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Aquatic High-Intensity Interval Deep Water Running Influence on Cardiometabolic Health and Cognitive Psychological Responses in Women

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ABSTRACT

KWOK, M. M. Y., S. S. M. NG, J. MYERS, and B. C. L. SO. Aquatic High-Intensity Interval Deep Water Running Influence on Cardiometabolic Health and Cognitive Psychological Responses in Women. *Med. Sci. Sports Exerc.*, Vol. 56, No. 11, pp. 2203–2210, 2024. Aquatic high-intensity interval training deep water running (AHIIT-DWR) has the potential to improve cardiometabolic health and cognitive psychological responses, offering a reduced risk of injuries and greater affordability for inactive elderly women. **Purpose:** To investigate the effects of an 8-wk AHIIT-DWR intervention compared with land-based HIT training (LHIIT) on cardiometabolic health, cognitive, and psychological outcomes in inactive elderly women. **Methods:** Seventy inactive elderly women aged 60 yr or above were randomly assigned into two groups: AHIIT-DWR and LHIIT. The AHIIT-DWR group engaged in DWR sessions comprising 30 min of interval training, consisting of ten 2-min exercise bouts at 80%–90% of their maximal heart rate (HR_{max}), with 1-min active recovery at 70% HR_{max} between bouts, for two sessions per week, for 8 wk. The LHIIT group performed treadmill running at the same intensity. **Results:** Both groups showed similar cardiovascular fitness, maximal aerobic capacity ($\dot{V}O_{2max}$), HR_{max}, and RER improvement ($P > 0.05$), whereas AHIIT-DWR showed a significant improvement in aerobic capacity minute ventilation ($\dot{V}E$), metabolic equivalents (METs), and O_2 pulse ($P < 0.05$) over the 8-wk intervention. Both AHIIT-DWR and LHIIT significantly decreased triglycerides, total cholesterol, HDL, and LDL postintervention ($P < 0.05$). No significant group differences were observed for cognitive function assessed by MMSE and MOCA ($P > 0.05$). Both groups showed similar enjoyment levels, self-efficacy scores, and high adherence rates (>90%). **Conclusions:** Our study suggests that AHIIT-DWR can elicit a similar improvement in cardiorespiratory health, metabolic blood markers, cognitive function assessed by MMSE and MOCA, and psychological responses as LHIIT in inactive elderly women. **Key Words:** HYDROTHERAPY, PHYSICAL FITNESS, COGNITIVE FUNCTIONS, PHYSICAL ACTIVITY, METABOLISM

Recent public health guidelines have promoted land-based high-intensity interval training (LHIIT) as an efficacious exercise strategy that may offer some time savings (1). LHIIT is generally defined as repeated bouts of vigorous but submaximal exercise that elicits ≥80% maximal heart rate (HR_{max}), interspersed with short periods of recovery (2,3). Although LHIIT has generally been shown to improve cardiometabolic health and cardiovascular function (4), some characteristics of this training performed on hard surfaces are considered less appropriate for elderly populations because of barriers such as deconditioning, arthritis and other joint degenerative processes, and movement difficulties compounded by the land environment (5). Therefore, an aquatic environment may harness a valuable alternative for LHIIT because of the unique hydrodynamic properties. For example, aquatic high-intensity interval training (AHIIT) provides a reduction in lower extremity joint weight bearing aerobic alternative to LHIIT. Previous evidence of aquatic exercise using interval training have reported significant aerobic and cardiorespiratory benefits (6). Among these aquatic exercises, deep water running (DWR) has gained prominence in the scientific literature. DWR is performed with the aid of a floatation vest, which serves to keep the body upright and prevent the feet from

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touching the bottom of the pool (7,8). This characteristic allows AHIIT to be applied in DWR by reducing weight bearing. Studies have shown that DWR has shown greater exercise compliance, potentially because of this (9,10). Hence, it appears that the use of AHIIT-DWR can be an effective strategy for older adults to train at higher intensities than on land.

It has been recommended that exercise training at a higher intensity is beneficial to middle-aged and older adults to prevent cardiometabolic diseases associated with aging (11). For instance, older women populations are vulnerable in terms of higher cardiometabolic risk and, hence, are the main target population of aquatic exercise programs. It is known that aerobic capacity declines 10% per decade of life beyond 20 yr of age (2). This is relevant to cardiometabolic function and related to functional capacity, which is an important predictor of mortality (12). Therefore, stimulating cardiometabolic function becomes fundamental to help decrease mortality in such populations.

