

Physiological Responses and RPE during Underwater Treadmill Walking in Women of Middle and Advanced Age

Tomoki Shono¹⁾, Kazutaka Fujishima²⁾, Noboru Hotta²⁾, Tetsuro Ogaki²⁾, Takeshi Ueda³⁾, Kodo Otoki⁴⁾, Keisuke Teramoto⁵⁾ and Tomihiro Shimizu⁶⁾

1) *Beppu Women's Junior College*

2) *Institute of Health Science, Kyushu University*

3) *Fukuoka Prefectural University*

4) *Kyushu Institute of Information Sciences*

5) *Graduate School of Human-Environment Studies, Kyushu University*

6) *Joetsu University of Education*

Abstract The purpose of this study was to examine the physiological responses and RPE during water walking using the Flowmill, which has a treadmill at the base of a water flume, in order to obtain basic data for prescribing water walking for people of middle and advanced age. Twenty healthy female volunteers with an age of 59.1 ± 5.2 years took part in this study. They belonged to the same swimming club and regularly swam and exercised in water. Walking in water took place in the Flowmill. Subjects completed four consecutive bouts of 4 min duration at progressively increasing speeds (20, 30, 40 and 50 m/min) with 1 min rest between each bout. In addition, water velocity was adjusted to the walking speed of each bout. Subjects were instructed to swing both arms in order to maintain their balance during walking in water. The water depth was to the level of the xiphoid process and the water temperature was $30.31 \pm 0.08^\circ\text{C}$. Both heart rate (HR) and oxygen uptake ($\dot{V}\text{O}_2$) increased exponentially as walking speed increased. HR was 125 ± 15 bpm, and $\dot{V}\text{O}_2$ was 18.10 ± 2.72 ml/kg·min⁻¹ during walking in water at 50 m/min, which was the highest speed. The exercise intensity at this speed was equivalent to 5.2 ± 0.8 Mets. The relationship between HR and $\dot{V}\text{O}_2$ during walking in water showed a highly significant linear relationship in each subject. There was also a highly significant linear relationship in the mean HR and $\dot{V}\text{O}_2$ of all subjects. Blood lactate concentration (LA) measured at rest and immediately after each bout was 1.1 ± 0.4 mmol/l at rest, 1.0 ± 0.2 mmol/l at 20 m/min, 1.0 ± 0.3 mmol/l at 30 m/min, 1.1 ± 0.2 mmol/l at 40 m/min, and 2.4 ± 0.7 mmol/l at 50 m/min. LA at 50 m/min was significantly higher than at rest and at the other speeds. The relationship between HR and RPE during walking in water showed a highly significant linear relationship. The relationship between walking speed and energy expenditure calculated

from $\dot{V}\text{O}_2$ and the respiratory exchange ratio (R) showed a high significant exponential relationship. These results suggested that HR and RPE can be effective indices for exercise prescription during Flowmill walking as with land walking. *J Physiol Anthropol* 19 (4): 195-200, 2000 <http://www.jstage.jst.go.jp/en/>

Keywords: walking in water, physiological responses, RPE, women of middle and advanced age

Introduction

Water walking and jogging have become popular non-swimming aerobic activities. These activities have been used as part of rehabilitative, therapeutic, and general conditioning programs, and are thought to be particularly useful for people with lower extremity injuries (Cureton, 1997). As indicated by Evans et al. (1978), the effects of water buoyancy and resistance make possible high levels of energy expenditure with relatively little movement and strain on lower extremity joints. For this reason, water walking and jogging are also effective exercises for individuals with body-weight problems and people of middle and advanced age. Many previous studies have reported metabolic and cardiorespiratory responses during walking and jogging in a pool (Evans et al., 1978; Whitley and Schoene, 1987; Bishop et al., 1989; Ritchie and Hopkins, 1991; Town and Bradley, 1991; Gehring et al., 1992), but it was difficult to fix the physical and physiological intensity for walking and jogging in a pool.

