake [VO_2], heart rate [HR], ground reaction force) by employing cadence strategies (Barbosa, Garrido, & Bragada, 2007; Benelli, Ditroilo, & de Vito 2004; Delevatti, Alberton, Kanitz, Marson, & Kruel, 2015; Dowzer, Reilly, Cable, & Nevill, 1999; Hoeger et al., 1995; Kruel et al., 2013) and underwater treadmills (Barela & Duarte, 2008; Fujishima & Shimizu, 2003; Pohl & McNaughton, 2003; Shono et al., 2000). In addition, self-regulated efforts based on rating of perceived exertion (RPE) or utilizing instructional cues provided either immediately prior to and/or during an aquatic exercise routine have been used to modulate effort (Campbell, D'Acquisto, D'Acquisto, & Cline, 2003; D'Acquisto, D'Acquisto, & Renne, 2001; Kruel, Posser, Alberton, Pinto, & Oliveira, 2009; Nagle et al., 2013).

The Borg 6–20 RPE scale has been advocated as an adjunct to various physiological measures to obtain useful information in a clinical or fitness setting regarding exercise intensity and an individual's tolerance to physical exertion (American College of Sports Medicine [ACSM], 2014; Borg, 1998; Noble & Robertson, 1996). A graded exercise test is typically employed to study and derive the relationship between RPE and physiological markers of exercise intensity (ACSM, 2014; Dunbar et al., 1992; Eston & Williams, 1988; Smutok, Skrinar, & Pandolf, 1980). The intensity on a laboratory ergometer, such as a treadmill or bike, is conveniently preset by the investigator, and participants are asked to rate their perceived exertion at the conclusion of the exercise time period. Consequently, the physiological outcome (e.g., HR 140) at a set work intensity (e.g., 150 watts) is tagged with a given RPE (e.g., RPE 13). RPEs anchored to a continuum of workloads corresponding to measured physiological responses are then applied by using the RPEs to prescribe and guide exercise intensity. This approach is referred to as an estimation-production model since the RPEs used are derived from graded exercise tests where the RPE is estimated by the participant at the conclusion of each preset work level (Faulkner & Eston, 2008; Faulkner, Parfitt, & Eston, 2007).

Another approach to controlling intensity during a graded test is self-regulated effort. Participants self-regulate their effort by exercising over a series of prescribed RPEs (e.g., RPE 9, 11, 13, 15, Borg 6–20 scale). This RPE-guided effort model is in contrast to the paradigm where investigators preset workloads on a laboratory treadmill or cycle ergometer, as described earlier. Studies employing land-based exercise have confirmed the usefulness of employing such an RPE-guided approach to systematically self-modulate exercise intensity during a graded exercise protocol (Eston, Faulkner, Mason, & Parfitt, 2006; Eston, Lamb, Parfitt, & King, 2005; Eston, Lambrick, Sheppard, & Parfitt, 2008; Faulkner et al., 2007). Eston et al. (2005, 2006) and Faulkner et al. (2007) found a strong, positive correlation between VO_2 and RPE. In addition, the above studies predicted maximal aerobic power (VO_2 max) by extrapolating the relationship between submaximal VO_2 (*y*-axis) regressed on preset RPE (*x*-axis; RPE = 9, “very light”; 11, “light”; 13, “somewhat hard”; 15, “hard”; 17, “very hard”) out to a theoretical maximum of RPE 20. The investigators found that predicted VO_2 max was similar to measured VO_2 max. The aforementioned findings support the effectiveness of RPE in regulating intensity and predicting VO_2 max from a submaximal self-regulated land-based exercise protocol. Utilizing RPE in a perceptually guided effort production paradigm approach may have implications for water exercise research where researchers wish to systematically regulate intensity in a controlled setting. In addition, using RPE to self-regulate intensity has applications in a more naturalistic environment (e.g., aquatic fitness setting) where instructors may wish to give their clients a sense of autonomy in modulating exercise effort.

There is a need to better understand the cardiorespiratory responses of SWE ranging from sustained light-to-moderate efforts to high-intensity, relatively short, interval exercise bouts (HIIE). The acute physiological responses to shallow water HIIE, in particular, are deserving of attention since land-based research examining the effects of high-intensity interval training suggests a time efficient approach for realizing gains in fitness and health (DiPietro, Dziura, Yeckel, & Neufer, 2006; Tabata et al., 1996; Roxburgh, Nolan, Weatherwax, & Dalleck, 2014). Furthermore, the American College of Sports Medicine recommends that individuals consider mixing HIIE into their workout regimen after an initial general conditioning phase (ACSM, 2014).

The overall aim of this investigation was to perform a series of experiments (Experiments I and II) exploring the metabolic, cardiovascular, and psychophysical aspects of SWE in healthy, physically active females. Experiment I, presented in this article, examined the cardiorespiratory responses to a graded, discontinuous SWE protocol encompassing an extensive range of physical efforts. The unique feature of Experiment I was that participants controlled their exercise intensity based on their perception of a prescribed RPE (Borg scale, 6–20; Borg, 1998). We hypothesized that a steady-rate cardiorespiratory response (VO_2 and HR) for each self-regulated SWE bout clamped at RPE 9, 11, 13, 15, and 17 would be achieved during a sustained 5-min time period for each bout (Hypothesis I). In addition, we hypothesized that VO_2, a measure of metabolic load, would be linearly, positively, and strongly related to perceived exertions ranging from “very light” (RPE 9) to “very hard” (RPE 17) (Hypothesis II). Lastly, we predicted that peak aerobic power, determined from extrapolating VO_2 regressed on RPE (9 through 17) to a theoretical maximum of RPE 20, would be no different than measured SWE- VO_2 peak (Hypothesis III). Understanding the strength of the relationship between VO_2 and RPE, and whether this relationship predicts measured VO_2 peak, may provide valuable information regarding the utility of RPE for self-regulating SWE intensity.