The perceptions of exercise will influence whether a participant continues with an exercise program, tries a different program instead, or stops exercising completely. This is a definite concern when considering inactive elderly populations. It is crucial that their perceptions for exercise are positive for participants to adhere to a program. It was observed that the perception of exercise variety is an important factor for adherence (13). It was also determined that the perception of health benefits and competence of facility staff resulted in improved adherence in older adults (14). It has been suggested that self-efficacy and enjoyment of exercise is positively correlated with exercise adherence and that lack of time was the most frequently reported barrier for physical activity (15). AHIIT-DWR may potentially provide further enjoyment or affective levels with a modification in the exercise environment. (16)

The American Psychological Association (APA) defined cognition as all forms of knowing and awareness, for instance, perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving (17). These high levels of mental processing have critical implications in synthesizing and integrating of thoughts and experiences (18). These cognitive abilities vary greater among older populations. Although overall cognitive function tends to diminish with age, a number of studies have shown that cognitive performance can improve at any age through physical exercise (19). It was reported that a global trend for positive improvements in cognitive function (i.e., through MMSE instrument) occurred as a result of intervention with aquatic exercise groups versus control groups (20). Aquatic exercise programs are potentially beneficial to older individual's cognition levels.

Despite the growing popularity of AHIIT, research investigating the cardiometabolic health benefits and the cognitive psychological responses comparing AHIIT-DWR and LHIIT has not been investigated to date. There is well-established evidence about the effects of LHIIT on cardiometabolic or physical health, whereas similar evidence regarding AHIIT-DWR is lacking (4). In addition to cardiometabolic health, cognitive psychological responses can have a significant behavioral impact on exercise compliance (21). Given this knowledge gap alongside the growing application of AHIIT, the purpose of this study was therefore to investigate the effects of 8 wk of AHIIT-DWR and LHIIT on cardiometabolic health and cognitive psychological outcomes among inactive elderly women. We hypothesized that 8 wk of AHIIT-DWR maybe similarly effective as LHIIT in improving cardiometabolic health and cognitive psychological responses in inactive elderly women.

METHODS

Participants. Seventy inactive elderly women with a stable medical history were recruited for this study. After providing their written informed consent, all participants declared that they were free of any cardiorespiratory, neurological pathology, and/or had an orthopedic fracture or any surgical intervention done to the lower extremities in the 6 months before the study. None of the participants were taking any medications.

Study design. A parallel two-group randomized controlled trial design was used according to the Consolidated

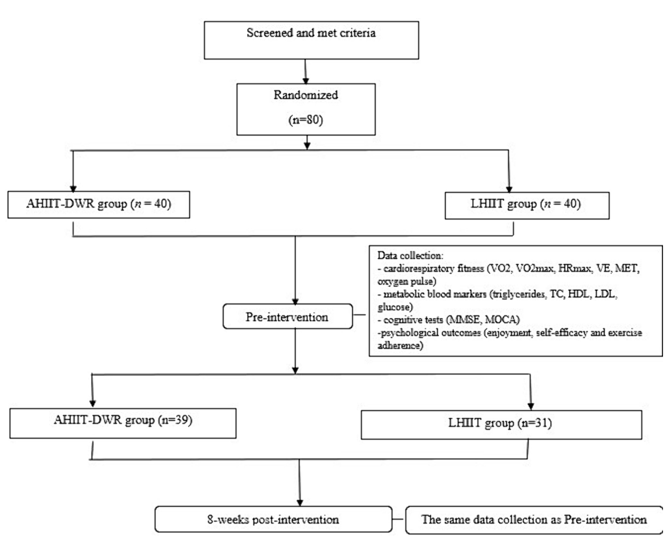

FIGURE 1—Flow chart of proposed study.

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Standards for Reporting of Trials (22). Selected participants who fulfilled the selection criteria were randomly assigned to either the AHIIT-DWR program or the LHIIT, using the computer software Research Randomizer (Fig. 1).

