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RELIABILITY AND ACCURACY OF A STANDARDIZED SHALLOW WATER RUNNING TEST TO DETERMINE CARDIORESPIRATORY FITNESS

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ABSTRACT

Nagle, EF, Sanders, ME, Gibbs, BB, Franklin, BA, Nagle, JA, Prins, PJ, Johnson, CD, and Robertson, RJ. Reliability and accuracy of a standardized shallow water running test to determine cardiorespiratory fitness. *J Strength Cond Res* 31 (6): 1669–1677, 2017—A standardized fitness assessment is critical for the development of an individualized exercise prescription. Although the benefits of aquatic exercise have been well established, there remains the need for a standardized nonswimming protocol to accurately assess cardiorespiratory fitness (CRF) in shallow water. The present investigation was designed to assess (a) the reliability of a standardized shallow water run (SWR) test of CRF and (b) the accuracy of a standardized SWR compared with a land-based treadmill (LTM) test. Twenty-three healthy women (20 ± 3 years), with body mass index (23.5 ± 3 kg·m^{-2}), performed 2 shallow water peak oxygen consumption ($\dot{V}O_2$peak) running tests (SWRa and SWRb), and 1 $\dot{V}O_2$max LTM. Intraclass correlation coefficients indicated moderately strong reliability for $\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}) ($r = 0.73$, $p < 0.01$), HRpeak (b·min^{-1}) ($r = 0.82$; $p < 0.01$), and O$_2$pulse ($\dot{V}O_2$ [ml·kg^{-1}·min^{-1}]·HR [b·min^{-1}]) ($r = 0.77$, $p < 0.01$). Using paired *t*-tests and Pearson's correlations, SWR $\dot{V}O_2$peak and HRpeak were significantly lower than during LTM ($p \leq 0.05$) and showed moderate correlations of 0.60 and 0.58 ($p < 0.001$) to LTM. O$_2$pulse was similar ($p > 0.05$) for the SWR and LTM tests with a moderate correlation of 0.63. A standardized SWR test as a measure of CRF is a reliable, and to some degree, valid alternative to conventional protocols and may be used by strength and conditioning professionals to measure program outcomes and monitor training progress. Furthermore, this protocol provides a water-based option for CRF assessment among healthy women and offers insight toward the development of an effective protocol that can accommodate individuals with limited mobility, or those seeking less musculoskeletal impact from traditional land-based types of training.

KEY WORDS aquatic exercise, aerobic fitness, hydrodynamic, cardiorespiratory assessment

INTRODUCTION

Aquatic exercise (AE) uses land-based physical activity (i.e., walking, jogging, calisthenics, and locomotor/resistive movements) adapted to a water medium (14). Popular forms of AE include water aerobics and both deep and shallow water running. Previous studies that compared AE with traditional swimming training programs in clinical and healthy populations reported improved health and psychosocial outcomes, with specific reference to metabolic, musculoskeletal, cardiorespiratory (CR), psychological, and performance benefits for various aquatic interventions (27,34,39,43,46). Used by trained individuals for rehabilitation or cross-training, shallow and deep water running have been shown to elicit similar chronic CR effects as compared with land-based treadmill (LTM) running (11). Compared to swimming training, AE is considered a viable alternative for certain individuals and has been reported to be a potentially more enjoyable form of physical activity (18,34) as substantiated by enhanced participation and compliance (14,34). Aquatic exercise can also serve as an attractive option for individuals unable to meet land-based training objectives or considered biomechanically limited and not capable of performing swimming strokes in a continuous fashion.

Shallow water AE is of particular interest because of its partial weight bearing characteristics that occur when performed at a water depth that offloads body weight 50%–90% when submerged from the hip to midaxillary levels (22). Shallow water running (SWR), a popular form of AE, is performed in a simple upright stance (head and shoulders above the water's surface), uses the feet as the base of support, and simulates familiar and functional land-based running movements. Previous studies comparing the physiological responses of AE to land-based movements have largely focused on deep water running exercise (5,11,12,15). A few SWR studies included aquatic treadmill, tethered, and stationary methods of running in water for healthy and clinical populations (1,4,6,10,29,45). However, evidence to support the utility of a reliable SWR protocol executed in a pool is lacking, despite greater accessibility to recreational pools nationwide. This highlights the need to accurately evaluate the CR and metabolic responses of SWR to quantify the associated energy expenditure for prescriptive and training applications in clinical and athletic populations.

