【Original paper】

Comparison of cardiovascular response to water immersion in elderly during rest and exercise

Nobuo Takeshima[*1], Makoto Narita[*2], Takeshi Matsui[*3],
Akiyoshi Okada[*4], Mohammod M. Islam[*5], William F. Brechue[*6]

Abstract

It is generally accepted that the central redistribution of blood volume with water immersion (WI) leads to an increase in stroke volume (SV). However, little research exists concerning the physiological effects of WI on the cardiorespiratory responses at rest and during dynamic exercise in the elderly. The purpose of this study was to determine the effect of xiphoid-level WI (30˚C) on SV and heart rate (HR) response to graded exercise in elderly (ELD) and young (Y) subjects. Elderly (n = 5 ; 78.4 ± 3.9 yr) and young (n = 6 ; 22.5 ± 5.2 yr) men performed two bouts of incremental exercise on land and in water (water treadmill) separated by one week in random order. Oxygen uptake and left ventricular (LV) end-systolic and end-diastolic volumes (M-mode echocardiography; Teichholz method) were recorded at rest and during exercise. Resting HR, SV and CO were not different between conditions. Peak HR was greater on land (181 ± 8 beats/min) than during WI (169 ± 12 beats/min) for Y, but was not different for ELD (land = 142 ± 8 beats/min; WI = 136 ± 19 beats/min). SV (controlled for CO) and HR (controlled for SV) showed a significant difference (least square means) between land and WI in Y, but not in ELD. The results indicate that age significantly affects the cardiac preload at rest and during WI.

Keywords : Water immersion, Elderly, Water walking, Stroke Volume, Heart rate.

Ⅰ. INTRODUCTION

Walking is the most convenient and common form of exercise for improving and maintaining physical fitness in the elderly. A large number of elderly in Japan and in the United States of America suffer from a myriad of musculoskeletal complications, thus, traditional forms of land-based exercise may be prohibitive. For frail older individuals, water activities have been shown to be therapeutic and beneficial[24, 29]. Water is an equalizing medium; its bouancy provides an optimum exercise environment for patients with arthritis, back problems or other medical conditions where physical loading associated with land exercise may limit or deter exercise and/or may increase the risk of orthopedic injury during land exercise. Therefore, some forms of water exercise may be a better option for many middle-aged and older persons[29].

It is generally accepted that the central shift in blood volume, with water immersion (WI, head out of water) is due to the hydrostatic pressure gradient that causes a shift of blood volume from the lower limbs to the thoracic region[1, 4, 5, 22, 27]. Previous WI studies showed that increased central

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*1 Department of Health and Sports Sciences, School of Health Sciences, Asahi University, Mizuho, Gifu 501-0296 Japan.
*2 Faculty of Health Sciences, Suzuka University of Medical Science, Suzuka, Mie 510-0293 Japan.
*3 Faculty of Sociology, Otemon Gakuin University, Ibaraki, Osaka 567-8502 Japan.
*4 Department of Psychology and Human Relations, Nanzan University. Faculty of Humanites, 466-8673 Japan.
*5 Laboratory of Public Health, National Institute of Fitness and Sports in Kanoya, Kanoya, Kagoshima 891-2393 Japan.
*6 Kirksville College of Osteopathic Medicine, A.T. Still University of Health Sciences, Kirksville, MO, 63501 USA.

blood volume reduces sympathetic nervous system activity and vagal dysfunction in young subjects compared to that on land [11, 13, 18, 30]. WI has been shown to increase right atrial blood pressure [2, 6], cardiac output (CO) and stroke volume (SV) [11, 22] at rest. The results of other studies using graded WI indicated that cardiac filling pressure also increases in a graded manner [22]. These physiological alterations associated with WI during rest are attributed to the increased central blood volume.

During exercise, stroke volume and breathing frequency are reported to increase during WI, along with concomitantly reduced tidal volume, right atrial blood pressure, pulmonary arterial pressure and cardiac index [15, 25]. During high intensity exercise, heart rate has been reported to be lower with WI exercise as compared to land [2, 25]. Similarly, Pugh et al. (2015) [21] reported that water-based exercise augments cerebral blood flow relative to land-based exercise at a similar intensity in healthy young subjects. In contrast, little is known about the hemodynamic effects of WI at rest and during exercise in the elderly.