Experimental procedures. Participants were required to perform an interview for screening and familiarization before signing an informed consent to the study. The experimental procedures completed comprise the basis for the baseline data. Subjects were screened by a standard health questionnaire (International Physical Activity Questionnaire), measuring their resting heart rate (HR), blood pressure (BP), body mass, and height. All participants performed and completed a familiarization session at the pool a week before the study. An incremental tests in water and on land were performed before the exercise interventions to confirm an individualized exercise intensity in each condition (23). The incremental tests in water and on land were carried out by DWR and treadmill running respectively. DWR trained groups performed DWR maximal test, whereas treadmill running subjects performed max tests during treadmill running maximal test. Before testing, all exercises were demonstrated first then practiced once. Participants were monitored continuously, and HR data were recorded at a frequency of 1 Hz by an HR sensor (Polar OH1, Kempele, Finland). During the incremental test, gas exchange data were obtained by a PNOE portable metabolic device. The PNOE device acquired data breath by breath and continuously measured ventilatory volume and determined expired gas concentrations simultaneously. The DWR incremental protocol increased the exercise load from 85 bpm and increased the cadence by 15 bpm every 2 min for each progression (23), whereas the land treadmill incremental followed the Bruce protocol (24). A metronome (Intelli IMT 300, Japan) was used to provide the target cadence during DWR protocol. The HR, the $\dot{V}O_2$, and the rate of perceived exertion each minute were recorded. A metronome was used to provide the target cadence during the DWR protocol.

Interventions. All intervention groups performed a standardized 3-min warm-up and 3-min cooldown that included pool walking, jogging, and pool wall stretches at 50% heart rate reserve (HRR). HRR is obtained by using the maximal heart rate (HR_{max}) determined from the incremental tests to subtract resting heart rate (HR_{rest}) (25).

AHIIT-DWR. The AHIIT-DWR training program consisted of ten 2-min bouts of DWR at 80% HRR with 1-min active recovery at 60% HRR in between bouts. The classes were held in a sports club pool with water depth ranging from 1.4 to 2 m, water temperature at 28°C, and air (room) temperature at 26°C. Participants participated in 30-min sessions twice a week for 8 wk (a total of 16 sessions). AHIIT-DWR was conducted by an experienced aquatic fitness instructor. Participants were asked to wear a flotation vest to prevent the feet from touching the pool floor and to keep the trunk straight with the chest out. The body angle was adjusted so it was slightly leaning forward in the sagittal plane. The arms were swung in a relaxed and slightly flexed position. The elbow was flexed at 90° while keeping the thumbs below the water level. The shoulder was flexed and extended to bring the elbow back and forth to complete the running cycle. The running stride began by flexing the hip to 70°–80° while maintaining the knee at right angle (about 90°). Both legs performed a cyclic movement, alternating between hip flexion and hip extension to complete the running cycle, while allowing for forward progress (Fig. 2). The quality of the movement was closely monitored by the aquatic fitness instructor.

LHIIT. The LHIIT training program consisted of ten 2-min bout of treadmill running were performed at 80% HRR with 1-min active recovery at 50% HRR between bouts. Participants participated in 30-min sessions twice a week for 8 wk

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FIGURE 2—AHIIT-DWR form.

TABLE 1. AHIIT-DWR and LHIIT training periodization.

Weeks	Volume × Intensity	Total Time
1–2	10 × (2 min 80%–85% HRR + 1 min 50% HRR)	30 min
3–5	10 × (2 min 85%–90% HRR + 1 min 50% HRR)	30 min
6–8	10 × (2 min 90%–95% HRR + 1 min 50% HRR)	30 min

(a total of 16 sessions). The quality of the movement was closely monitored by an experienced exercise instructor.

Exercise progression. During the first 2 wk, the participants performed 10 bouts of 2 min at 80%–85% HRR (weeks 1–4), with 1 min of active recovery at 50% HRR between bouts. During weeks 3–5, the participants performed 10 bouts of 2 min at 85%–90% HRR of the AHIIT-DWR, with 1 min of active recovery 50% HRR between bouts. During the last 6–8 wk, the participants performed 10 bouts of 2 min at 90%–95% of the HRR, also with 1 min of active recovery at 50% of HRR between bouts.

In the LHIIT protocol, for the first 2 wk, participants performed the HIIT treadmill run using 10 bouts of 2 min at 80%–85% HRR (weeks 1–4), with 1 min of active recovery at 50% HRR between bouts. During weeks 3–5, the participants performed 10 bouts of 2 min at 85%–90% HRR of the AHIIT-DWR, with 1 min of active recovery at 50% HR_{max} between bouts. During the last 6–8 wk, the participants performed 10 bouts of 2 min at 90%–95% of the HRR, also with 1 min of active recovery at 50% of HRR between bouts. The AHIIT-DWR and LHIIT training periodization is shown in Table 1.

