Physiological responses during shallow water exercise in elderly females

by Leo D’Acquisto, Debra D’Acquisto and Dave Renne

Abstract

The purpose of this investigation was to examine oxygen uptake (VO\textsubscript{2}), heart rate (HR), oxygen pulse (VO\textsubscript{2}/HR), and ventilatory (V\textsubscript{E}) responses of elderly females performing walking and jogging movements in a shallow water medium. Sixteen females (66.3±1.3 yr) performed five, eight min., shallow water exercise (SWE) bouts ranging from low (bout 1) to moderate effort (bout 5). Metabolic response was measured by collecting expired air (open-circuit spirometry), while HR was assessed by telemetry. SWE elicited the following range of physiological responses for bouts 1 to 5: (1) HR and VO\textsubscript{2} ranged from 90±3 to 120±3 bpm (~62 to 83% estimated peak HR) and 0.57±0.02 to 1.19±0.06 l min\textsuperscript{-1} (~33 to 69% estimated peak VO\textsubscript{2}), respectively (p<0.05); (2) oxygen pulse increased steadily from 6.3±0.2 to 9.9±0.4 mlO\textsubscript{2} beat\textsuperscript{-1}(p<0.05); and, (3) V\textsubscript{E} increased from 13.97±0.93 to 28.00±1.72 l min\textsuperscript{-1}(p<0.05). Shallow water exercise efforts involving brisk walking, jogging with arms pumping at sides, or jogging in combination with breaststroke arm-like movements resulted in physiological responses conducive to maintaining cardiovascular fitness.

Key words: elderly, shallow water exercise, oxygen uptake, heart rate, ventilation

Rhythmic and continuous limb movements when exercising in a water medium provides a training stimulus for both cardiovascular and muscular development (Hasson, 1998; Kravitz & Mayo, 1997; Takeshima, Rogers, Watanabe, Brechue, Okada, Yamada, Islam, and Hayano, 2002; Tsourlou, Benik, Dipla, Zafeiridis, and Kellis, 2006; Weinstein, 1986). In addition, the buoyancy experienced while exercising in water minimizes compressive joint forces, therefore making water aerobic exercise an attractive physical activity for individuals who are overweight and/or have orthopedic disorders (Hasson, 1998; Kravitz & Mayo, 1997; Weinstein, 1986; Hall, Grant, Blake, Taylor, and Garbutt, 2004). Despite the many positive attributes of water based activity, and the fact that many studies have investigated the physiological responses of deep and shallow water exercise in younger populations (Benelli, Massimiliano, and De Vito, 2004; Gleim & Nicholas, 1989; Hoeger, W., Hopkins, D, & Barber, D. 1995; Svendenhag and Seger, 1992; Town and Bradley, 1991), little research regarding general physiological responses of healthy elderly females performing shallow water locomotion exists (D’Acquisto, D’Acquisto & Renne, 2001; Campbell, D’Acquisto, D’Acquisto, & Cline, 2003).

Metabolic and cardiovascular data presented in the present study is part of a larger scale aquatic exercise investigation (D’Acquisto, et al., 2001). This latter study focused on physiological responses during a continuous 40 minute water exercise class in older females (~67 yrs). Investigators concentrated on reporting metabolic response, expressed as metabolic equivalent, heart rate and rating of perception for select parts (warmup, body, and cooldown) of the 40 minute water exercise session. Members of the University’s senior aquatic exercise program participated. These individuals, on average, had participated in aquatic exercise for a number of years, thereby providing the investigators with a unique population to study.

Other aspects of D’Aquisto et al.’s 2001 investigation were measurements of physiological responses during a series of shorter duration (8 minutes) shallow water exercise bouts (walking and jogging) ranging from low to moderate effort. Walking and jogging movements were performed over a 25 meter distance from one end of the shallow water pool to the other while measurements (i.e., open circuit spirometry) were conducted. Another feature of the D’Acquisto et al. (2001) study was that participants were given standard verbal instructions regarding the intensity of effort just before each exercise bout. Although it may be argued that such an approach may not fully optimize control of intensity among participants for each work bout, it does reflect a real field approach in which the instructor delivers a variety of verbal instructions from pool side to participants in order to regulate intensity.

The intent of the present investigation was to describe the metabolic (oxygen uptake (VO\textsubscript{2}), carbon dioxide production (VCO\textsubscript{2}),cardiovascular(HR and O\textsubscript{2} pulse, (VO\textsubscript{2}/HR), and ventilatory responses to submaximal shallow water exercise consisting of walking and jogging performed by older females. In addition, peak VO\textsubscript{2} was estimated based on extrapolating submaximal VO\textsubscript{2} versus heart rate response to predicted HR peak. Knowing estimated peak VO\textsubscript{2} allowed for the computation of relative physiological load (%VO\textsubscript{2} peak) associated with the submaximal exercise efforts. This specific information is not reported in the 2001 study by D’Acquisto et al., and consequently, such data would add to our general understanding of the physiological demands associated with water exercise in older females. Given the popularity of aquatic exercise, an understanding of the general physiological responses to walking and jogging is of importance to the aquatic instructor when prescribing shallow water exercise to an older female clientele.