Autonomic nervous system and cardiac function decrease with advancing age [9, 20, 30]. It has been reported that sympathetic nerve activity and/or sympathetic neural outflow, which influences heart rate, are reduced with advancing age [8] both at rest and during exercise. The purpose of this study was to determine the effect of xiphoid-level WI on cardiovascular response to graded exercise while walking on a treadmill in elderly compared to young subjects.

Ⅱ. MATERIALS AND METHODS

Subjects. Recreationally active elderly (ELD ; age 66-82 years, n=5) and young (Y ; age 18-27 years ; n=6) men volunteered to participate in the present study. The physical characteristics of the subjects are shown in Table 1.

Table 1. Physical characteristics of the subjects

ELD (n = 5)	mean (± SD)
Age (yr)	78.9 ± 3.9
Height (m)	1.621 ± 0.05
Body mass (kg)	56.5 ± 4.7
BMI	21.5 ± 1.4
Peak $\dot{V}O_2$ (ml/kg/min) (land)	34.1 ± 6.2*
Peak $\dot{V}O_2$ (ml/kg/min) (WI)	31.1 ± 7.5
Peak HR (beats/min) (land)	142.4 ± 8.2*
Peak HR (beats/min) (WI)	136.0 ± 18.5
Y (n = 6)	**mean (± SD)**
Age (yr)	22.5 ± 5.2
Height (m)	1.698 ± 0.03
Body mass (kg)	63.8 ± 6.3
BMI	20.1 ± 2.5
Peak $\dot{V}O_2$ (ml/kg/min) (land)	43.6 ± 3.6
Peak $\dot{V}O_2$ (ml/kg/min) (WI)	35.7 ± 5.8
Peak HR (beats/min) (land)	180.8 ± 8.0
Peak HR (beats/min) (WI)	169.0 ± 12.1

Note : BMI(Body Mass Index)=Weight/(Height)^2, * P<0.05 between OLD and Y group

General Procedures. Procedures for this study were approved by the Ethics Committee, Nagoya City University and were conducted in accordance with the policy of American College of Sports Medicine for human experimentation. Subjects were administered a comprehensive medical examination and were informed as to the potential risks and requirements of participating in the study prior to giving informed consent. A physician was present during the performance of all testing. Prior to data collection, subjects were familiarized with all pertinent laboratory procedures and had the opportunity to practice the graded-exercise walking protocol on land and with WI.

Experimental testing. Subjects conducted two bouts of a graded-exercise test (GXT) by walking on a treadmill either on land or during WI. Repeated trials were separated by one week and were conducted in random order. WI walk testing was performed with a water treadmill (Edmund Medical Co., Aquatrex, USA) with the subject immersed to the level of the xiphoid. To avoid potentially invoking the diving bradycardia reflex, the subjects were required to keep their faces out of the water at all times. Air temperatures averaged 28.0 ± 2 C˚ for the land-based laboratory and 28.2 ± 2 C˚ for the WI laboratory. Throughout all tests, water temperature was maintained at a constant value of 30°C.

Exercise testing. Subjects reported to the land-based laboratory and rested in the supine posture for at least 1-hour prior to each test. At the end of this period, cardiac function was recorded in the supine position. Following the initial rest period, subjects walked down the hall to the land- or water-based laboratory for exercise testing.

Before beginning each GXT, subjects rested for at least 3 minutes in the standing position, then cardiac function data were collected prior to the start of each test.

Subjects performed the graded-exercise until maximal effort and volitional exhaustion. Following a warm up in the water, treadmill speed was set at 3.0 km per hour and increased by 0.5 km per hour in ELD and 1.0 km per hour in Y group every 3 min for 5 stages, and then in one minute stages until volitional exhaustion.