In recent years, a device that has a treadmill at the base of a water flume was developed. This device, which is called Flowmill, allows the water flow and belt velocities to be fixed, and consequently the physical and physiological intensity can be fixed. The Flowmill is able

to measure various physiological responses during water walking under fixed load conditions, and various studies have been conducted (Onodera et al., 1992, 1993; Kanaya et al., 1993; Migita et al., 1994, 1996; Hotta et al., 1993a, 1993b, 1994, 1995; Shimizu et al., 1998; Takaoka et al., 1999) However, there is less cardiorespiratory and metabolic data on a prescription for water walking for people of middle and advanced age than data for land walking.

The purpose of this study was to examine physiological responses and RPE during water walking using the Flowmill in order to obtain basic data for prescribing water walking for people of middle and advanced age.

Methods

Subjects

Twenty healthy female volunteers with an age of 59.1 ± 5.2 (a range of 50 to 68) years took part in this study. They belonged to the same swimming club and regularly swam and exercised in water. Subjects had a height of 153.4 ± 3.7 cm, a body mass of 55.3 ± 5.4 kg, a body mass index of 23.6 ± 2.7 , and a body fat level of $29.4 \pm 4.7\%$.

This study was approved by the Ethics Committee of Institute of Health Science, Kyushu University. Before testing, each subject was informed of the purpose of the study and the testing procedures. Each subject gave her written informed consent.

Protocol

Walking in water took place in the Flowmill (FM1200D, Japan Aqua Tech Co., Ltd., Japan), a newly developed piece of equipment that has a treadmill at the base of a water flume. Subjects completed four consecutive bouts of 4 min duration at progressively increasing speeds (20, 30, 40 and 50 m/min) with 1 min rest between each bout. In addition, water velocity was adjusted to the walking speed of each bout. Subjects were instructed to swing both arms in order to maintain their balance during walking in water. The protocol for this study is illustrated in Fig. 1.

The water depth of the Flowmill was the level of the xiphoid process. The water and room temperatures were $30.31 \pm 0.08^\circ\text{C}$ and $24.53 \pm 0.07^\circ\text{C}$ respectively.

Measurements

Oxygen uptake ($\dot{V}\text{O}_2$) and ventilation (\dot{V}_E) were calculated every 30 secs during the experiment by a mass spectrometer (WSMR-1400, WESTRON CORP., Japan) and an automatic breath gas analyzer (RM-300i, Minato Medical Science Co., Ltd., Japan). Heart rate (HR) was monitored using a telemetry method (ST-30, DS-501, Fukuda-denshi Co., Ltd., Japan). Blood samples were taken from an earlobe immediately following each bout. Blood lactate concentration (LA) was determined by a lactate analyzer (LT-1710, ARKRAY, Japan). At the same time, rating of perceived exertion (RPE) was measured using Borg's 6-20 scale.

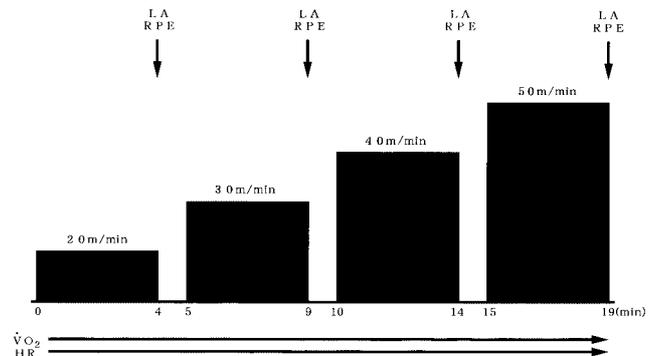


Fig. 1 Protocol for this study.

Statistical analyses

All values were expressed as the mean \pm SD. The relationships between HR and $\dot{V}\text{O}_2$ and RPE were analyzed using linear regression. The relationships between walking speed and $\dot{V}\text{O}_2$, HR, and energy expenditure were analyzed using exponential regression. Differences of LA among walking speeds, and differences between fifties ($n=12$) and sixties ($n=8$) in the measurements were examined using one factor analyses of variance, and then post hoc tests (Scheffe's F-test) were conducted. The level of statistical significance was set at $p < 0.05$.