Another unique aspect of Experiment I was that VO_2 and HR peak were measured on participants while they performed a perceptually regulated maximal SWE test. In addition, resting VO_2 and HR results obtained on participants while they stood quietly in water (axillary level) were used in conjunction with VO_2 and HR peak findings to compute relative physiology intensity for SWE efforts prescribed at RPEs 9 through 17 (percent oxygen uptake and HR peak and reserve; %VO_2 and %HR peak, %VO_2 and %HR reserve). Furthermore, VO_2 and HR peak findings from Experiment I (present study) were used in Experiment II. Miller, D' Acquisto, D' Acquisto, Roemer, and Fisher (2015) measured cardiorespiratory responses and perceived exertion in the same subjects while they performed a Tabata-style SWE, a form of high-intensity interval exercise adapted from the research work of Izumi Tabata (Tabata et al., 1997).

Method

Participants

Nine healthy, physically active female participants gave their written informed consent for taking part in the investigation (26 ± 6 years, 168 ± 3 cm, 66.1 ± 6.2 kg, %adipose tissue 24.7 ± 5.5). The research protocol was approved by the institution's Human Subjects Review Council. Each volunteer completed a health history and physical activity questionnaire (PAQ). Participants were excluded if they self-reported having had any injuries during the previous 2 months, currently taking any medications to control heart or pulmonary function, being pregnant, or not feeling comfortable exercising in water. Results from the PAQ indicated that volunteers had been exercising 4.0 ± 0.8 $\text{sessions}\cdot\text{wk}^{-1}$, 52.5 ± 13.8 $\text{min}\cdot\text{session}^{-1}$ for at least the last 10 weeks, consisting of a blend of light, moderate, and heavy exercise. Volunteers also reported prior experience with water exercise.

Experimental Approach

A study design comprising a within-subjects, repeated measures protocol was employed. Approximately 1 to 2 weeks following a familiarization session, participants underwent body composition assessment followed by physiological testing during resting, submaximal, and maximal SWE efforts (Experiment I). Two days to 2 weeks later, volunteers underwent physiological testing while resting and performing a high-intensity interval SWE workout (Experiment II; Miller et al., 2015). All SWE efforts were performed with participants immersed to axillary level. All testing was conducted during morning hours and during times in which the pool was free of any public aquatic activities. Water temperature for all testing was 28.6 ± 0.3 °C, meeting the Aquatic Exercise Association (AEA) recommendation for most moderate to vigorous exercise workouts (AEA, 2010).

For Experiment I, participants performed five 5-min, perceptually regulated SWE bouts preset at 9, 11, 13, 15, and 17 according to the Borg 6–20 RPE scale

(Borg, 1998). Select metabolic parameters (open-circuit spirometry) and HR (radiotelemetry) were continuously monitored throughout the SWE bouts. In addition, a finger stick was performed following each bout for collection of blood for whole blood lactate (BLa) analysis. The sequencing of RPE from very light to very hard was selected to elicit step-up changes in exercise intensity and metabolic load similar to the RPE-guided paradigm approach for land-based exercise (Eston et al., 2008; Faulkner and Eston, 2008; Faulkner et al., 2007). Specifically, prescribed RPE 9, 11, 13, 15, and 17 was designated suitable because it resembles an increase in exercise intensity analogous to an incremental cycle ergometry exercise test (Eston et al., 2008; Faulkner & Eston, 2008; Faulkner et al., 2007).

One minute after completion of Bout 5 (RPE 17), participants performed a 5-min maximal SWE bout for determination of peak oxygen uptake and HR, among other select cardiorespiratory responses. To elicit maximal exertion, participants were asked to self-regulate intensity by up-regulating perceived exertion with each succeeding minute from an initial RPE 17–18 (Minute 1) to a theoretical maximum of RPE 20 (Minute 5) (described below). Peak VO_2 and HR measures from the maximal test, in addition to SWE VO_2 and HR responses for Bouts 1 through 5 (RPE 9 through 17), were used to compute $\%VO_2$ peak and %HR peak in order to gauge relative physiological intensity. SWE relative intensity was also described as a percentage of oxygen uptake reserve (%VO2R) and heart rate reserve (%HRR) (see section on Computations under Methods section).

Description of SWEs

The SWE movements employed in this study are representative of base movements in aquatic choreography (AEA *Aquatic Fitness Professional Manual*, Tables 9.1 and 9.2 and Appendix A; AEA, 2010). Participants received verbal and written instructions describing the SWE movements and practiced the movements during the familiarization trial. They also received instructions about the movements and were allowed to incorporate the movement patterns during an instructor-guided warm-up during the testing session. Instructions provided to participants regarding shallow water movements for Bouts 1 (RPE 9) through 5 (RPE 17) were the following: Bout 1: Jog—jog with slightly cupped hands; Bout 2: Tuck Jumps With Plunge—start with knees slightly flexed, jump, both knees to chest as arms with extended wrists simultaneously push water downward; Bout 3: Cross-Country Ski (X-C Ski)—start in X-C Ski stance, alternate legs and arms in opposition, hands are narrow and streamlined (slice) moving least amount of water; Bout 4: Deep Split Jump Lunge—start staggered stance, knees slightly flexed, alternate stance, simultaneously swinging arms forward and back in tandem while breaking the water surface, elbows flexed, hands fisted; Bout 5: Alternating Long Leg kicks—alternate forward straight leg kicks toward water surface with opposing hand reaching toward foot, fingers spread and fingertips breaking surface of the water (icebergs).