Regardless of whether an activity is aquatic or land-based, assessment of cardiorespiratory fitness (CRF) using a standardized test protocol that is specific to the performance medium is essential to the development of safe and effective exercise training programs (28). Physiologic responses to land-based activity differ from aquatic activities due primarily to the hydrodynamic and physical properties of water. Accordingly, consistently lower peak heart rate (HR) and oxygen consumption ($\dot{V}O_2$) responses at maximal exercise intensities during stationary running, water walking, and deep water running exercise have been shown when compared to LTM protocols (16,38). Therefore, standardized aquatic testing procedures must be used to ensure the accuracy and generalizability of CRF data for effective AE programming (1,4). The test accuracy should involve precise and careful measurement of physiological/perceptual responses to a standardized mode-specific aquatic (i.e., SWR) test protocol using previously established (validated) methodologies as the criterion measure. To date, only 2 studies have examined the validity or reliability of SWR protocols. Silva et al. (3) reported a high test-retest reliability ($r = 0.91$) using a 12-minute running test in shallow water depths ranging from 1.1 to 1.3 meters. However, peak oxygen uptake ($\dot{V}O_2$peak) was not determined or predicted. Kaminsky et al. (26) developed a statistical model using a 500-yard shallow water run alone (1.2–1.5 meter water depth) and in conjunction with anthropometric measures to accurately predict $\dot{V}O_2$peak where field tests such as the 1.5 mile run were employed as the test criterion. Both studies, however, were limited by the absence of a criterion measure of CRF (i.e., directly measured maximal oxygen uptake [$\dot{V}O_2$max]) that was assessed using a standardized mode-specific aquatic test protocol.

Presently, a standardized nonswimming protocol capable of accurately assessing CRF in shallow water is not available. Although newly developed commercial aquatic treadmills can systematically regulate speed, grade, and work output during water immersion, such devices are costly, and studies on the validity of these measurement procedures are lacking. Considering the issues around feasibility and practical application, investigation of the accuracy of a standardized pool-based SWR test to assess CRF, using the indirect calorimetry method, is warranted. Symptomatic individuals with physical limitations from chronic conditions such as obesity, arthritis, and fibromyalgia may prefer aquatic fitness testing protocols that are partial weight bearing and provide optimal thermoregulatory properties of shallow water (2,5,8,18,32,34,38,48). For athletes who are injured or seeking an alternative modality to aerobic conditioning, SWR may offer an ideal aquatic medium for training (11,50). Furthermore, for those individuals who may be comparatively less comfortable performing AE and less skilled at swimming strokes, an SWR test may be used to assess CRF in an aquatic medium. It follows that a standardized, mode-specific SWR test is needed to provide an accurate measure of CRF (i.e., $\dot{V}O_2$peak), having application in health-fitness and sport performance settings. A standardized SWR test protocol is one that when carefully administered, will evoke measures that are generally accepted as uniform, reliable and/or authoritative rendering them useful as a rule or bases of comparison in measuring quantitative and/or qualitative responses. For strength and conditioning professionals, an SWR test will provide an alternative $\dot{V}O_2$peak assessment that will assist with further understanding of the aerobic demands of a particular training type or sport. This will allow for an exclusive aquatic prescription complimentary to traditional forms of land-based training. Therefore, the present investigation was designed to examine the reliability and accuracy of a standardized SWR test of $\dot{V}O_2$peak in healthy adult women, using an LTM test as the criterion protocol, with specific reference to the associated aerobic, metabolic, cardiovascular, and perceptual responses.

METHODS

Experimental Approach to the Problem

This study employed a multiple observation, within subject, counterbalanced design. Subjects were habituated to the protocol via an orientation practice session. On separate days, 2 shallow water $\dot{V}O_2$peak running (SWRa and SWRb) tests and an LTM maximal oxygen consumption ($\dot{V}O_2$max) running test were administered. All 3 experimental trials were counterbalanced and separated by at least 2, but no more than 7 days.