Results

The measurements for each walking speed are presented in Table 1. The relationships between walking speed and $\dot{V}\text{O}_2$, and walking speed and HR are shown in Fig. 2. Both HR ($p < 0.01$) and $\dot{V}\text{O}_2$ ($p < 0.01$) increased exponentially as walking speed increased. HR and $\dot{V}\text{O}_2$ during walking in water at 50 m/min, the highest speed, were 125 ± 15 bpm and 18.10 ± 2.72 ml/kg·min⁻¹ respectively. The exercise intensity at this speed was equivalent to 5.2 ± 0.8 Mets (metabolic equivalent).

The relationship between HR and $\dot{V}\text{O}_2$ during walking in water is shown in Fig. 3. The relationship between HR and $\dot{V}\text{O}_2$ was a highly significant linear relationship in each subject ($r=0.963-0.999$, $p < 0.001-0.05$). In the mean HR and $\dot{V}\text{O}_2$ of all subjects, there was also a highly significant linear relationship ($r=0.999$, $p < 0.01$).

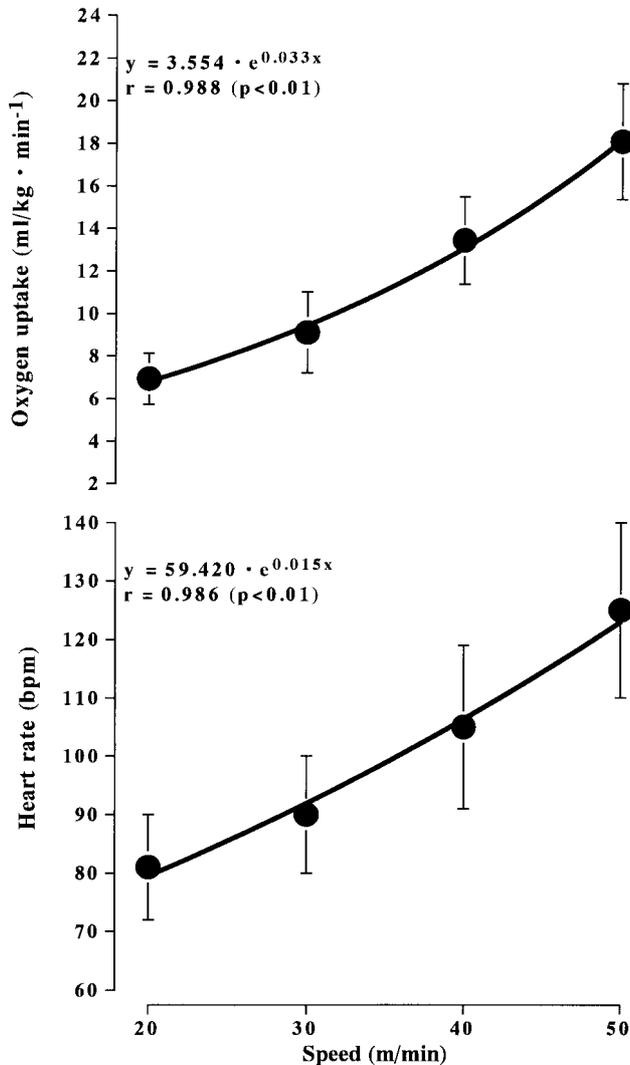
LA measured at rest and immediately after each bout was 1.1 ± 0.4 mmol/l at rest, 1.0 ± 0.2 mmol/l at 20 m/min, 1.0 ± 0.3 mmol/l at 30 m/min, 1.1 ± 0.2 mmol/l at 40 m/min, and 2.4 ± 0.7 mmol/l at 50 m/min. LA at 50 m/min was significantly higher than at rest and at the other speeds ($p < 0.0001$). The variation of LA is shown in Fig. 4.

The relationship between HR and RPE during walking in water was a highly significant linear relationship ($r=0.996$, $p < 0.01$). The relationship between HR and RPE is shown in Fig. 5.