Instructions provided to participants regarding shallow water movements for each minute of the 5-min maximal bout included the following: Minute 1: Jog—jog with slightly cupped hands; Minute 2: Tuck Jumps With Scoop—start with knees slightly flexed, jump, both knees to chest as arms draw water from the sides of the body moving water toward chest, hands cupped; Minute 3: Cross-Country Ski (X-C Ski)—start in X-C Ski stance, alternate legs and move arms in opposition, pushing and pulling water; Minute 4: Deep Split Jump Lunge—start staggered stance, knees slightly flexed, jump, alternating stance simultaneously swinging arms forward and back in tandem, elbows flexed, hands fisted then spread wide (scoop) while breaking surface of water; Minute 5: Alternating Long Leg Kicks—alternate forward straight leg kicks toward water surface with opposing hand reaching toward foot with wrist extended, fingers spread, hand fully submerged. Note that Minute 1 of the maximal test was the same movement as during the first sustained 5-min bout (RPE 9). Lower extremity motions for Minutes 2, 3, 4, and 5 of the maximal effort were the same as Bouts 2, 3, 4, and 5 of the sustained 5-min efforts (RPE 11, 13, 15, and 17, respectively); however, arm and hand movements were modified to increase resistance to motion.

Measurements

Participants completed a familiarization session in which they were instructed on basic principles of performing SWE and the use of Borg's 6–20 RPE scale to self-regulate exercise intensity based on a prescribed RPE (RPE-effort guided model; Experiment I; present article) and estimation protocol (Experiment II; Miller et al., 2015). In addition, they practiced performing a variety of SWEs under the supervision of an instructor. These exercise efforts encompassed the same movements that were performed in all SWE exercise testing sessions. In addition, participants practiced wearing a two-way breathing valve and were allowed as much time as they wanted to become familiar with the breathing apparatus. Literature prepared by the investigators consisting of (a) basic information about exercise principles of SWE, (b) illustrations of SWE movements that would be used in the study, and (c) use of the 6–20 Borg scale was also provided. Participants reviewed the literature provided by the investigators and were encouraged to ask questions.

The instructions regarding perceptually regulated SWE efforts associated with the Borg 6–20 RPE scale (Borg, 1998) were adapted from Morris, Lamb, Cotterrell, and Buckley (2009). Participants were instructed to regulate the effort by their overall perception (feeling) of prescribed RPEs. The investigator showed the participants the Borg scale and described RPE 6 (no exertion at all) and 20 (maximum effort) and explained that numbers between these extremes represent different levels of exertion. The following RPEs and their descriptions were articulated to the participants. No. 9 means a very light effort; for a healthy person this would be like walking, cycling, or performing water exercise comfortably for quite a while. No. 11 means fairly light. No. 13 means the exercise is getting somewhat hard, but it still feels OK to continue at this level of exertion. No. 15 means that the exercise is getting harder or heavy. No. 17 means exercise that is very strenuous; a healthy person can still go on, but he or she really has to push himself or herself as it now feels very heavy. No. 19 is an extremely strenuous exercise level; for many people, this is the most strenuous exercise they have ever experienced. Participants were instructed that after completion of the first 5-min effort (RPE 9), the next target RPE number for the second 5-min SWE bout (RPE 11) would be provided. Participants were instructed to use the first part of the exercise bout to adjust the intensity until they felt they matched the prescribed RPE number. This process was guided by the instructor by reminding the participant of the prescribed RPE number at 1, 2, and 3 min of the SWE bout. The instructor also informed the participants

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when 2, 4, and 5 min had elapsed. Exercise at the newly achieved RPE level was maintained for the remainder of the bout. Participants were also reminded to focus on their overall feeling of exertion.

The above process was repeated three more times at different SWE efforts (RPE 13, 15, and 17). For the maximal SWE test, participants were asked to self-regulate intensity by up-regulating perceived exertion from an initial RPE 17–18 (Minute 1) to a theoretical maximum of RPE 20 (last minute of 5-min effort). To facilitate a smooth and timely transition, the instructor reminded the participant of the target RPE for the subsequent 1-min period after 55 s of exercise at the prescribed RPE.

Experiment I was completed approximately 1–2 weeks postfamiliarization. Participants were asked to arrive to the body composition laboratory at least 4 hr postprandial, having refrained from strenuous physical activity during the prior 24 hr and from products containing caffeine for at least 12 hr before testing, and to arrive in a hydrated state. They drove themselves to the laboratory and parked within 50 m of the laboratory. A stadiometer (Detecto Inc., Webb City, MO, USA) was used to measure height, while pletysmography was employed to estimate body volume for determination of body density (mass/volume) (BOD POD, Life Measurement, Inc., Concord, CA, USA). Siri equation was employed to estimate percent adipose tissue.

Following body composition testing, participants were pushed in a wheelchair directly to the locker room of the aquatic center about 400 m away to minimize any increase in metabolic rate. Upon arrival, participants were fitted with an HR monitor (Polar Electro, CE0537, Lake Success, NY, USA), followed by measurement of axillary height (distance from base of heel to axillary fold). Water is a great conductor of heat energy compared with air (Biewener, 2003), and the hydrostatic pressure that one experiences when immersed in water results in HR-dampening due to increased stroke volume secondary to enhanced venous return (Avellini, Shapiro, & Pandolf, 1983;Becker, 2009; Onodera et al., 2013). Hence, participants' oxygen uptake (VO_2) and HR were measured while standing relaxed and immersed in water to the same level (axillary) in which the SWE bouts were performed. Participants, however, were first asked to sit and relax for 10 to 12 min while final instructions were provided. Subsequently, they were fitted with a two-way breathing valve and assumed a comfortable upright stance for approximately the next 8 min while metabolic (Parvo Medic Analyzer, Sandy, UT, USA) and HR responses were monitored. The metabolic analyzer was calibrated with standard gases (16.01% O_2 and 4.01% CO_2) before each testing session according to manufacturer's guidelines.