Methods

Participants

Members of the University Senior Water Exercise Program were screened with a questionnaire developed to determine exercise and medical history. In addition, a Physical Activity Readiness Questionnaire (PAR-Q) was employed to determine readiness to participate in exercise (Kenny, Humphrey & Bryant, 1995). Sixteen females (66.3±1.3 yr, Wt. 76.3±3.2 kg., Ht. 166.1±1.6 cm) who passed the PAR-Q and who were not taking medications to regulate cardiac function, participated in the project after reading and signing an informed consent. Subjects had participated in aquacise exercise for an average of 6 yrs, 3-4 sessions per week, and 40 minutes per session. This study was approved by the University Human Subjects Review Committee.
of oxygen uptake versus heart rate response to shallow water exercise.

Participants were asked to avoid rigorous exercise the day prior to testing, to rest well the evening prior to testing, and to arrive to the morning (~6-9 a.m.) testing session following a 12 hour fast and in a hydrated state. Upon arrival to the pool, participants were pre-fitted with a breathing apparatus (Hans Rudolph, Inc., Kansas City, MO) and a heart rate monitor (Polar). During a standard warmup, participants practiced moving in the shallow end of a standard 25 meter pool while performing walking and jogging like motions. Water temperature ranged from 27.5-28 °C. In addition, part of the warmup in the water involved the participants moving while wearing the breathing apparatus for familiarization purposes.

Subsequently, participants performed five shallow water exercise bouts ranging in intensity from low to moderate effort. Water level ranged from approximately the xiphoid process to the axillary region (pool depth, 1.2 m). Prior to each exercise effort, standard verbal instructions were read to the participant by the same member of the research team (Table 1). The intent of the verbal instructions was to elicit exercise efforts ranging from low (bouts 1, 2, 3) to moderate intensity (bouts 4 and 5). All participants started with bout 1 and progressed to bouts 2, 3, 4 and 5 with a three minute break between bouts. During the break, participants moved around (walking easy) and stretched. Participants were provided with periodic verbal feedback during each exercise bout to help maintain a steady effort.

### Table 1. Standard verbal instructions delivered to participants just prior to performing shallow water exercise bouts one through five

<table>
<thead>
<tr>
<th>Bout</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Do not use your arms, let arms rest (float) on top of water. Be relaxed, and remember, use no arms. Your legs are walking at a normal pace. Should be able to carry on a conversation and not be out of breath. Maintain an even pace.</td>
</tr>
<tr>
<td>Two</td>
<td>Bring arms down to sides and swing naturally through the water. Legs are walking at a normal pace. Should be able to carry on a conversation and not be out of breath. Maintain an even pace.</td>
</tr>
<tr>
<td>Three</td>
<td>Use slightly bigger steps, longer strides, with your legs. Keep arms down at sides and swing naturally through the water. Should feel that you are walking with a purpose, like to answer the phone when it is ringing, walking to the golfball after you have hit it, or going after the grandchild. You should still be able to carry on a conversation and not be out of breath. Maintain an even pace.</td>
</tr>
<tr>
<td>Four</td>
<td>Legs are now in a jog with arms pumping at sides and underwater. Should feel like you are folk dancing or performing some type of rhythmal dance at a fairly good pace. No kicking or high knees, though. Maintain an even pace.</td>
</tr>
<tr>
<td>Five</td>
<td>Jog with arms performing breaststroke movements under and toward the surface of the water. You should feel like you are in an aquacise class working on a particular exercise routine. Maintain an even pace.</td>
</tr>
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</table>

Each exercise bout lasted eight minutes. Following approximately three minutes of exercise, subjects were stopped and fitted with the breathing valve. Stop time ranged from 15 to 30 seconds. Subsequently, subjects resumed exercise. After two more minutes of exercise (total elapsed exercise time, ~ 5.0 minutes), two samples of expired air were collected (~75-90 sec collection periods) for the remainder of the exercise bout (3 minutes) through a low resistance collection apparatus (Daniels, 1971) into meteorological balloons and analyzed with a calibrated metabolic unit (Quinton Q-Plex) and a dry gas meter. Metabolic values obtained from the two bags were averaged. It has been reported that a metabolic steady-rate is established with the aforementioned shallow water exercise protocol Campbell, et al. 2003). Average HR over the final three minutes represented the HR response for the exercise bout.