All GXT's were conducted to volitional exhaustion and none of the subjects had to be stopped because of ECG abnormalities or symptoms.

Techniques- Expired gases and heart rate were recorded throughout the entire GXT. Echocardiographic measures were made during the last 15-seconds of each stage.

Oxygen Uptake- Expired gas samples were measured continuously and displayed at one-minute intervals during rest and exercise and analyzed for $\dot{V}O_2$ and $\dot{V}CO_2$ using an instrument having a volume turbine, automatic gas analyzer system (Vise Medical CO, Type-Mets900, Chiba, Japan). Expired gases were averaged during the last 1 min of each stage (Stage 1-5) or the entire minute (>Stage 6). The Mets900 system was calibrated at the beginning and end of each exercise session, according to the procedures recommended by the standard method.

Cardiac function- ECG recordings from a 12-lead ECG telemetry unit (Nihonkoden CO., Model WEP-7202, Tokyo, Japan) were used to continuously monitor HR during rest and exercise. LV end-systolic and diastolic volumes were measured by M-mode echocardiography (Teichholz method, Toshiba Medical Co., Type SSH-260A, Tokyo Japan) recorded at rest and during exercise. All echocariograpic tests were conducted by cardiologists and an echocardiography technologist. Given that subjects had no history of cardiovascular problems and were not obese, it was relatively easy for the technician to obtain clear echocardiograms.

Echocardiograms were collected three times for each stage and averaged. Due to the reliability problems associated with echocardiography at high exercise intensities, cardiac function was determined only at the submaximal exercise intensities (HR≤160 beats/min).

End-diastolic and end-systolic volumes were determined from two-dimensional video view of heart chambers taken from the long axis of the heart. SV was calcualted from the difference of LV end-diastolic volume and end-systolic volume. Cardiac output (CO) was calculated as the product of HR and SV.

Statistical analysis. The SV-HR relationship of each subject for each exercise environment until peak value of SV was determined by linear regression analysis. The influence of exercise environment on HR and SV adjusted for SV and/or CO were statistically controlled by using the analysis of covariance (ANCOVA). Additionally, individual slopes, intercepts and calculated SV response at HR values of 80, 100, 120, 140 and 160 beats/min were compared between exercise environment using an analysis of variance (ANOVA) with repeated measures within each group. These HR values were chosen because they represent target intensities for exercise training widely used by young and elderly subjects. Data analysis was completed using the statistical software program Super ANOVA (ABACUS Concepts Inc, Berkeley, CA), and SPSS for MAC (V.19.0, SPSS Inc., Chicago, IL). P values ≤ 0.05 were used to determine significance for all analyses. Data are reported as a mean and standard deviation (SD).

Ⅲ. RESULTS

No significant difference was noted in resting CO, SV, or HR within group and between groups irrespective of position or environmental condition (Table 2). Peak $\dot{V}O_2$ on land was signfiicantly greater in Y than ELD which decreased in Y during WI (Table1). However, no significant change in peak $\dot{V}O_2$ was observed in ELD between land and WI environments (Table 1).

When ANCOVA was used to statistically control the influence of CO on SV, a significant difference in SV was observed in Y between exercise environments (Table 3). However, SV was not altered in ELD during exercise in either environment (Table 3).

When ANCOVA was used to statistically control the influence of SV on HR, a significant difference in HR was observed in Y between exercise environments (Table 4). However, no significant change in HR was observed in ELD between environments (Table 4).

In the present study, HR matched SV (mean values: 145% at 80 beats/min, 137% at 100 beats/min, 123% at 120 beats/min, and 118% at 140 beats/min of HR with WI) was higher (two of them significantly higher) in Y while performing walking exercise during WI compared to land walking (Figure 1). In contrast, no significant difference in HR matched SV was observed ELD (mean values: 137% at 80 beats/min, 109% at 100 beats/min and 98% at 120 beats/min) while performing exercise on land or during WI (Figure 1).