Subjects

Twenty-three healthy female subjects were recruited from (a) University and community postings in the surrounding areas; (b) University of Pittsburgh fitness classes; (c) University of Pittsburgh Faculty and Staff Fitness Center; and (d) basic instruction classes. Females were recruited because most participants in AE classes tend to be women (10). Subjects were included in the study if they met the following criteria: (1) female; (2) aged 18–35 years; (3) body mass index $\geq$18 and $<$34.9 $kg\cdot m^{-2}$ (37); (4) reported regular aerobic activity $<$150 minutes per week for the previous 6 months; (5) were $>$157 and $<$182 cm in height; and (6) felt comfortable exercising in shallow water. After initial contact, potential subjects were screened using a medical inventory and the Physical Activity Readiness Questionnaire (PAR-Q) (20). If eligible, subjects were informed of the benefits and risks of participation, followed by signature of the informed consent document, and were scheduled for an orientation session. All procedures received approval from the Institutional Review Board at the University of Pittsburgh. Physical characteristics of the study participants are presented in Table 1.

Procedures

Orientation Session. On arrival to the laboratory, standing height (in centimeters) was obtained followed by body composition assessment using a Tanita (Arlington Height, IL) bioelectrical impedance analyzer (25). Next, practice test protocols to control for test familiarization bias in those subjects who had not previously undergone a maximal oxygen consumption ($\dot{V}O_2$max) LTM test or SWR $\dot{V}O_2$peak running test were administered. Subjects were allowed to practice running on the Trackmaster TMX425C treadmill (Newton, KS) using a standard land-based heel-to-toe gait, to become familiarized with the metabolic measurement system (i.e., facemask, nose clip, and mouthpiece) used in the experimental trial (Cosmed, Chicago, IL). This included an explanation of the test termination procedures which were read to all subjects before the assessments. Subjects were also familiarized with the Adult OMNI (1–10) rating of perceived exertion (RPE) scale which was used in all experimental trials. A standard set of OMNI scale rating instructions and anchoring procedures was employed and in full view of the subject during the orientation, SWR, and LTM trials. This scale is used by health-fitness professionals and coaches to objectively evaluate an individual's perceived level of effort, strain, discomfort, and fatigue during aerobic or resistance exercise (41,42).

The next phase of the experiment occurred in the pool where subjects were shown a brief video clip of correct SWR technique and biomechanics. The familiarization period also included a written explanation of the procedures for the SWR $\dot{V}O_2$peak running test. Subjects were fitted with a Polar heart rate monitor (Port Washington, NY), mouthpiece, and nose clip and instructed to practice SWR in the 22 meter pool while wearing fitted water exercise shoes provided by the investigators. Investigators gave subjects feedback regarding water running technique (i.e., upright posture, standard toe-to-heel gait, knees high, arms at sides similar to running on land, and so on) and allowed them to become familiar with the specified protocol intensities, as well as the COSMED K4b2 and Aquatrainer metabolic unit (Chicago, IL). Standardized running movements ensured that upward knee movement did not exceed the hip line and that the upper body was slightly forward leaning. The elbows were submerged at 90-degree flexion, and moved alternately similar to arm movements used while jogging (3). Water temperature was maintained at approximately 27.5° Celsius.

Shallow Water $\dot{V}O_2$peak Running Test. On arrival to the pool, subjects were fitted with a Polar heart rate monitor, mouthpiece, and nose clip and performed an incremental test protocol as previously described (45). This protocol was performed in a water depth of 1.2 meters with the water surface ranging from slightly below the participant's xyphoid process to the midaxillary region. Similar to previous studies, $\dot{V}O_2$peak values were directly measured and identified as the highest $\dot{V}O_2$ achieved during the SWR test (49). This incremental self-regulated intensity protocol involved running a minimum of 10 lengths of the 22 meter pool, with rest periods after each length that decreased from 10 to 3 seconds throughout the test. Using both visual

Table 1. Participant characteristics (n = 23).