### Statistics

Simple linear regression analysis was employed for oxygen uptake versus heart rate. Individual regression equations were used to project submaximal heart rate to an estimated peak heart rate (210- age; Hoeger, et al., 1995) in order to estimate VO2 peak for shallow water exercise. One way analysis of variance with repeated measures was employed to examine for main effect of shallow water exercise bouts. Post hoc analysis (Tukey) was employed if a significant F value was found. Level of significance was set a-priori at \( p \leq 0.05 \).

### Results

Table 2 provides descriptive data for regression analysis of submaximal oxygen consumption on heart rate response. Individual regression equations were used to estimate each participant’s peak VO2. The average estimated peak VO2 was 1.76±0.09 l.min\(^{-1}\) (23.30±1.18 ml.O2.min\(^{-1}.kg\(^{-1}\)), while estimated peak HR was 144±1bpm. Knowing the estimated peak VO2, and heart rate (210-HR) allowed for the prediction of relative physiological load (% VO2 peak, %HR peak) for each exercise bout (presented below).

Metabolic and cardiovascular responses for the five shallow water exercise (SWE) bouts are presented in Table 3. For SWE bouts one to five, VO2 increased from 0.57 to ~1.20 l.min\(^{-1}\), whereas VCO2 increased from 0.44 to 0.98 l.min\(^{-1}\). Heart rate ranged from ~ 90 bpm to 120 bpm for bouts 1 to 5 (p<0.05). Percentage of predicted peak heart rate varied from ~62 to 83 percent, while %VO2 peak varied from ~33 to 69 percent for bouts one to five (p<0.05). Ventilation increased steadily from 13.97±0.93 to 28.00±1.72 l.min\(^{-1}\) (bout 1 to bout 5) (p<0.05).
Table 3. Metabolic and cardiovascular responses to shallow water exercise bouts one through five

<table>
<thead>
<tr>
<th>Variable</th>
<th>One</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
<th>Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (l.min⁻¹)</td>
<td>0.57±0.02</td>
<td>0.68±0.03</td>
<td>0.84±0.04</td>
<td>1.03±0.06</td>
<td>1.19±0.06</td>
</tr>
<tr>
<td>VO₂ (ml.min⁻¹.kg⁻¹)</td>
<td>7.50±0.31</td>
<td>9.02±0.31</td>
<td>11.10±0.44</td>
<td>13.71±0.66</td>
<td>15.71±0.83</td>
</tr>
<tr>
<td>VCO₂ (l.min⁻¹)</td>
<td>0.44±0.02</td>
<td>0.52±0.02</td>
<td>0.66±0.03</td>
<td>0.84±0.05</td>
<td>0.98±0.06</td>
</tr>
<tr>
<td>Vₚ (l.min⁻¹)</td>
<td>13.97±0.93</td>
<td>15.89±0.78</td>
<td>18.97±1.10</td>
<td>24.03±1.31</td>
<td>28.00±1.72</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>89.8±3.0</td>
<td>94.2±3.0</td>
<td>100.5±3.2</td>
<td>109.7±3.0</td>
<td>119.5±3.3</td>
</tr>
<tr>
<td>% VO₂ peak</td>
<td>33.2±2.0</td>
<td>40.0±2.2</td>
<td>49.4±3.0</td>
<td>60.0±3.0</td>
<td>68.8±3.6</td>
</tr>
<tr>
<td>% HR max</td>
<td>62.5±2.1</td>
<td>65.6±2.1</td>
<td>70.0±2.3</td>
<td>76.3±2.0</td>
<td>83.1±2.3</td>
</tr>
</tbody>
</table>

Note: Values expressed as mean±SE. All pair wise comparisons are significant (p<0.05) with the exception of one versus bout two for VCO2, HR, %VO₂ and %HRmax.

Oxygen pulse (ml O₂ · beat⁻¹) for bouts 1, 2, 3, 4 and 5 were 6.3±0.2, 7.3±0.3, 8.4±0.3, 9.4±0.4, and 9.9±0.4, respectively. With the exception of bout 4 vs. bout 5, all other pair wise comparisons for oxygen pulse were different from one another (p<0.05). The predicted peak oxygen pulse is the quotient of the predicted peak VO₂ and HR. The predicted peak oxygen pulse was 12.3±0.6 ml O₂ · beat⁻¹ (0.16±0.008 ml O₂ · kg⁻¹ · min⁻¹ · beat⁻¹).

Discussion

Few studies have reported on the general physiological responses of healthy elderly females performing submaximal shallow water exercise involving whole body translocation consisting of walking and jogging movements ((D’Acquisto, et al., 2001; Campbell et al., 2003). One reason for the lack of research attention may be the difficulty in selecting and establishing an evenly paced shallow water exercise effort which would result in a steady-rate physiological response while the participant is moving from one end of the pool to the other. A second reason may be challenges in establishing a controlled incremental increase in work intensity over a wide range of submaximal efforts.