After 8 min of standing, a finger stick was performed; ~30 μl of blood was collected into a capillary tube and analyzed for whole BLa (Analox Analyzer, Analox Instruments Ltd., The Vale, London, UK). This measurement was defined as "resting" BLa concentration. The lactate analyzer was calibrated with an 8.0 mM standard before each testing session according to manufacturer's guidelines. Participants, with the assistance of the research team, then transitioned (with headgear-breathing apparatus still secured and interfaced to metabolic cart) into the pool by slowly walking down gradually sloping steps. Participants assumed a position immersed to axillary level (75 ± 2% of stature, range 73–78%) with arms resting easy at sides and were asked to stand quietly for approximately 8 min. The transition from deck to final standing position in the pool took place over a 90- to 120-s period. Total time from first assuming a seated position on deck to the start of quiet standing in water was about 20 min.

Metabolic and HR responses over the final 5 min of standing on deck and in water were each averaged and defined as representing "resting" state under these two respective conditions. Following resting measurements in water, the breathing valve was removed, and participants were encouraged to drink water and subsequently engaged in an instructor-guided warm-up (6 min). The warm-up provided another opportunity for the participants to perform the same exercises that were employed for the SWE test bouts. At the completion of 6 min, participants were asked to rate their overall perceived exertion for the warm-up and were encouraged to drink water.

Headgear and breathing valve was resecured; subsequently, participants engaged in five 5-min SWE bouts at prescribed RPEs (9, 11, 13, 15, and 17) and one bout to maximal exertion to a theoretical maximum of RPE 20. Employing RPEs ranging from 9 to 17 has been shown to result in a systematic step-up response in metabolic load with land-based exercise protocols (Eston et al., 2006; Faulkner & Eston, 2008; Faulkner et al., 2007; Morris et al., 2009). After participants performed their fifth SWE bout (RPE 17) they rested for 1 min and then performed a final 5-min perceptually regulated maximal SWE bout (described below). An enlarged version of Borg's 6–20 scale was placed in front of the participant before the start of each SWE effort. The investigator pointed to the target RPE and verbalized descriptive anchor statements associated with the specific numerical value right before the start of the SWE bout. All SWE efforts were started from a ready, standing position with participants immersed to axillary level. Participants were reminded of the prescribed RPE at Minutes 1, 2, and 3 and were informed of elapsed time at 2, 4, and 5 min for each submaximal SWE bout. Providing this level of guidance was deemed appropriate because, to some degree, it resembles instructor–aquacise client interaction in a practical setting. In a field setting, instructors periodically cue clients about the nature of the movement pattern, intensity, and remaining time for a particular movement or phase of an aquatic workout.

Exercise efforts were performed in the same place (stationary) with maximal horizontal displacement of about 1 m forward or back and 0.5 m lateral on either side of the start point being tolerated by the experimenters. Immediately following each submaximal bout, participants moved to deck side where a finger stick was performed and ~30 μl of blood collected into a capillary tube for lactate analysis. Participants then assumed their ready stance in the water at axillary level and performed the next bout of exercise. Time between submaximal bouts was 1 min.

The incremental maximal SWE bout was performed 1 min following the last submaximal effort and consisted of a guided, participant-controlled, perceptually regulated effort. Participants were asked to perform the 1st, 2nd, 3rd, 4th, and 5th min at RPEs of 17–18, 17–18, 18, 18–19, and theoretical maximum of 20, respectively. Just before beginning the maximal effort, participants were told that by the time they reach the beginning of the final minute, they should feel that they only have 1 min of effort left. The instructor guided the participants by providing reminders of target RPE just before transitioning into the next level of exertion. Furthermore, after 3½ min, members of the research team began to cheer the participants for the remainder of the exercise effort.

VO_2 and HR peak were defined as the highest VO_2 and HR a subject achieved during two consecutive 30-s sampling periods. Despite participants' being cued a priori and guided to self-, up-regulate to a theoretical maximum RPE 20 during the final minute, they were asked to rate their overall perception of exertion for the maximal bout upon completion. A finger stick was performed 1 min post and a capillary blood sample collected and analyzed for lactate concentration. This value was defined as peak BLa. Participants then performed a 10-min cooldown at a freely chosen effort while the instructor guided them through a variety of exercises. Immediately afterward, participants rated their overall perceived exertion for the cooldown followed by a finger stick for lactate determination. Metabolic and HR responses were monitored continuously beginning with Bout 1 (RPE = 9) through the cooldown. Participants had no direct visual of the metabolic cart during the actual exercise bouts.

Computations and Statistical Analyses

Percent VO_2 and HR peak for each SWE bout (RPE 9, 11, 13, 15, 17) were calculated by dividing the exercise VO_2 and HR response by VO_2 and HR peak, respectively, and multiplying these quotients by 100. In addition, %VO_2 R and %HRR for the SWE bouts were calculated from exercise VO_2 and HR responses, VO_2 peak and HR peak, and standing-resting VO_2 and HR while immersed to axillary level (SVO_{2rest} and SHR_{rest}). The following formulas were used to compute %VO_2 and HR reserves for SWE:

$$\%\dot{V}O_2R = \left[\left(SWE\,\dot{V}O_2 - S\,\dot{V}O_{2rest}\right)/\left(\dot{V}O_2peak - S\,\dot{V}O_{2rest}\right)\right]\times 100$$

$$\%HRR = \left[\left(SWE\,HR - SHR_{rest}\right)/\left(HRpeak - SHR_{rest}\right)\right]\times 100$$

After checking for normality via a Shapiro–Wilk test of all distributions for select physiological parameters of interest, descriptive statistics (means and standard deviations) were computed. Paired *t* tests were employed to compare standing VO_2 and HR between standing on deck versus in water. The data were analyzed with a generalized linear mixed model using the minutes and bouts as fixed effects. In addition, the nested terms of minutes within bouts and bouts within minutes were used to analyze time and intensity related differences within the respective levels. The significance level was defined as $p < .05$. Sequential Bonferroni adjustment was applied for the pairwise comparisons. VO_2 recorded over the final minute of each submaximal SWE bout was regressed against RPE in a linear regression analysis for each participant. The regression equation $VO_2 = a + b\,(RPE)$ was employed to estimate VO_2 peak at a theoretical maximum RPE of 20. A paired *t* test was used to compare the estimated to measured VO_2 peak. All data were analyzed using IBM SPSS Statistics V.22.