Characteristic	Mean ± *SD*
Age (yrs)	20.1 ± 2.9
Height (cm)	163 ± 5.2
Weight (kg)	63.0 ± 9.5
BMI ($kg\cdot m^{-2}$)	23.5 ± 3.4
Body fat (%)	26.28 ± 7.6
Fat-free mass (kg)	45.4 ± 3.1
Leg length (cm)	90.8 ± 4.9

Table 2. Shallow water running Protocol.*

Stage	Intensity	No. lengths	Rest period
1	50% (moderate)	4	10 s
2	70% (hard)	3	5 s
3	90% (very hard)	2	3–5 s
4	100% (maximal)	4–6	Continuous

*Rest period, rest time between pool lengths; Intensity, subjectively determined; No. Lengths, 1 pool length = 22 meters.

Table 3. Peak cardiorespiratory and perceptual responses of repeated SWR trials.*†

Variable	*N*	SWRa	SWRb	Difference	ICC
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	18	38.2 ± 6.05	38.5 ± 5.8	−0.3 ± 4.5	0.73‡
HRpeak ($b \cdot min^{-1}$)	22	181 ± 11.0	178 ± 11.0	3.0 ± 6§	0.82‡
O_2pulse ($\dot{V}O_2$peak/HRpeak)	18	0.21 ± 0.04	0.22 ± 0.03	−0.01 ± 0.02	0.77‡
Peak RER	17	1.08 ± 0.12	1.09 ± 0.11	0.01 ± 0.16	NS
VEpeak ($l \cdot min^{-1}$)	17	89.7 ± 11.0	93.6 ± 17.0	3.9 ± 14.5	0.50§
Immediate posttest RPE	22	9.7 ± 0.6	9.7 ± 0.6	0.0 ± 0.8	NS

*SWR = Shallow Water Run; SWRa = first shallow water running trial; SWRb = second shallow water running trial; RER = respiratory exchange ratio; NS = nonsignificant; RPE = rating of perceived exertion.

†Values are in mean ± *SD*.

‡$p < 0.01$.

§$p \leq 0.05$.

and verbal cues throughout each stage, the moderate, hard, very hard, and maximal intensities listed in Table 2 corresponded to 4–6, 6–8, 8–9, and >9 on the OMNI-RPE scale, respectively (41). These targeted perceptual intensities approximated 40–85% of oxygen uptake reserve (VO_2R), or 65–95% of maximum heart rate reserve (HRR) as specified by American College of Sports Medicine (ACSM) (31). After 9 lengths, subjects ran continuously as fast as possible with upward high knee movements nearly breaking the surface of the water till velocity completed per pool length declined or until volitional fatigue occurred.

Expired ventilatory volume (VE), standard temperature and pressure, dry, and concentrations of expired O_2 ($l \cdot min^{-1}$) and CO_2 ($l \cdot min^{-1}$) were analyzed by the calibrated COSMED K4b2 system and measured by open circuit spirometry in 15-second intervals. Immediate posttest RPE values were obtained by having subjects touch the desired numerical category rating on a posted scale attached to the pool wall. Subjects participated in a cool-down by walking for 3 minutes or until HR decreased to <110 $b \cdot min^{-1}$.

Land-Based Treadmill $\dot{V}O_2$max Running Test. Similar to the SWR test, subjects were fitted with a Polar monitor, facemask, and mouthpiece. As previously described, resting values of HR ($b \cdot min^{-1}$), $\dot{V}O_2$ ($l \cdot min^{-1}$), and $\dot{V}CO_2$ ($l \cdot min^{-1}$) were obtained before testing. The progressive incremental Bruce treadmill test consisted of 3-minute stages as follows: Stage 1 (2.74 $km \cdot h^{-1}$) 10.0% grade; Stage 2 (4.02 $km \cdot h^{-1}$) 12% grade; Stage 3 (5.47 $km \cdot h^{-1}$) 14% grade; Stage 4 (6.76 $km \cdot h^{-1}$) 16% grade; Stage 5 (8.0 $km \cdot h^{-1}$) 18% grade; and Stage 6 (8.9 $km \cdot h^{-1}$) 20% grade (31). $\dot{V}O_2$max was identified as a change in $\dot{V}O_2$ of <2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ with increasing exercise intensity, and reflected by the highest $\dot{V}O_2$ attained. Additional secondary criteria for aquatic and land-based tests included (a) a respiratory exchange ratio (RER) >1.10 (defined as ratio of [CO_2]: [O_2]) (b) HR ± 5 $b \cdot min^{-1}$ of the age-predicted maximum at maximal exercise; (c) an RPE-OMNI >9; and (d) volitional termination due to exhaustion (36). Expired ventilatory volume, $\dot{V}O_2$ ($l \cdot min^{-1}$), and $\dot{V}CO_2$ ($l \cdot min^{-1}$) were analyzed and calculated by open circuit spirometry in 15-second sampling intervals. On