Outcomes. Cardiometabolic markers were measured at baseline (preexercise) and at least 48 h after but within 5 d after the final session of the 8-wk intervention. For each pre- and postexercise assessment, the session lasted for 30 min.

Cardiorespiratory fitness. Gas exchange data were obtained by a portable metabolic device PNOE after incremental tests. A PNOE device was used to assess participants cardiorespiratory fitness level (i.e., $\dot{V}O_2$ max, oxygen pulse, $\dot{V}CO_2$, RER, MET) and HR_{max} before and after AHIIT-DWR and LHIIT. $\dot{V}O_{2max}$ was considered to be attained when the following standardized criteria were met: 1) an RER of greater than or equal to 1.10; 2) failure of heart rate to increase with increases in workload; 3) postexercise blood lactate ≥8.0 $mmol \cdot L^{-1}$ (24); 4) clear signs of exhaustion (facial flushing, unsteady gait); and 5) refusal to carry on despite strong verbal encouragement. Blood lactate was measured via capillary blood sampling from the fingertips with a portable analyzer (Lactate Plus, Nova Biomedical, Waltham, MA) (24). Data collected from the incremental test were used to determine the intensity required for the exercise interventions for each participant.

Blood metabolic markers analysis. A qualified nurse performed a venous blood sampling of 20 mL after a 12-h fasting period. Glucose levels were measured using the enzymatic–amperometric method with a coefficient of variation (CV) of 0.5% (Biosen-C; EKF Diagnostics, Germany). The lipid profile was assessed using commercially available kits (RX Monza; Randox Biosciences, UK). Total cholesterol levels were determined using the cholesterol oxidase, esterase, and peroxidase colorimetric method, with an intra-assay CV of 1.3%. HDL cholesterol levels were measured using the polyethylene glycol direct method, whereas LDL cholesterol levels were assessed using the direct method, with respective intra-assay CVs of 0.7% and 1.3%. Triglyceride levels were measured using the enzymatic method without glycerol blanking, with an intra-assay CV of 1.3%. Insulin levels were determined using an enzyme-linked immunosorbent assay (Insulin ELISA; Mercodia AB, Sweden). Duplicate measures were taken for each marker, and the average value was reported. Insulin resistance was estimated using the homeostasis assessment model for insulin resistance (HOMA-IR) (26).

Cognitive psychological responses. Cognition was be assessed before and after the 8-wk exercise intervention using cognitive batteries, including MMSE and MOCA. Both are validated instruments suitable for use as a mediator variable for devising interventions for promoting cognition. The perceptions of exercise will influence whether a participant continues with an exercise program, tries a different program instead, or stops exercising completely. It was observed that the perception of exercise variety is an important factor for adherence (13).

Statistical analysis. Analyses were performed using the Statistical Package for Social Sciences for Windows version 22.0 (SPSS, Inc., Chicago, IL). Statistical significance was delimited at $P < 0.05$. All continuous variables are presented as means and standard deviation. Mean differences among groups (AHIIT-DWR and LHIIT) for each cardiometabolic and cognitive psychological variable were tested by mixed-model repeated-measures ANOVA. Mixed-effects models were applied to analyze the effects of group (AHIIT-DWR vs LHIIT), time (0 vs 8 wk), and group–time interaction on cardiometabolic outcomes and cognitive responses. Turkey *post hoc* analysis was used to analyze within-group and between-group comparisons.

Effect sizes (ES) were calculated by Cohen's *d*. The sample size was calculated based on the primary outcome of a previous study comparing the effects of interval DWR and land trainings on aerobic fitness (27). Using the G*power software and based on the 0.28 ES obtained, the primary outcome ($\dot{V}O_2$ max) assuming a 5% type I error and 80% power, the sample size computed was 30 or more subjects per group. Considering an estimated 20% attrition rate, the total enrolled sample size for each group required to ensure adequate statistical power was 36.

RESULTS

The mean ages of participants in the AHIIT-DWR and LHIIT groups were 66.33 ± 4.99 and 65.68 ± 6.19 yr, respectively. Eight participants (10.1%) were excluded from the statistical analysis, with one dropout from the AHIIT group and nine from the LHIIT group. The anthropometric parameters in terms of height, body weight, and BMI are shown in Table 2.