Results

Resting and Peak Metabolic and HR Responses

VO_2 was ~11% greater (0.28 ± 0.07 vs. 0.25 ± 0.04 l•min) ($p = .02$) while HR was ?26% (89 ± 19 vs. 66 ± 14 bpm) ($p = .001$) lower when standing in water (SW) compared with standing on deck (SD). Resting ventilation remained unchanged between the two environments (7.54 ± 1.92 [SW] vs. 7.50 ± 1.44 $l{\bullet}min^{-1}$ [SD]) ($p > .05$). Resting BLa, measured immediately after SD, was 1.2 ± 0.3 mM. VO_2 peak was 2.72 ± 0.33 $l{\bullet}min^{-1}$ (41.3 ± 4.6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$), while HR peak ventilation, and respiratory exchange ratio (RER) were 181 ± 7 bpm, 84.3 ± 11.2 $l{\bullet}min^{-1}$, and 1.05 ± 0.05. Participants' rating of perceived exertion following the maximal exertion was 19.7 ± 0.5, while peak BLa was 8.1 ± 1.7 mM.

Submaximal SWE

Figures 1 and 2 highlight minute-by-minute VO_2 and HR, respectively, for participant controlled, perceptually regulated submaximal SWE bouts (RPE 9, 11, 13, 15, 17). Average physiological reserve is also illustrated in Figure 1 (VO_2 peak–$SWVO_{2rest}$) and Figure 2 (HR peak–$SWHR_{rest}$). Observing the minute-by-minute changes in VO_2 and HR in reference to their respective reserves provides a diagrammatic perspective on the magnitude of physiological responses during

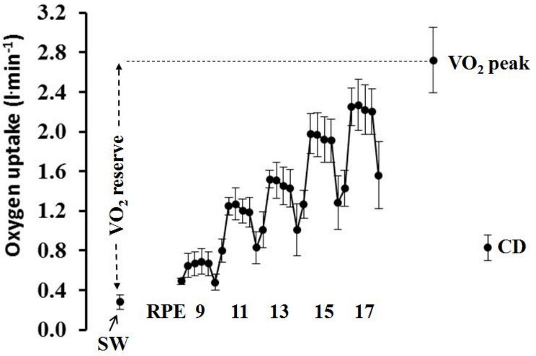

Figure 1 — Oxygen uptake (VO_2) while standing in water (SW, axillary level), minute by minute for each 5-min rating of perceived exertion (RPE) self-regulated shallow water exercise bouts, each recovery minute and cooldown (CD). VO_2 reserve is shown as the difference between VO_2 peak and VO_2 SW ("resting").

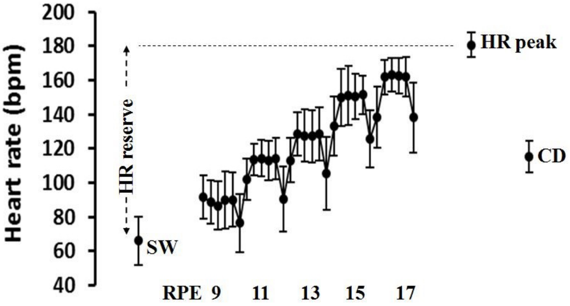

Figure 2 — Heart rate (HR) while standing in water (SW, axillary level), minute by minute for each 5-min rating of perceived exertion (RPE) self-regulated shallow water exercise bouts, each recovery minute and cooldown (CD). HR reserve is shown as the difference between HR peak and HR SW ("resting").

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each succeeding submaximal SWE effort. In addition, average VO_2 and HR for the 10-min cooldown are presented. VO_2 and HR for Minutes 2, 3, 4, and 5 within each 5-min SWE bout were similar ($p > .05$), suggesting that a steady-rate VO_2 and HR response was established for each bout. Furthermore, VO_2 and HR following each bout (recovery minute) decreased compared with the previous 4 min of the respective bout ($p < .02$) but increased following each successive SWE bout with all pairwise recovery minute comparisons being different ($p < .001$).

Given that VO_2 and HR responses over the final 4 min of each 5-min bout were the same, Minute 5 of each bout was chosen to represent steady-rate physiological response for RPE 9, 11, 13, 15, and 17. Steady-rate VO_2 was regressed against RPE in a linear regression analysis for each participant. Figure 3 illustrates an example of VO_2 regressed on RPE for one participant. The linear regression equation is nested within the figure, and predicted versus measured VO_2 peak is also observed. The regression equation for the group was as follows: $VO_2 = -0.97 \pm 0.189(\text{RPE})$ ($r = .94$, $R^2 = .89$, $p < .0001$). Estimated and measured VO_2 peak were 2.81 ± 0.28 and 2.72 ± 0.33 l·min^{-1}, respectively ($p = .32$). Immediately following the maximal test, participants rated their exertion at 19.7 ± 0.5.