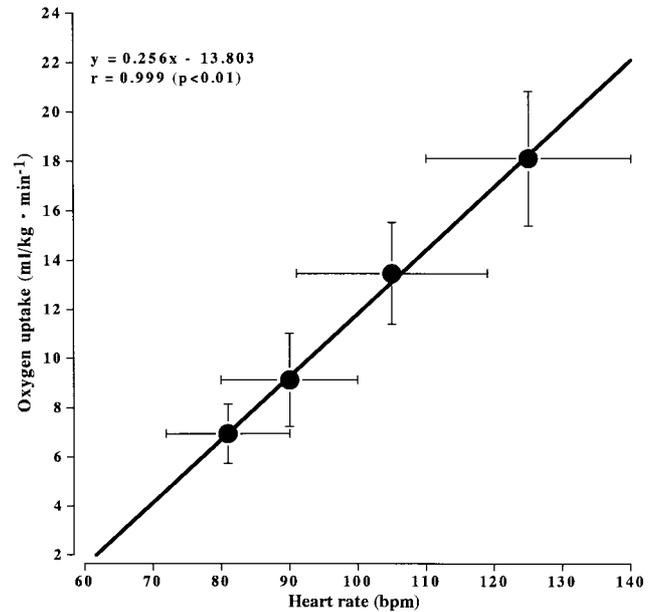
Table 1 Responses of physiological parameters and RPE to Flowmill walking

Speed (m/min)	\dot{V}_E (l/min)	$\dot{V}O_2$ (ml/kg·min ⁻¹)	HR (bpm)	R	Blood lactate (mmol/l)	Mets	RPE
rest					1.1 ± 0.4		
20	12.0 ± 2.1	6.94 ± 1.20	81 ± 9	0.84 ± 0.05	1.0 ± 0.2	2.0 ± 0.3	9.7 ± 2.0
30	14.6 ± 3.0	9.12 ± 1.90	90 ± 10	0.83 ± 0.04	1.0 ± 0.3	2.6 ± 0.5	10.6 ± 1.5
40	21.0 ± 3.2	13.46 ± 2.06	105 ± 14	0.88 ± 0.05	1.1 ± 0.2	3.8 ± 0.6	12.4 ± 1.4
50	29.9 ± 4.7	18.10 ± 2.72	125 ± 15	0.96 ± 0.04	2.4 ± 0.7	5.2 ± 0.8	14.0 ± 1.8

mean ± S.D.

**Fig. 2** Responses of heart rate and oxygen uptake to walking speed during Flowmill walking.

The relationship between walking speed and energy expenditure calculated from $\dot{V}O_2$ and the respiratory exchange ratio (R) was a high significant exponential relationship ($r=0.985$, $p<0.01$). The relationship between walking speed and energy expenditure is shown in Fig. 6.

**Fig. 3** Relationship between heart rate and oxygen uptake during Flowmill walking.

There were no significant differences between fifties and sixties in the measurements.

Discussion

Like the previous studies using the Flowmill (Migita et al, 1994; Hotta et al., 1993a, 1993b, 1994, 1995), the relationships between walking speed and $\dot{V}O_2$, and walking speed and HR increased exponentially as walking speed increased, and the relationship between HR and $\dot{V}O_2$ was linear. Because the relationship between HR and $\dot{V}O_2$ was a highly significant linear relationship in each subject, the maximal oxygen uptake ($\dot{V}O_{2max}$) of each subject was estimated from a regression equation for each subject. The mean value was 27.97 ± 4.49 ml/kg·min⁻¹.

Evans et al. (1978) studied the energy expenditure during walking at two speeds and during jogging at three speeds across a pool in waist-deep water. They found that $\dot{V}O_2$ at all speeds was greater in water than during treadmill

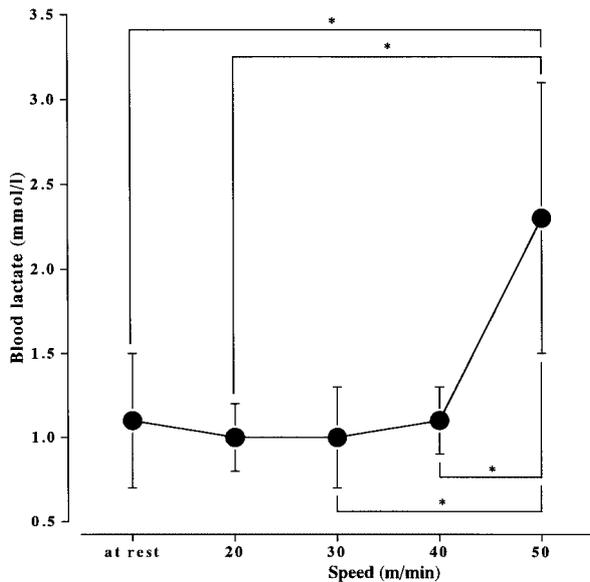


Fig. 4 Response of blood lactate to Flowmill walking. * $p < 0.0001$.