Table 4. Peak cardiorespiratory and perceptual responses of SWR and LTM tests.*†

Variable	*N*	SWRa	LTM	Difference	Pearson's *r*
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	23	37.1 ± 6.8	44.2 ± 8.4	−7.1 ± 6.9‡	0.60‡
HRpeak ($b \cdot min^{-1}$)	23	181 ± 11	191 ± 11	−10.0 ± 10‡	0.58‡
O_2pulse ($\dot{V}O_2$peak/HRpeak)	23	0.206 ± 0.038	0.231 ± 0.040	−0.025 ± 0.034	0.63‡
Peak RER	23	1.09 ± 0.12	1.11 ± 0.10	−0.02 ± 0.15	NS
VEpeak ($l \cdot min^{-1}$)	23	89.0 ± 13.8	74.4 ± 15.0	14.70 ± 17.0‡	NS
Immediate posttest RPE	23	9.6 ± 0.8	8.5 ± 1.6	1.0 ± 1.5‡	NS

*SWR = Shallow Water Run; SWRa = first shallow water running trial; LTM = land-based treadmill; SWRb = second shallow water running trial; RER = respiratory exchange ratio; NS = nonsignificant; RPE = rating of perceived exertion.

†SWR included SWRa + SWRb when SWRa values were not captured. Values are in mean (*SD*).

‡$p < 0.01$.

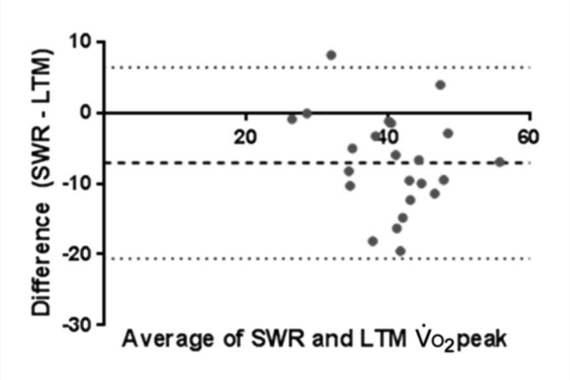

Figure 1. Bland-Altman plot for SWR $\dot{V}O_2$peak accuracy. The difference between SWR $\dot{V}O_2$peak and LTM $\dot{V}O_2$peak is shown on the Y-axis. The dotted line shows the mean of the differences. SWR = Shallow Water Run; LTM = land-based treadmill test.

completion of the test, subjects underwent a cool-down at 2.0 km$\cdot$h^{-1} and 0% grade for an additional 3 minutes, or until HR decreased to <110 b$\cdot$min^{-1}.

Statistical Analyses

Sample size calculations showed that 22 participants would provide 80% power with $\alpha = 0.05$ to reject the null hypothesis of an interclass correlation coefficient (ICC) of $\leq$0.50, assuming a true underlying ICC of 0.80. Subject characteristics were summarized by means and *SD*s. Reliability of the SWR was assessed by comparing mean values of SWRa and SWRb with paired *t*-tests and by calculating ICCs between tests for $\dot{V}O_2$peak, VEpeak, RER, HRpeak, O$_2$pulse, and immediate posttest RPE. Accuracy of the SWRa test compared to the LTM test was assessed by comparing mean differences between tests with paired *t*-tests and Pearson's correlations for $\dot{V}O_2$peak, VEpeak, RER, HRpeak, O$_2$pulse, and immediate posttest RPE. Data were drawn from the first SWRa test to simulate application where little to no practice would typically occur for a participant before an initial AE class. Table 4 included SWRa + SWRb values when SWRa values were not captured (reflected as SWR). In addition, Bland-Altman plots were used to evaluate concordance between methods including systematic bias, patterns of error, and a 95% confidence interval for observed differences between methods (limits of agreement) (7).