Physiological responses over Minute 5 of each submaximal RPE are presented in Table 1. A main effect for VO_2, HR, RER, ventilation, $\%VO_2$ and HR peak, $\%VO_2$R, and %HRR reserve was found ($p < .001$). All pairwise comparisons for VO_2, regardless of unit expression (l·min^{-1} and $\text{ml·kg}^{-1}\text{·min}^{-1}$), were different ($p < .02$) with the exception of RPE 15 versus 17. All pairwise comparisons for HR were different ($p < .02$) with the exception of RPE 15 versus 17 ($p = .07$). RER for RPE bouts 9, 11, and 13 were similar ($p > .05$). RER was different between RPE bouts 9 versus 17 ($p = .03$), 11 versus 17 ($p < .0001$), and 13 versus 17 ($p = .01$). All pairwise comparisons for Ve and $\%VO_2$ peak were different ($p < .01$) with the exception of RPE bouts 15 versus 17 (Ve, $p = .11$; $\%VO_2$ peak, $p = .14$). All pairwise comparisons for %HR peak and reserve were different ($p < .02$) with the exception of RPE bouts 15 versus 17 (%HR peak, $p = .07$; %HR reserve, $p = .06$). Shapiro–Wilk test revealed that $\%VO_2$ reserve for RPE 9 bout was not normally

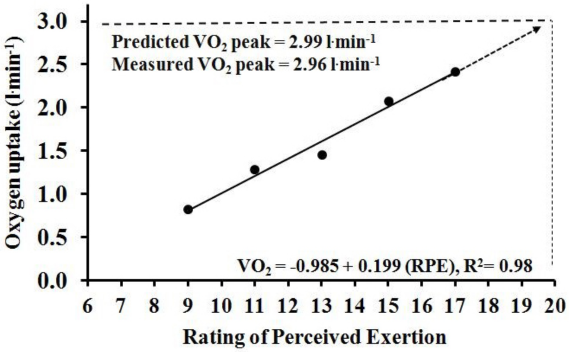

Figure 3 — Example relationship between oxygen uptake (VO_2) and rating of perceived exertion (RPE) for one participant. The arrow represents the extrapolation of steady state VO_2 during a self-regulated incremental shallow water exercise test from prescribed RPEs out to a theoretical maximum of RPE 20. The dotted line represents the predicted VO_2 peak.

Table 1 Physiological Responses for Perceptually Regulated Shallow Water Exercise Efforts Based on Prescribed Rating of Perceived Exertion (RPE)

	RPE				
Variables	**9**	**11**	**13**	**15**	**17**
VO_2 ($l{\cdot}min^{-1}$)	0.68 ± 0.13	1.19 ± 0.16	1.44 ± 0.19	1.91 ± 0.22	2.21 ± 0.24
VO_2 ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	10.25 ± 1.70	18.05 ± 1.9	21.82 ± 2.85	28.99 ± 2.79	33.54 ± 3.79
RER	0.86 ± 0.06	0.85 ± 0.04	0.88 ± 0.07	0.91 ± 0.05	0.95 ± 0.05
V_E ($l{\cdot}min^{-1}$)	16.9 ± 4.3	26.2 ± 3.5	32.8 ± 6	47.6 ± 8.2	58.8 ± 8.0
HR (bpm)	90 ± 16	114 ± 12	129 ± 16	151 ± 11	162 ± 11
BLa (mM)	2.0 ± 0.7	1.9 ± 0.7	2.3 ± 1.0	2.60 ± 1.1	3.9 ± 1.6
$\%\dot{V}O_2$ peak	25.3 ± 6.5	44.0 ± 6.0	53.3 ± 9.2	70.9 ± 10.5	81.3 ± 6.2
$\%\dot{V}O_2$ R	16.6 ± 6.2	37.6 ± 5.6	48.0 ± 9.5	67.7 ± 11.3	79.2 ± 6.7
%HR peak	49.6 ± 7.1	63.0 ± 5.0	71.0 ± 7.3	83.8 ± 5.1	89.7 ± 5.4
%HRR	21.2 ± 5.2	42.0 ± 5.1	54.7 ± 10.1	74.8 ± 7.3	84.0 ± 8.2

Note. VO_2 = rate of oxygen uptake (absolute & relative to body mass); RER = respiratory exchange ratio; V_E = ventilation; HR = heart rate; BLa = blood lactate; relative exercise intensity is expressed as a percentage of peak oxygen uptake and peak heart rate ($\%VO_2$ peak & %HR peak), and as a percent of oxygen uptake reserve and heart rate reserve ($\%VO_2R$ & % RR, respectively).

distributed. Friedman’s nonparametric test was subsequently employed. Percent VO_2 reserve was different between RPE 9 versus 15 and 17 ($p < .0001$), RPE 11 versus 15 and 17 ($p = .046$ and $p = .003$, respectively). BLa among the first four bouts was similar ($p > .05$). BLa for Bout 5 was different compared with Bouts 1 and 4 ($p = .04$) and 2 and 3 ($p = .01$). VO_2, HR, RER, BLa, and RPE during the cooldown were 0.83 ± 0.13 $l{\bullet}min^{-1}$, 115 ± 9 bpm, 1.04 ± 0.06, 6.4 ± 1.6 mM, and 7.7 ± 0.7, respectively.

Discussion

The general aim of this experiment was to examine the cardiorespiratory responses to SWE in young healthy females. The unique feature of this study was that the participants controlled exercise intensity according to their perception of prescribed RPE, which ranged from very light (RPE 9) to a maximum of RPE 20. The participants, therefore, had a given sense of independence in establishing the intensity within the context and exertional boundaries of the Borg 6–20 RPE scale. This approach of self-regulating exercise intensity over a wide range of exertions during SWE is noteworthy given that most studies examining physiological responses during head out water immersion exercise have used cadence strategies, underwater treadmill, and on occasion instructional cues to regulate exertion (Barbosa et al., 2007, Benelli et al., 2004; Campbell et al., 2003; D’Acquisto et al., 2001; Fujishima & Shimizu, 2003; Hoeger et al., 1995; Nagel et al., 2013; Pohl & McNaughton, 2003). Thus, this research provides valuable insight into absolute and relative cardiorespiratory responses for a broad continuum of participant controlled, perceptually regulated SWE efforts and on the usefulness of RPE for the regulation of SWE intensity.