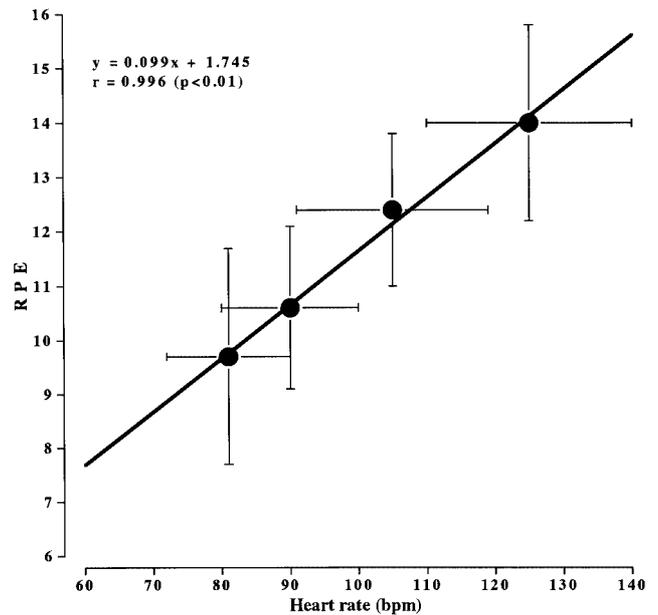


Fig. 5 Relationship between heart rate and RPE during Flowmill walking.

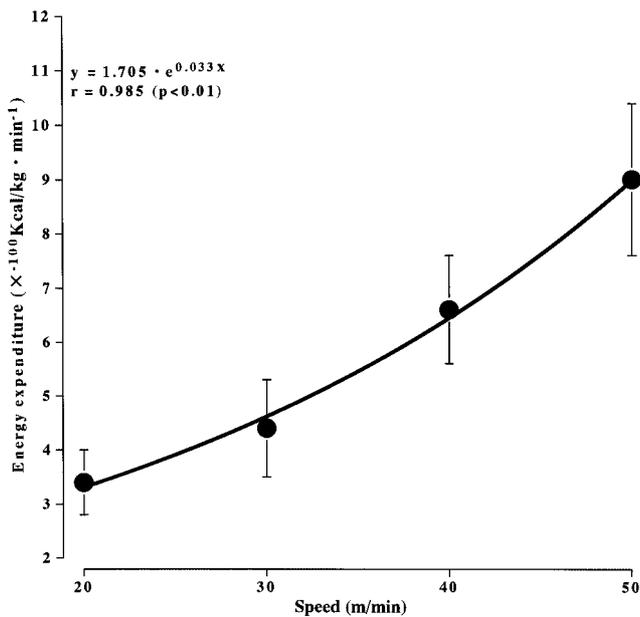


Fig. 6 Relationship between walking speed in the Flowmill and energy expenditure.

exercise on land. They concluded that approximately one-half to one-third of the speed was needed to walk or jog across a pool in waist-deep water in order to obtain the same level of energy expenditure as during treadmill walking and jogging on land.

Gleim and Nicholas (1989) compared energy expended during walking and jogging on a treadmill on land

to walking and jogging at various speeds on an underwater treadmill at different water depths. When compared with the data of Evans et al. (1978), this data suggested that the energy expenditure of walking on an underwater treadmill in waist-deep water is considerably less than that of walking across a pool. For this reason, they suggested that walking on an underwater treadmill is a different situation from walking in a pool, where the body must actually move through the water.

Migita et al. (1994) compared cardiorespiratory responses during walking on a treadmill on land with walking in the Flowmill. They reported that approximately one-half of the speed was needed to walk in the Flowmill in order to obtain the same level of physiological load as during treadmill walking, and that this result was similar to the result of Evans et al. (1978). The cause of this result was attributed to the fact that the water flow and belt velocities of the Flowmill can be adjusted. That is to say, work load against water flow increases because an additional load is created by the belt running at the same speed as the water flow.