TABLE 2. Anthropometric parameters (mean ± SD).

Parameters	AHIIT-DWR (n = 39)	LHIIT (n = 31)
Age (yr)	66.33 ± 4.99	65.68 ± 6.19
Height (m)	156.31 ± 6.12	154.65 ± 5.67
Weight (kg)	62.97 ± 10.05	57.069 ± 9.05
BMI ($kg \cdot m^{-2}$)	25.73 ± 3.55	23.84 ± 3.37

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TABLE 3. Cardiovascular fitness in AHIIT-DWR and LHIIT after the 8-wk intervention (mean ± SD).

	AHIIT-DWR (n = 39)		LHIIT (n = 31)		Time Effect		Group–Time Effect	
Parameter	Pretraining	Posttraining	Pretraining	Posttraining	*P* Value	ES	*P* Value	ES
HR_{max} (bpm)	136.75 ± 20.18	145.36 ± 17.97*	138.88 ± 21.06	142.88 ± 19.56*	<0.01	0.15	0.21	0.02
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	1299.19 ± 303.98	1738.22 ± 468.10*,#	1253.19 ± 357.70	1529.29 ± 448.14*	<0.01	0.55	0.04	0.06
RER	0.97 ± 0.12	1.13 ± 0.12*	1.01 ± 0.11	1.11 ± 0.15*	<0.01	0.44	0.07	0.05
$\dot{V}E$ ($mL \cdot min^{-1}$)	45.58 ± 11.59	66.05 ± 17.70*,#	47.29 ± 14.11	59.32 ± 20.60*	<0.01	0.64	<0.01	0.11
MET ($kcal \cdot kg^{-1} \cdot h^{-1}$)	5.83 ± 1.43	7.60 ± 1.92*,#	6.36 ± 1.66	7.62 ± 1.80*	<0.01	0.46	<0.05	0.06
O_2 pulse	8.79 ± 2.17	11.85 ± 3.37*,#	9.16 ± 2.35	10.67 ± 2.51*	<0.01	0.23	<0.05	0.07
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	20.76 ± 4.14	26.62 ± 6.73*	21.92 ± 5.75	26.57 ± 6.37*	<0.01	0.5	0.35	0.01

* $P < 0.05$ vs. pre-training.
\# Significant group-time effect difference on pairwise comparison ($P < 0.05$).

Effects of AHIIT-DWR and LHIIT on cardiovascular fitness. Group–time interactions revealed a significant difference in relative $\dot{V}O_2$ (ES = 0.06, $P = 0.04$), $\dot{V}E$ (ES = 0.11, $P < 0.01$), METs (ES = 0.06, $P < 0.01$), and O_2 pulse (ES = 0.07, $P < 0.05$) between AHIIT-DWR and LHIIT. However, no significant main effects in $\dot{V}O_{2max}$ (ES = 0.01, $P = 0.35$), HR_{max} (ES = 0.02, $P = 0.21$), and RER (ES = 0.05. $P = 0.07$) were observed between groups. Maximal exercise performances of both training groups in the cardiopulmonary exercise test pre- and postintervention are presented in Table 3. Significant improvements in absolute $\dot{V}O_{2max}$ ($P < 0.01$), relative $\dot{V}O_2$ ($P < 0.01$), HR_{max} ($P < 0.01$), peak O_2 pulse ($P < 0.01$), RER ($P < 0.01$), $\dot{V}E$ ($P < 0.01$), and METs ($P < 0.01$) were detected after both AHIIT-DWR and LHIIT.

Effects of AHIIT-DWR and LHIIT on metabolic blood markers. None of the metabolic blood markers exhibited a significant difference in the group–time interactions or between groups despite nearly significant interactions shown in fasting glucose level ($P = 0.05$, ES = 0.07) (Table 4). However, simple effects testing revealed both AHIIT-DWR and LHIIT significantly decreased triglycerides ($P < 0.05$, ES = 0.07). Eight weeks of AHIIT-DWR and LHIIT did not change total cholesterol ($P > 0.05$), HDL, or LDL despite the fact that both interventions decreased TC, HDL, and LDL.

Effects of AHIIT-DWR and LHIIT on cognitive tests. There were no significant differences or interactions shown in either cognitive tests between the AHIIT-DWR and the LHIIT groups ($P > 0.05$). However, there was significant improvement in MOCA score ($P < 0.01$, ES = 0.22) after AHIIT-DWR versus LHIIT (Table 5). Moreover, MMSE remained similar after AHIIT-DWR and LHIIT ($P > 0.05$).