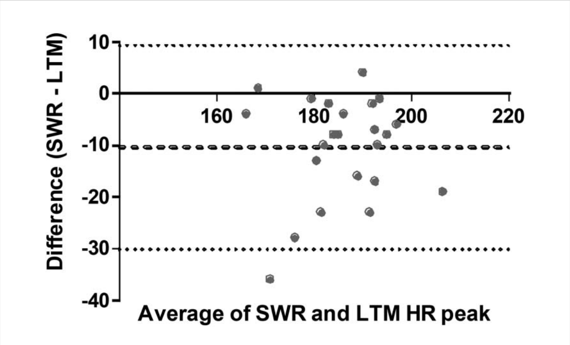

Figure 2. Bland-Altman plot for SWR HRpeak accuracy. The difference between SWR HRpeak and LTM HRpeak is shown on the Y-axis. The dotted line shows the mean of the differences. SWR = Shallow Water Run; LTM = land-based treadmill test.

RESULTS

Shallow Water Run Test Reliability

Twenty-two subjects completed the SWRa and SWRb trials. Peak CR responses during the SWRa and SWRb tests are presented in Table 3. Intraclass correlation coefficients indicated moderately strong reliability for $\dot{V}O_2$peak ($r = 0.73$, $p < 0.01$), HRpeak ($r = 0.82$; $p < 0.01$), and O$_2$pulse ($r = 0.77$; $p < 0.01$) between the 2 repeated trials. A moderate agreement was observed for VEpeak ($r = 0.50$; $p \leq 0.05$), with a lack of significance occurring between peak RER and immediate posttest RPE trials ($p > 0.05$). A paired *t*-test revealed no differences in CR variables between SWRa and SWRb with the exception of a greater HRpeak observed in the SWRa trial ($p \leq 0.05$).

Shallow Water Run Test Accuracy

To assess accuracy, peak CR responses measured during the SWR were compared to those measured during the LTM tests (Table 4). Twenty-three subjects completed valid SWR and LTM tests. Shallow water run included SWRa + SWRb trials when SWRa values were not captured. A moderate correlation was found between SWR and LTM for $\dot{V}O_2$peak ($r = 0.60$; $p < 0.01$), HRpeak ($r = 0.58$; $p < 0.01$), and O$_2$pulse ($r = 0.63$, $p < 0.01$). There was no significant correlation found between trials for VEpeak, peak RER, and immediate posttest RPE trials ($p > 0.05$). Compared to SWR, the LTM test elicited greater mean $\dot{V}O_2$peak and HRpeak values ($p \leq 0.05$).

Bland-Altman analyses (Figure 1) revealed a systematic error with a mean difference of -7.1 ml$\cdot$kg$^{-1}\cdot$min^{-1} for $\dot{V}O_2$peak. A mean difference of -10 b$\cdot$min^{-1} for peak HR across SWRa and LTM trials suggests a systematic error with a slightly negative mean bias (Figure 2). In both cases, limits of agreement were wide (-20.5 to 6.6 ml$\cdot$kg$^{-1}\cdot$min^{-1}; -30 to 9 b$\cdot$min^{-1}). Furthermore, the Bland-Altman plots revealed no obvious patterns of error, suggesting that errors were not related to mean $\dot{V}O_2$ or HR.

DISCUSSION

Our findings indicated that a standardized SWR test of CRF demonstrated moderately strong test-retest reliability and that it may be considered a viable alternative to land-based protocols. This is the first SWR pool protocol to examine the reliability of $\dot{V}O_2$peak using indirect calorimetry. Using a 12-minute running test in a pool, Silva et al. (3) found a strong agreement between the completed distances in 2 repeated tests ($r = 0.91$) where distance traveled and HRs served as the primary outcome measures. Although separate studies have examined SWR performance using underwater treadmill or stationary tethered running, the present protocol was conducted in a pool using a standardized self-regulated graded intensity protocol similar to previous investigations (16,40,45,47). This methodology offered several advantages. The protocol standardization included conducting the test at a water depth of 1.2 meters. The weight bearing effect of partial water immersion allowed participants foot contact with the bottom of the pool. Also, the standardized ramped protocol varied between 9 and 14 minutes in duration, fell within optimal recommendations for duration of graded exercise testing (30,51), and was well tolerated by subjects. Finally, stage × stage increases in running velocity and corresponding intensities were self-regulated via a cueing system that used RPE and associated somatic signals learned during the orientation session. The cues prompted participants to regulate one's individual SWR intensity. In our study, the reliability coefficients for $\dot{V}O_2$peak, HRpeak and O_2pulse ranged from 0.73 to 0.85. This demonstrated the efficacy of the standardized SWR test in young healthy females who participate in AE. The nonsignificant findings for peak RER and immediate posttest RPE trials may be explained by low *SD*s reflecting a lack of distribution in the data. Although our results may not be generalized to all populations, this study provides valuable insights to support the development of a standardized SWR test protocol for clinical populations and those unable to participate in land-based programs.