The results of this study were compared to land walking using the standard value of RMR (relative metabolic rate), because treadmill walking on land was not performed in this study. Exercise intensity during Flowmill walking at 50 m/min (mean value 5.2 is Mets) was almost equivalent to that during land walking at 100 m/min (the standard value of RMR is 5.0, Mets $0.83 \times 5.0 \pm 1 = 5.15$). This result was similar to that of the study using the Flowmill by Migita et al. (1994).

Migita et al. (1994) reported that similar relationships

Table 2 Guidelines for Flowmill walking

Speed (m/min)	%HRmax (%)	Mets	Energy expenditure (kcal/kg·min ⁻¹)	RPE	Walking pace in a pool (sec/50 m; sec/25 m)
20	50	2.0	0.034	7~11	150 : 75
30	55	2.6	0.044	9~12	100 : 50
40	65	3.8	0.066	11~13	75 : 38
50	75	5.2	0.090	12~15	60 : 30

*HRmax = 220 - age.

between HR and $\dot{V}O_2$ were observed both with treadmill walking and Flowmill walking. Hotta et al. (1993a, 1993b, 1994, 1995) also reported that it is possible to prescribe water walking on the basis of HR as with land walking. In this study, the relationship between HR and $\dot{V}O_2$ was similar to previous studies using the Flowmill, which supports the theory that it is possible to prescribe water walking on the basis of HR as with land walking.

\dot{V}_E , $\dot{V}O_2$, HR, and Mets in this study were higher than those of the studies using the Flowmill by Hotta et al. (1994, 1995). The subjects of the study by Hotta et al. held the handrails on both sides of the flume to exclude the effect of the movement of the arms. In this study, the subjects swung their arms as if they were stroking water along with the velocity of the water flow. Therefore, it was supposed that the energy expenditure with the movement of the arms during walking in water increased.

The mean exercise intensity of the subjects at 50 m/min in this study was 5.2 ± 0.8 Mets and $66.3 \pm 14.7\%$ $\dot{V}O_{2max}$. These values were higher than those of the study for aged men and women by Hotta et al. (1994). This difference may have been caused by the arm swing. In addition, because the subjects of this study did not hold the handrails, they may have expended excess energy to maintain their balance. All of the subjects could complete the walk at 20, 30, and 40 m/min without any problems. At 50 m/min, however, some of the subjects recovered their balance by holding the handrails. Because of the concurrent and continuous load of belt velocity and water flow velocity, Flowmill walking, which is different from walking in a pool, caused even the subjects that regularly swam and exercised in water to make a considerable effort in order to walk while maintaining their balance. That the extra load was caused by the arm swing was also proved by the fact that blood lactate concentration at 50 m/min was significantly higher than at rest and at the other velocities. It was estimated that the lactate threshold in most subjects was reached at around 50 m/min. Therefore, it is suggested that sufficient caution must be exercised in Flowmill walking without holding handrails as the walking speed is gradually increased.

The relationship between walking speed and energy expenditure calculated from $\dot{V}O_2$ and R was a highly significant exponential relationship. Hotta et al. (1994, 1995) also reported a similar relationship. Consequently,

using this relationship, energy expenditure can be estimated without actually measuring it if the walking speed is known beforehand. In addition, it is supposed that this equation of the relationship between walking speed and energy expenditure can be applied to pool walking, because walking in the Flowmill is performed against water flow (water resistance).

Takaoka et al. (1999) examined the physiological responses and RPE with water flow velocity different from belt velocity during walking in the Flowmill. Two types of tests were performed. One was to increase water flow velocity with a fixed belt velocity, and the other was to increase belt velocity with a fixed water flow velocity. RPE during both types of walking linearly increased with increased speed. They reported that RPE was proportional to cardiorespiratory responses in the belt velocity gradual increase protocol, but it was not so in the water flow velocity gradual increase protocol, therefore RPE is useful for the former protocol. In this study, the same velocities for the belt and water flow were loaded concurrently, and the relationship between HR and RPE during walking in the Flowmill showed a highly significant linear relationship.