Effects of AHIIT-DWR and LHIIT on psychological response and exercise adherence. There were no significant differences for enjoyment ($P = 0.88$) or self-efficacy score between AHIIT-DWR and LHIIT ($P = 0.57$). Meanwhile, exercise adherence was similar in both groups (>90% session completion rate, $P = 0.832$) (Table 6). There were no adverse events reported.

DISCUSSION

The purpose of this study was to examine the effects of 8 wk of AHIIT-DWR and LHIIT on cardiometabolic parameters, cognitive tests, and perceptions in inactive elderly women. The major findings found in this study after the 8-wk intervention were that cardiorespiratory fitness improved in both the AHIIT-DWR and the LHIIT cohorts, but there were greater increases in relative $\dot{V}O_2$, HR, $\dot{V}E$, and oxygen pulse in the AHIIT-DWR cohort.

There were decreases in metabolic blood markers (TC, LDL, triglycerides, and blood glucose) without a significant group difference, whereas only triglycerides significantly decreased after AHIIT-DWR and LHIIT. AHIIT-DWR and LHIIT had no significant group differences in the cognitive tests in MMSE and MOCA, but a significant increase in the MOCA score was detected after both AHIIT-DWR and LHIIT. In terms of psychological responses, no significant group difference for enjoyment and self-efficacy were found after either AHIIT-DWR or LHIIT.

AHIIT-DWR can improve several cardiometabolic health markers, particularly cardiorespiratory fitness in inactive older women. The current study extends the previous literature by using a more precise approach by adopting an incremental test performed on land and an aquatic medium to assess $\dot{V}O_{2max}$ and HR_{max} to determine the HRR to monitor individuals' exercise intensity. HRR takes into account differences between individuals resting heart rate and has been recommended over percentage of HR_{max} by ACSM (24). There were significant improvements in all the cardiorespiratory parameters after both interventions, whereas AHIIT-DWR particularly demonstrated a significant group difference in relative $\dot{V}O_2$, $\dot{V}E$, MET, and O_2 pulse versus LHIIT. This finding agrees with the majority

TABLE 4. Cardiometabolic blood markers in AHIIT-DWR and LHIIT after the 8-wk intervention (mean ± SD).

	AHIIT-DWR (n = 39)		LHIIT (n = 31)		Time Effect		Group Effect		Group–Time Effect	
Parameters	Pretraining	Posttraining	Pretraining	Posttraining	*P* Value	ES	*P* Value	ES	*P* Value	ES
TC ($mmol \cdot L^{-1}$)	5.53 ± 0.95	5.50 ± 1.09	5.36 ± 1.06	5.55 ± 0.91	0.06	0.06	0.40	0.01	0.83	0.00
HDL ($mmol \cdot L^{-1}$)	1.60 ± 0.34	1.76 ± 0.52	1.68 ± 0.44	1.78 ± 0.39	0.09	0.05	0.25	0.02	0.27	0.02
LDL ($mmol \cdot L^{-1}$)	3.26 ± 0.86	3.09 ± 1.0	3.48 ± 0.92	3.30 ± 0.81	0.05	0.06	0.36	0.02	0.93	0.00
Triglycerides ($mmol \cdot L^{-1}$)	1.47 ± 0.71	1.32 ± 0.56*	1.26 ± 0.64	1.11 ± 0.37*	0.04	0.07	0.16	0.03	0.10	0.00
Glucose ($mmol \cdot L^{-1}$)	5.38 ± 0.44	5.39 ± 0.0.51	5.25 ± 0.71	5.08 ± 0.64	0.52	0.01	0.21	0.04	0.05	0.07

TABLE 5. Cognitive batteries in AHIIT-DWR and LHIIT after 8-wk intervention.

Parameters	AHIIT-DWR (n = 39)		LHIIT (n = 31)		Time Effect		Group Effect		Group–Time Effect	
	Pretraining	Posttraining	Pretraining	Posttraining	*P* Value	ES	*P* Value	ES	*P* Value	ES
MMSE (score of 30)	29.08 ± 1.29	29.10 ± 1.11	29.18 ± 1.23	28.97 ± 1.08	0.95	0.00	0.95	0.07	0.55	0.01
MOCA (score of 30)	27.36 ± 2.25	28.49 ± 1.85	27.16 ± 2.45	28.52 ± 2.31	<0.01	0.22	0.73	0.35	0.69	0.00

of previous studies comparing the efficacy of aquatic exercise and land-based exercise for cardiorespiratory improvement (28). Mechanistically, it has been suggested that the responses in water are caused by increased venous return to the heart with enhanced peripheral venous blood pressure because of the compression of the lower body by water pressure.