The *r* values between SWR and LTM tests could be considered moderately accurate and somewhat valid. The SWR test elicited systematically lower $\dot{V}O_2$peak values compared to those obtained during LTM. Because these responses are similar to those of previous investigations, the SWR protocol can be considered a reproducible and uniform alternative to the LTM test. This is consistent with previous findings comparing land-based protocols to both shallow and deep water protocols (19,33,47). $\dot{V}O_2$peak and HRpeak values determined during the SWR test were 84 and 95% of those observed for the LTM test. These results are similar to several previous investigations that used both underwater treadmill and swimming pool running protocols (16,33–35,45,47). The underlying mechanisms that explain these differences involve hydrodynamic properties, viscosity, and hydrostatic pressure, as well as the water depth. These variables will, in turn, affect buoyancy, propulsion, drag forces, ground reaction forces (i.e., forces exerted by the floor on the body), and muscle recruitment patterns throughout AE movements (12,13,16,23). When the individual is immersed to a depth where water level reaches the xiphoid process, buoyancy properties reduce vertical ground reaction forces and offload body weight by approximately 60% or more (22,24). This decreases neuromuscular activation of the postural and lower extremity muscles. As such, cellular oxidative energy demand and $\dot{V}O_2$peak values are comparatively lower (12). Although an individual's body composition (i.e., greater percentage of fat mass) can augment the effects of buoyancy in water (44), the present study's participants had normal BMI (23.5 $kg \cdot m^{-2}$) and healthy percent body fat (26.3%). Furthermore, the addition of anterior ground reaction forces caused by frontal drag and turbulence decreases the frequency and velocity of running strides while moving forward in water (16,23). Given the standardized requirements of the SWR test protocol, including a water depth similar to or greater than that used in the present study (1.2 meters), a reduction in energy expenditure and HR would result. In addition, increased hydrostatic pressure on the CR system lowers the HR response in shallow water as compared with land-based exercise performed at similar relative metabolic rates (13).

There was no statistically significant difference between the SWR and LTM tests in peak O_2pulse, despite consistently lower $\dot{V}O_2$peak and HR values during the former tests. Although not significantly correlated, the immediate posttest RPE was significantly greater in the SWR than in the LTM test. In contrast to previous investigations, the present study did not examine the $\dot{V}O_2/HR$ relationship by stage (10,16). Therefore, examining metabolic efficiency of an SWR test may be of value to clarify the impact of increased intensity and drag forces on running proficiency in water. Compared to an LTM test, this may influence neuromuscular recruitment patterns of active muscles and elicit a greater RPE response.

Of interest, the VEpeak was significantly greater during the SWR than LTM test. Shallow water and deep water studies (9,17) have shown similar or lower VEpeak responses during AE compared to land-based running. However, our results were similar to previous studies that observed greater VEpeak from an SWR vs. land-based running protocol (9,45). The higher VEpeak in our study could be explained by increased breathing frequency that occurs while submerged in water where the surface is equal to the chest level (45). A comparatively greater ventilatory drive may have been needed to overcome the effects of hydrostatic pressure on the thoracic cavity, causing an increased residual volume, and decreased tidal volume and vital capacity. This may have resulted in an increased work of breathing, less O_2 available to working muscles, and reduced $\dot{V}O_2$peak values in water (21,45). Because SWR evokes a comparatively greater increase in respiratory rate, this inspiratory muscle challenge may serve as an important component of an aquatic therapy prescription or training stimulus for athletic performance.