Table 2. Cardiac output (CO), stroke volume (SV) and heart rate (HR) at rest between the ELD and Y

position		ELD (n=5)	Y (n=6)
Supine (on land)	CO (L/min)	4.23 ± 0.85	3.63 ± 1.32
	SV (ml/beat)	65.7 ± 13.6	50.5 ± 20.0
	HR (beats/min)	64.4 ± 10.9	74.7 ± 20.9
Standing (on land)	CO (L/min)	4.00 ± 0.56	3.09 ± 1.34
	SV (ml/beat)	61.9 ± 12.0	38.5 ± 20.1
	HR (beats/min)	66.0 ± 10.3	78.2 ± 15.7
Standing (in water)	CO (L/min)	4.58 ± 1.40	5.44 ± 3.20
	SV (ml/beat)	73.4 ± 11.7	65.1 ± 32.7
	HR (beats/min)	62.2 ± 11.8	68.3 ± 9.8

Table 3. Least squares means of the SV adjusted for CO between on land and water walking in the ELD and Y

variables	Mean	SE
ELD (n=5)		
Land walking	86.540 ml/beat	2.589
Water walking	92.597 ml/beat	2.337
Y (n=6)		
Land walking	98.159 ml/beat	3.645
Water walking	122.488 ml/beat*	3.125

Note : *P<0.05 for significant bewtween land and water walking, SE: standard error

Table 4. Least squares means of the HR adjusted for SV between on land and water walking in each age group

variables	Mean	SE
ELD (n=5)		
Land walking	93.581 beats/min	3.444
Water walking	85.332 beats/min	3.816
Y (n=6)		
Land walking	122.815 beats/min*	3.952
Water walking	97.715 beats/min	4.615

Note : *P<0.05 for significant between land and water walking, SE: standard error.

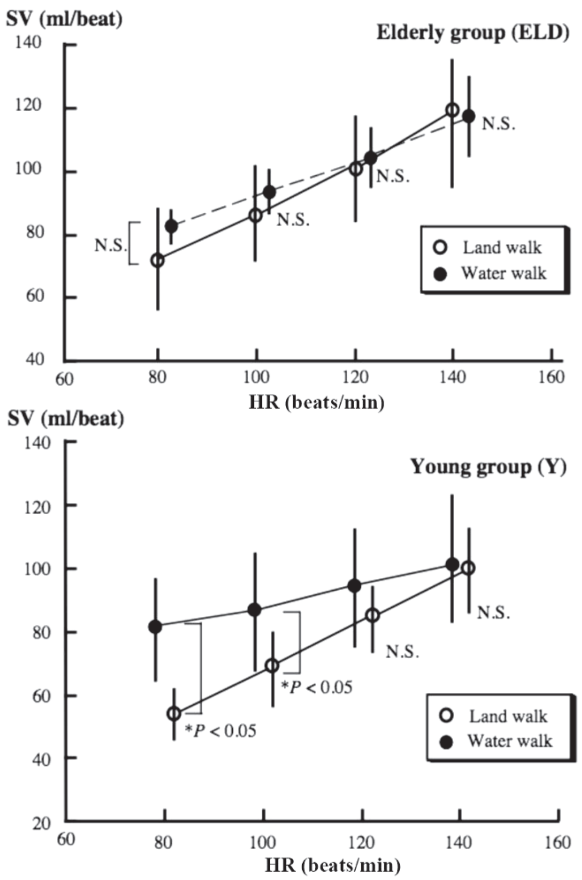

Figure 1. The stroke volume (SV) values calculated at the same heart rate (HR) for both land and water immersion (WI) walking for the elderly (ELD) and young (Y) groups

Ⅳ. DISCUSSION

HR has been reported either to remain unchanged or to decrease slightly at rest with WI [1, 13, 25]. Additionally, it has been shown that the HR response is similar during easy to moderate intensity steady-state exercise in WI compared to land exercise in young subjects. However, HR has been found to be significantly lower during high intensity WI exercise compared to land exercise [2, 3, 25, 27]. Gabrielsen et al. (1993) [21] demonstrated that WI in humans induces an increase in cardiac filling pressures with an increase in arterial pulse pressure and a consequent decrease in HR. Pugh et al (2015) [21] suggested that the water- and land-based exercise bouts were closely matched for $\dot{V}O_2$ and HR in younger subjects.