Participant controlled, perceptually regulated SWE intensity resulted in an invariant VO_2 and HR response being established during the designated 5-min time period regardless of exertional level (RPE 9, 11, 13, 15, 17) (Figures 1 and 2). This finding supports Hypothesis I that a steady-rate physiological response would be achieved within the prescribed exercise time for SWE Bouts 1 (RPE 9, very light) through 5 (RPE 17, very hard). Interestingly, a stable cardiorespiratory response was achieved early in the designated time period for each steady-rate exertional level, suggesting that the time required for participants to reach a steady metabolic response was not related to intensity level. For example, as a group, VO_2 and HR reached an asymptote after 2 min of SWE for physiological intensities ranging from ~25% (RPE 9) to 81% VO_2 peak (RPE 17). The latter results support the utility of RPE as a means of regulating SWE intensity and achieving steady physiological responses over a wide range of exercise efforts, including intensities associated with enhancing cardiorespiratory fitness (i.e., 50–80% VO_2 peak) (ACSM, 2014).

Findings in the current study highlight a strong, positive, and linear relationship between steady-rate VO_2 and RPE, thus supporting Hypothesis II. Individual correlation coefficients ranged from .94 to .99. The sample coefficient of determination for VO_2 regressed on RPE was .89, indicating that RPE explained 89% of the variability in VO_2. Furthermore, the slope of the regression equation predicted about a 0.2 $l{\bullet}min^{-1}$ (~3.0 $ml{\bullet}kg^{-1}{\bullet}\ min^{-1}$) average increase in VO_2 per unit increase in RPE (i.e., 13–14–15 etc.). This finding becomes more meaningful if one considers that the two-unit step-up in RPE employed in the current study (i.e., 9–11–13 etc.) corresponded to a predicted increase of ~0.4 $l{\bullet}min^{-1}$ (~6.0 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$) in VO_2, which corresponds with ACSM's standard of a one to two metabolic equivalent (~3.5–7.0 ml kg min) increase during a standard submaximal incremental exercise test (ACSM, 2014). The above findings support the use of RPE in regulating SWE intensity in a controlled setting. Future research should consider exploring the utility of RPE as a means of self-regulating SWE intensity in a practical setting, such as a group SWE session. Nonetheless, our findings provide initial insight into the use of employing RPE to self-regulate intensity in a systematic, step-up fashion during SWE.

The final 5-min maximal SWE effort was designed with the intent of bringing participants to physical exhaustion to determine peak cardiorespiratory responses (VO_2 and HR peaks). To our knowledge, the maximal test employed in this study is unique in SWE research because participants self-regulated exercise intensity in a progressive, minute-by-minute step-up protocol according to prescribed RPEs under the guidance of an investigator experienced in water exercise instruction. Furthermore, participants were not constrained to one movement pattern, such as water jogging. Participants incorporated a variety of water exercises that are popular in aquatic workouts (AEA, 2010). SWEs encompassed jogging, tuck jumps, cross-country ski, deep split jump lunge, and alternating long leg kicks. Participants were instructed to perceptually regulate intensity during the first and second minutes at a prescribed RPE range of 17–18. The third and fourth minute was controlled at an RPE of 18 and 19, respectively, while the final minute was performed at 20. Just before the maximal bout, participants were told that they should feel like they only have 1 min of physical exertion left by the time they reach the start of the final minute. In addition, with 1.5 min remaining, participants received verbal encouragement from the research team. Average VO_2 and HR during the recovery minute following the last sustained 5-min effort, the minute preceding the maximal bout, corresponded to ~60% VO_2 peak and ~70%HR peak. Thus, the incremental nature of SWE Bouts 1 (RPE 9) through 5 (RPE 17) rendered participants in a significantly elevated cardiorespiratory state by the time they started the maximal bout. Following the maximal bout, participants moved to poolside. Three of the 9 participants were supported by two members of the research team because of difficulty in standing due to apparent exhaustion, while the remaining participants supported themselves with their arms in the pool gutter, also appearing fatigued.

Absolute VO_2 peak was 2.72 ± 0.33 $l\cdot min^{-1}$, which corresponded to a relative value of 41.3 ± 4.6 $ml\cdot min^{-1}\cdot kg^{-1}$. HR peak was 181 ± 7 bpm, approximately 95% of predicted land-based HR max (~190 bpm; $207 - (0.67 \times Age)$; Gellish et al., 2007), while RER and self-reported RPE were 1.05 ± 0.05, 19.7± 0.5, and peak BLa was nearly 7 times above resting (8.1 ± 1.7 vs. 1.2 ± 0.3 mM). About 100 s elapsed from the completion of the maximal test and beginning of the 10-min active cooldown. The reason for this time lapse was that a capillary blood sample was collected between 60 and 80 s post maximal test. Participants then moved back into position immersed to axillary level before starting the cooldown. Despite the light nature of the active cooldown (RPE ~8), average RER was 1.04 ± 0.06 while BLa obtained from an immediate postcooldown capillary blood sample was 6.4 ± 1.6 mM. The elevated RER, in addition to BLa at 5 times above resting, suggests that participants incurred a substantial physiological load during the self-regulated SWE maximal test. HR peak equating to 95% of predicted land-based HR max, and a corresponding BLa and RER of ~8.0 mM and 1.05 during the SWE max test, also points to the high physiological load incurred by the participants. Given the physiological responses and appearance of exhaustion exhibited by the participants, in addition to the numerous comments regarding the intense nature of the SWE maximal test, we believe that the perceptually regulated protocol resulted in participants' achieving their highest attainable VO_2 and HR peak values.