This investigation found that older females are able to perform shallow water exercise efforts yielding a strong, linear relationship between oxygen uptake and heart rate when provided with verbal information devised to elicit a steady effort over a continuum of submaximal shallow water exercise exertions. Furthermore, results from the linear regression analysis show considerable variation in slope and intercept values among the participants (Table 2). This may reflect differences in specific walking and jogging movement patterns through the water. This finding suggests that developing individual VO₂-HR regression equations is important, in particular when the intent is to predict VO₂ peak or energy expenditure from estimated peak HR and measured submaximal heart rate response during a shallow water exercise effort.

The average estimated peak VO₂ value was 1.7 l min⁻¹ or 23.3 mlO₂.min⁻¹.kg⁻¹. The estimated peak aerobic power value in this study is reasonable in light of Shepard’s (Shepard, 1997) summary report of research showing VO₂ max values ranging from ~20 to 25 ml O₂ . min⁻¹ . kg⁻¹ for 60-65 year old females for land based activities, and Campbell’s (2003) finding of ~22 ml O₂ . min⁻¹ . kg⁻¹ in females (~67 yrs old) performing maximal shallow water exercise. Despite the strong linear relationship between oxygen uptake and heart rate, one must interpret the estimated peak VO₂ with some caution. Firstly, one is not sure that the VO₂-HR relationship remains linear at higher submaximal shallow water exercise intensities. If the VO₂-HR relationship is exponential at higher workloads (i.e., ~70% VO₂ peak), the estimated peak VO₂ of 1.76 l min⁻¹ may be an underestimation of the actual VO₂ peak. Secondly, an estimated HR peak (210-age (Hoeger, et al., 1995)) was utilized in the regression equation to predict VO₂ peak. The associated error with this method of predicting peak HR can be ~10-12 bpm (Adams, 1998)).

Campbell et al. (2003) measured a peak HR of 156±5 bpm in healthy, physically active, elderly females (67±1 yr) during a maximal shallow water exercise bout. In comparison, the present study estimated a peak HR of 144±1 bpm. It appears that using the 210-age equation, on average, may result in an underestimation of true max HR achieved by elderly females during shallow water exercise, and consequently, may lead to an under prediction of peak oxygen uptake. For land based activities, 220-age is a popular equation for estimating max HR. The rationale for adjusting the latter equation down by 10 bpm (210-age) for prediction of peak HR during water exercise is that the hydrostatic pressure on the body results in a lowered HR response due to an increased stroke volume secondary to an increased venous return (Swendenag and Segar, 1992). Additional studies are warranted to confirm the use of 210-age for the prediction peak HR in the water. Such insight would have important implications for exercise prescription for an individual performing exercise in a shallow water medium.

Oxygen uptake for efforts involving easy walking (bouts 1 and 2) to more aggressive walking (bout 3) resulted in a relative physiological load ranging from ~33 to 50 % VO₂ peak. Whereas, jogging (bout 4) and jogging with arms undergoing breaststroke like movements (bout 5) elicited a load of ~60 and 69 % VO₂, respectively. The associated increase in oxygen uptake from bout one (0.57 l min⁻¹) to five (1.19 l min⁻¹) was ~109% and this was matched with a similar relative increase in ventilation (~14 l min⁻¹ (bout 1) to 28 l min⁻¹ (bout 5), 100% increase). These findings suggest that the increase in ventilation was not disproportionate to the rise in oxygen demand associated with performing more demanding movements in the water. This highlights that the older, healthy females did not experience ventilatory distress when performing shallow water exercise efforts eliciting a substantial metabolic demand.

Predicted peak O₂ pulse was 12 ml O₂ . beat⁻¹ (0.16 ml O₂ . kg⁻¹ . min⁻¹ . beat⁻¹). Wasserman et al. (1994) has predicted a max O₂ pulse for a 70 year old woman of 8 ml O₂ . beat⁻¹, and has indicated that considerably greater values in a cardiovascually fit person could be possible. Seals, Hagberg, Hurley, Ellsani, & Holloszy (1984) investigated the effects of low (LI) and high intensity (HI) endurance training on maximal aerobic power and its determinants in healthy men and women (age range, 61-67 yr). Estimated O₂ pulse from maximal exercise response presented by Seals et al. (1984), yields values of ~.15 (before training), ~.17 (after LI
Physiological Responses

Dr. Leo D’Acquisto and Mrs. Debra D’Acquisto teach at Central Washington University and Dave Renne is employed at Providence Everett Medical Center, Everett, WA.

References