Our results support the previous findings in Y (Table 2); that is HR decreased slightly at rest during WI in Y, but not ELD. There are several possible mechanisms for HR reduction during WI exercise. One might expect a decrease in HR due to a WI-induced increase in stroke volume [25]. Another possible explanation for WI effects on HR is that sympathetic neural outflow is lower when performing exercise in the water compared to on land [2, 14, 17, 23, 25].

CO during upright dynamic exercise performed on the land is known to increase linearly with an increase in $\dot{V}O_2$ [2]. In healthy subjects, the SV index (from the Doppler flow measurements was calculated as the product of systolic flow velocity integral and aortic cross-sectional area divided by body surface area, ml/m) in water might be expected to contribute to a lower HR during exercise in order to maintain a CO-$\dot{V}O_2$ relationship similar to that occurring with exercise performed on the land [2]. Sheldahl et al. (1987) reported that SV was elevated at rest and during exercise during WI compared with the value at the same level of exercise in the upright posture on land in young and middle-aged persons. WI significantly affects CO, SV, right atrial blood pressure, and sympathetic nervous activity, and thus, would change function by aging.

In the present study, WI resulted in a marked increase in HR matched SV during rest to submaximal exercise compared to land walking in the Y group. However, no HR matched SV response was observed in ELD compared to the Y group. That is, the effect of WI on the SV-HR responses at rest and during exercise is altered by aging.

A reduction in sympathetic neural activity during WI exercise can result from altered baroreceptor activation caused by an increased central blood volume and reduced chemical activation of neural afferent fibers in the working muscles ; the latter being due to increased muscle blood flow [2]. It is also possible that there is both sympathetic and parasympathetic nervous system compensation of cardiovascular function in response to an age-related decrease in baroreceptor sensitivity [10, 20, 30]. Miwa et al. (1993) [16] reported that muscle sympathetic nerve activity is suppressed with advancing age. They concluded that this could be due to age-related decreases in vascular volume shifts during WI, decreases in baroreceptor sensitivity, decreases in sensitivity to parasympathetic nerve activity, and decreases in the fluctuation of blood pressure waves during WI. We demonstrated that changes in high-frequency component (0.15~0.45 Hz) of R-R interval variability (RRI) were lesser in ELD compared Y during WI [19]. The high-frequency component of RRI was decreased in Y while standing compared with the supine position on land, and increased with WI compared with standing. In contrast, in ELD, the high-frequency component of RRI was greater only during WI compared with supine position on land. The RRI low-frequency (0.04~0.14 Hz) to high frequency ratio increased significantly in Y in the standing position compared with supine position on the land and decreased during WI compared with the supine position on land. ELD group showed a similar response as Y except that there were no changes in the RRI low frequency to high frequency ratio with WI. These results indicate that age significantly affects cardiac preload at rest and during exercise with WI, while the increased central volume previously observed with WI appears to increase the cardiac vagal activity while suppressing the cardiac sympathetic activity compared to the upright exercise on land.

Another possibility is that there is a small amount of cephalad-fluid shift in older subjects [17]. The stimulation intensity of the cardiopulmonary barorecepters is dependent on the amount of cephalad-fluid shift induced by WI. Some investigators have reported that increases in cardiac output during WI are of lesser magnitude in ELD compared to that of younger individuals [19, 26, 28]. It seems that the smaller amount of fluid shift in ELD may affect the change in CO with WI. Moreover, it is generally accepted that the increase in central blood volume during WI induces an increased rate of renal fluid and electrolyte excretion. While, several hormones have been suggested as mediators of the natriuresis and diuresis associated with WI [12], such reflex accommodations during WI may be suppressed with advancing age.

In conclusion, the SV response at a given HR was significantly higher at rest and during walking with WI in Y, but was unaltered in ELD. The results indicate that age significantly affects the cardiac preload response to WI at rest and during submaximal exercise.

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