Previous research has yielded varying results regarding cardiorespiratory responses to maximal SWE (Campbell et al., 2003; Kruel et al., 2013; Silvers, Rutledge, & Dolny, 2007). For example, Kruel et al. (2013) reported a VO_2 and HR max of 34.0 ml•min^{-1}•kg^{-1} (~2.0 l•min^{-1}, estimated from reported body mass [BM] of 58.6 kg) and 187 bpm, respectively, in physically active females (age 23 years) performing stationary running in water immersed to xiphoid level (cadence regulated; water temperature 31–31 °C). Silvers et al. (2007) reported peak VO_2, HR, and RER values (males and females combined, age range = 19–26 years, college runners) of 52.8 ± 7.7 ml•min^{-1}•kg^{-1} (~3.5 l•min^{-1}, estimated from reported BM of 67.0 kg), 189 ± 10 bpm, and 1.15 ± 0.04 during a shallow water run test to volitional exhaustion while immersed to xiphoid level (underwater treadmill; water temperature 28 °C). The female participants in the Silver et al. study achieved a VO_2 and HR peak of 46.2 ± 6.6 ml•min^{-1}•kg^{-1} (~2.8 l•min^{-1}) and 187 ± 12 bpm, respectively, during water exercise (personal communication, July 20, 2015). Campbell et al. (2003) reported peak VO_2, HR, and RER values of 37.9 ± 2.2 ml•min^{-1}•kg^{-1} (~2.2 l•min^{-1}, estimated from reported BM of 59 kg), 182 ± 3 bpm, and 1.11 ± 0.06 in physically active females (age 21 years) performing a maximal SWE effort that was translatory in nature at midsternum level (intensity regulated via instructor cues; water temperature 28 °C). Comparing results among SWE studies is problematic given the different testing protocols and conditions (e.g., cadence and underwater treadmill guided intensity, water temperature, immersion level, stationary vs. translatory motion). Despite these considerations, our finding of a VO_2 and HR peak of 2.72 l•min^{-1} and 181 bpm appears reasonable for our physically fit females in light of what has been reported in the literature.

The linear relationship between steady-rate VO_2 and perceptually regulated intensities (RPE 9 through 17) was such that extrapolating the data to a theoretical exertional limit of RPE 20 resulted in a predicted VO_2 peak (2.81 l•min^{-1}) that was not different than the measured value (2.72 l•min^{-1}), thereby supporting Hypothesis III. The prediction of VO_2 peak was based on RPEs that covered a broad continuum of submaximal SWE intensities ranging from very light (RPE 9) to very hard (RPE 17). For example, %VO_2R and %HHR for RPE 9 through 17 were ~17–79% and 21–84%, respectively. To add to the metabolic profile, BLa buildup remained relatively low for bouts performed at prescribed RPEs 9 through 15 (~0.8–1.4 mM above resting), whereas for Bout 5 (RPE 17) BLa was ?2.8 mM above resting. In addition, RER values remained below 1.0 for all bouts (~0.85–0.95) (Table 1). The accumulation of lactate, especially during Bout 5, suggests an anaerobic metabolic contribution to the total rate of energy expenditure (di Prampero & Ferretti, 1999; Margaria, Cerretelli, diPrampero, Massari, & Torelli, 1963), the extent of which, however, is unknown given the scope of our measurements. Despite this suspected anaerobic energy contribution, a steady-rate cardiorespiratory response was achieved at the higher workloads.

Our finding of a strong, positive, linear relationship between VO_2 and RPE, in addition to no significant difference between measured and predicted VO_2 peak, is in agreement with the work of Eston et al. (2005, 2006, 2008) and Faulkner et al. (2007). Participants in these latter studies perceptually regulated intensity according to prescribed RPEs (9–17) by having the resistance on a cycle ergometer adjusted until they were satisfied that the mechanical power output (watts) equated with the given RPE. In addition, the graded exercise test for determining VO_2 max was controlled by the investigators (i.e., planned increases in cycle power output) as participants exercised to volitional exhaustion. Participants in the current study were not locked into an ergometer and performed a variety of movements throughout the incremental perceptually regulated SWE protocol. The step-up increase in cardiorespiratory response from RPE 9–17, and to a theoretical maximum of RPE 20, suggests that the rate of mechanical work output increased throughout. The increase in metabolic cost and HR was presumably due to participants' increasing the rate and total amount of muscle force production until they were satisfied that their effort equated to the prescribed RPE and associated movement patterns.

In summary, findings provide evidence for the prospective use of perceptually regulated SWE efforts based on prescribed RPEs. Using perceived exertion for self-regulation of SWE effort over a broad range of intensities has implications in the aquatic fitness community where instructors could regulate clients' exercise intensity by varying levels of effort. This approach is especially attractive when working with a group of individuals who may vary in their overall fitness level. The potential use of RPE to regulate intensity becomes even more attractive when one considers the unique characteristics of water as the workout medium and the challenges associated with regulating intensity. Participants were successful in establishing and maintaining an intensity that matched the prescribed RPE. The evidence for this was that regardless of the prescribed RPE (9, 11, 13, 15, 17), a steady-rate cardiorespiratory response was established early and maintained throughout the 5-min time period for each effort. Employing RPE for self-regulation of SWE effort was further supported by linear regression analysis, which revealed a strong, positive, linear relationship between VO_2 and RPE. This strong relationship resulted in a predicted VO_2 peak that was nearly identical to measured VO_2 peak, thus advancing the view of utilizing RPE for prescribing and guiding SWE intensity. Lastly, self-regulation of intensity based on a preset RPE presumably gave the participants a sense of autonomy in establishing the physiological load for each SWE bout. Such independence in establishing the work intensity in a more naturalistic setting may lead to a greater exercise adherence for some individuals (Faulkner & Eston, 2008; Faulkner et al., 2007), an outcome that is desirable in the fitness community.

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