Low cardiovascular fitness, indicated by maximal oxygen uptake ($\dot{V}O_{2max}$), is in part a consequence of a physically inactive lifestyle and is a powerful predictor of premature cardiovascular mortality (29). Despite exercise using different mediums, our results revealed that AHIIT-DWR induced a similar absolute $\dot{V}O_{2max}$ and HR_{max} increase (approximately 5–6 $mL \cdot kg^{-1} \cdot min^{-1}$ in both groups) as LHIIT. In our results, simple effect analyses showed that aerobic fitness in both the AHIIT-DWR and the LHIIT groups were significantly elevated. This suggests that aerobic fitness of inactive elderly individuals may be effectively improved by both interventions, regardless of the lack of significant main effects by group. As reported by most previous studies, HIIT is beneficial for improving aerobic fitness, either on land or in water (30,31). In a recent AHA Scientific Statement, an increase in $\dot{V}O_2$ max of just 1 MET is valuable for increasing health outcomes and survival (32). Two other trials have reported an increase in $\dot{V}O_2$ max of ≥3,5 $mL \cdot kg^{-1} \cdot min^{-1}$ using aquatic exercise (33,34). AHIIT-DWR may be as beneficial as LHIIT, which provides inactive elderly women another option for effective HIIT or potentially a more successful environment to start and continue with high-intensity training. In sum, the unique nature of physiological benefits of hydrostatic pressure and the enabling effect of buoyancy in water may facilitate such effectiveness. Traditional LHIIT exercises may not be suitable for all inactive elderly women given that it requires a higher level of skill, impact, and physical function to perform.

Our results showed no group differences in any of the blood markers after either AHIIT-DWR or LHIIT. However, both AHIIT-DWR and LHIIT markedly reduced triglycerides ($P < 0.05$), but both groups showed nonsignificant decreases in TC, HDL, and LDL after training ($P > 0.05$). The lack of differences between groups could be due to the timeframe of the study, as some previous evidence suggests that a minimal period of 8–12 wk may be required for high-intensity interval training to demonstrate a positive impact on physiological adaptions that improve metabolic health (4,35). Another potential reason for our finding could be that most participants already presented with blood markers within the normal range at baseline, and hence the likelihood of observing notable differences was reduced. Further research in different clinical populations with longer timeframes will be required to determine if AHIIT-DWR is superior to LHIIT in terms of metabolic blood markers.

There were no group differences in cognitive ability measured by MMSE and MOCA between AHIIT-DWR and LHIIT. This suggests that both AHIIT-DWR and LHIIT may be useful for improving cognitive ability in older women measured by MMSE and MOCA. The lack of difference between groups may be due to insufficient physiological changes from our 8-wk intervention. A recent review reported the largest effects after interventions with longer sessions and intervention duration (36), suggesting that a longer intervention may be required to produce a significant group-level change in global cognition. The within-group difference in change in MMSE and MOCA, in favor of both AHIIT-DWR and LHIIT, may be explained by increased cerebral blood flow and improvements in cardiovascular function (aerobic capacity, cardiac output, oxygen transport, and metabolism), which can improve neurotransmitter function and brain health (37). As such, a higher cardiac output is associated with higher cerebral blood flow, which suggests that HIIT results in a better adaptation to the cardiovascular system and has a positive effect on cognitive ability (38). Another possible mechanism is related to the increased level of brain derived neurotrophic factor (BDNF) in the brain. Acute aerobic exercise increases BDNF levels, which is an important component of the brain's neuroplasticity (39). Physical exercises can improve the circulation level of BDNF, which has beneficial neurotrophic, neuroprotective, and cognitive properties, consistent with a previous review (40).