The importance of standardizing water depth should be considered when comparing physiological responses of shallow water compared with land-based test protocols. The present test protocol used a uniform water depth of 1.2 meters. This resulted in water surface levels that ranged from the participant's xyphoid to midaxillary levels. As such, the energy cost to overcome anterior and vertical ground forces varied between female participants, highlighting interindividual differences in body height. Stride frequency was not measured, and because of its potential to alter respiratory-metabolic responses, its absence could be considered a limitation of the study. At water depths less than 1.2 meters, foot contacts and stepping velocity will increase, requiring a greater energy cost to overcome frontal resistance and elicit potentially greater $\dot{V}O_2$peak responses. Therefore, SWR protocols that are not standardized to a uniform water depths (i.e., <1.2 meters) may evoke a higher $\dot{V}O_2$ and associated energy expenditure.

Similarly, the significance of conducting a standardized orientation session to practice SWR technique should not be overlooked. Those who are more proficient at running in water demonstrate lower HR responses for a given $\dot{V}O_2$ (i.e., O_2pulse), favoring submaximal performance and metabolic efficiency of SWR (16). Although our study used an orientation session, all running speeds were not performed equally in duration. Therefore, a more standardized orientation session is recommended as part of the SWR experimental design.

There are several areas of interest regarding SWR testing that warrant further investigation. Despite our use of a standardized test protocol, the present results apply only to young adult females. Therefore, future studies should examine the efficacy of the SWR test using clinical populations, athletes, and those unable to perform land-based programs. Also, given limitations of a fixed water depth and pool length, the effects of different water depths and pool lengths during SWR tests on $\dot{V}O_2$ and energy cost should be explored. The present results were considered somewhat valid. Furthermore, the nonsignificant correlation observed between LTM and SWR tests for immediate posttest RPE and VEpeak questions if the SWR tests may be more valid at lower intensities. Therefore, future validation experiments should compare responses to a pool-based SWR test with those from flume-based protocols at a wide range of intensities where an underwater treadmill would allow systematic control of standardized velocities in an aquatic environment. By establishing the validity of the SWR test, statistical models may be designed to predict CRF. The inclusion of dependent variables such as HR or RPE into these models would eliminate the need for costly and technically complex indirect calorimetry measures and serve as a practical tool to estimate CRF in a swimming pool setting. A standardized pool-based running protocol would also promote investigations on the chronic effects of SWR or other AE training regimens on health-fitness and other performance outcomes. This should help inform aquatic agencies and coaches on the most appropriate and safe methods to assess and monitor, considering an individual's health history and baseline level of CRF and conditioning.

PRACTICAL APPLICATIONS

Currently, a standardized and uniform pool protocol to accurately measure CRF in a shallow water community type pool is not available. Outcomes of aquatic training can only be accurately assessed and appropriately generalized if standardized testing (i.e., SWR protocol) is also performed in an aquatic medium. Investigating a standardized SWR protocol to assess CRF is a vital step for determining an athlete's or client's baseline level of fitness for prescriptive purposes and will serve as a method of outcome assessment of an SWR or other AE training program. For athletes, implementation of standardized test methodology for CRF evaluation can be important to the development of a training needs analysis and serves as a baseline measure from which AE training adaptations may be monitored. Furthermore, when CRF or other performance outcomes are evaluated, both before and periodically throughout an AE program, such testing protocols will serve as motivational tools to monitor training and promote program compliance.

Measurement of a mode-specific (i.e., aquatic running) CRF training using a standardized aquatic test protocol can be administered in most swimming pools. Once an accurate assessment of CRF has been conducted, the proposed AE program would provide the appropriate conditioning stimulus necessary to improve health-fitness outcomes and athletic performance. The identification of a $\dot{V}O_2$peak in water may be used to prescribe training protocols, including initial intensity level, session duration, and activity type (31). Specifically, self-regulated running intensity using prescribed target RPEs can aid in the implementation of high-intensity interval training or lower intensity physical conditioning. This may be ideal for an athlete or client unable to exercise on land, or those who exclusively train on land, and desire to cross-train or run in water for assessment or rehabilitative purposes. By standardizing methods of AE assessment and programming, we are encouraging strength and conditioning professionals to better promote the unique benefits and physiologic advantages of AE. This may lead to the adoption of AE as a more widely practiced form of physical activity.

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