In terms of psychological responses, no significant group differences for enjoyment or self-efficacy were found. Although the cardiometabolic benefits of AHIIT-DWR and LHIIT have been demonstrated in this study and others (3), a typical public health concern is how the general population, particularly inactive and less fit elderly women, perceive AHIIT-DWR and LHIIT and whether they can adhere to it in the long term (41). Our results agree with our previous study suggesting that a single bout of AHIIT or LHIIT (matched with exercise intensity) elicited similar enjoyment, self-efficacy, and exercise adherence (42). However, there were also conflicting findings with one study suggesting that AHIIT was perceived as being more effective and enjoyable than LHIIT in men with obesity (43). Such mixed results are likely explained by the variability in water depth, subject characteristics, genders, exercise intensity, intervals, and depend on the modalities performed. Furthermore, both AHIIT-DWR and LHIIT showed excellent exercise compliance rates (>90%),

TABLE 6. Psychological outcomes in AHIIT-DWR and LHIIT after the 8-wk intervention (mean ± SD).

	AHIIT-DWR (n = 39)	LHIIT (n = 31)	*P* Value
Enjoyment (score out of 126)	110.5 ± 8.5	104.6 ± 13.5	0.88
Self-efficacy (score out of 100)	68.7 ± 13.7	65.7 ± 15.2	0.57
Exercise adherence (%)	93.26 ± 6.69	92.29 ± 11.04	0.81

suggesting that both can be a practical exercise option for inactive elderly women in terms of enjoyment and self-efficacy.

Strengths and limitations. This study has several strengths, including examining the effects of AHIIT-DWR and LHIIT using a randomized research design. By adopting accurate and reliable measures of cardiorespiratory fitness in both aquatic and land environments, blood sampling, matching participant exercise intensity with HRR, and achieving excellent adherence in both exercise groups are strengths of the study. These findings can provide valuable insights regarding the applications of AHIIT-DWR and LHIIT. LHIIT could be a time-efficient and efficacious approach for health professionals when designing individualized programs targeted to cardiometabolic health benefits in women. However, because of the unique physical properties of water, AHIIT-DWR can be applied in appropriate individuals who need a lower weight bearing alternative to LHIIT. Few randomized controlled trials have compared the impact of AHIIT-DWR and LHIIT performed at matched intensities. Limitations of the present study included the fact that only elderly women were recruited and hence caution should be taken when generalizing to men, as well as young women. In addition, it is acknowledged that the relatively short intervention of 8 wk may limit the ability to draw conclusions about the relative potency of AHIIT-DWR versus that of LHIIT; this may explain why some secondary outcomes on metabolic blood markers were not statistically different between the AHIIT-DWR and the LHIIT programs. We believe, however, that our findings provide valuable insights regarding the potential applications of AHIIT-DWR versus LHIIT and understand that the effects on cardiometabolic parameters and cognition perceptions were comparable with each other. From a practical point of view, our results may suggest that AHIIT-DWR could be an alternative to LHIIT and considered by healthcare professionals when designing programs that target cardiometabolic health benefits, metabolic blood markers, cognitive function, and perception in physically inactive elderly women. Future studies on a larger scale for longer duration may be warranted.

CONCLUSIONS

In summary, 8-wk programs of AHIIT-DWR and LHIIT showed no group differences in aerobic capacity and HR_{max}, metabolic blood markers, cognitive function, and psychological responses, but AHIIT-DWR improved oxygen capacity, metabolic equivalents, oxygen pulse, and minute ventilation. This suggests that a practical model of AHIIT-DWR can offer cardiometabolic health benefits, especially for cardiorespiratory fitness, comparable with traditional LHIIT in inactive older women. AHIIT-DWR also showed a similar enjoyment level and self-efficacy to LHIIT and had high adherence. Further research in different populations with longer duration is required to determine how AHIIT-DWR compares with LHIIT in terms of overall cardiometabolic health, cognitive, and psychological benefits.

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This study was performed in accordance with the ethical standards of the Declaration of Helsinki. Ethics approval was obtained from the ethics committee of the Hong Kong Polytechnic University (HSEARS20220926002). Informed consent was obtained from all subjects involved in the study.

Consent for publication: not applicable.

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

M.M.Y.K. and J. M. participated in the design of the study and contributed to data collection and data analysis; B.C.L.S. and S.S.M.N. participated in the design of the study; M.M.Y.K and B.C.L.S. contributed to data collection; M.M.Y.K., S.S.M.N., J. M., and B.C.L.S. contributed to data analysis and the interpretation of results. All authors contributed to the manuscript writing. All authors have read and agreed to the published version of the manuscript.

The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

APPLIED SCIENCES

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