In conclusion, the results of this study suggest that HR and RPE can be effective indices for exercise prescription for Flowmill walking in the same way as land walking, because of a highly significant relationship between physiological responses and walking speed, and RPE during walking in the Flowmill. However, caution is advised when using RPE with elderly people because of the decrease in maximum heart rate with aging. It is important to set a low RPE and to check the HR so that exercise intensity does not become stronger than the target intensity. Based on the data obtained, we tried to make guidelines for exercise prescription during walking in the Flowmill (Table 2). These guidelines are for women of fifties and sixties that regularly swim and exercise in water, under Flowmill conditions in which the water depth is the level of the xiphoid process and the water temperature is 30°C.

Acknowledgements The authors wish to thank President Michihito Ogura and staff of Japan Aqua Tech Co., Ltd. for supporting this research. This research was supported by a Grant-in-Aid for Scientific Research from Institute of Health Science, Kyushu University.

References

- Bishop PA, Frazier S, Smith J, Jacobs D (1989) Physiologic responses to treadmill and water running. *Phys Sportsmed* 17: 87-94
- Cureton KJ (1997) Physiologic responses to water exercise. In Ruoti RG, Morris DM, Cole AJ eds. *Aquatic Rehabilitation*. Lippincott, Philadelphia, 39-56
- Evans BW, Cureton KJ, Purvis JW (1978) Metabolic and circulatory responses to walking and jogging in water. *Res Q* 49: 442-449
- Gehring M, Keller B, Brehm B (1992) Physiological responses to deep water running in competitive and non-competitive runners. *Med Sci Sports Exerc* 24: S23
- Gleim GW, Nicholas JA (1989) Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. *Am J Sports Med* 17: 248-252
- Hotta N, Muraoka Y, Ogaki T, Kanaya S, Fujishima K, Hong JP, Masuda T (1993a) Cardiovascular responses to treadmill (flowmill) walking in water. *Kurume Journal of Health & Physical Education* 1: 19-23 (in Japanese with English abstract)
- Hotta N, Ogaki T, Kanaya S, Hagiwara H (1993b) Exercise treatment to low physical fitness level's patients in water. *J Health Sci* 15: 57-61 (in Japanese with English abstract)
- Hotta N, Ogaki T, Kanaya S, Fujishima K, Hagiwara H (1994) Exercise prescription for aged men and women in water. *Descende Sports Science* 15: 78-83 (in Japanese with English abstract)
- Hotta N, Ogaki T, Kanaya S, Fujishima K (1995) Exercise prescription with a new mode of exercise (flowmill) in water. *Bulletin of Physical Fitness Research Institute* 88: 11-17 (in Japanese with English abstract)
- Kanaya S, Hotta N, Ogaki T, Fujishima K, Shono T, Shimizu T, Hagiwara H, Fujino T (1993) New exercise ECG by treadmill walking in water, using the flow water training system. *J Health Sci* 15: 69-74 (in Japanese with English abstract)
- Migita T, Muraoka Y, Hotta N, Ogaki T, Kanaya S, Fujishima K, Masuda T (1994) Cardiorespiratory responses during water and land walking. *Kurume Journal of Health & Physical Education* 2: 25-30 (in Japanese with English abstract)
- Migita T, Hotta N, Ogaki T, Kanaya S, Fujishima K, Masuda T (1996) Comparison of the physiological responses to treadmill prolonged walking in water and on land. *Japan J Phys Educ* 40: 316-323 (in Japanese with English abstract)
- Onodera S, Kimura K, Miyachi M, Yonetani S, Hara H (1992) Influence of viscous resistance on heart rate and oxygen uptake during treadmill walking in water. *Jap J Aerospace Environ Med* 29: 67-72 (in Japanese with English abstract)
- Onodera S, Miyachi M, Kimura K, Yonetani S, Nakamura Y (1993) The effects of viscosity and depth of water on energy expenditure during water treadmill walking. *Descende Sports Science* 14: 100-104 (in Japanese with English abstract)
- Ritchie SE, Hopkins WG (1991) The intensity of exercise in deep-water running. *Int J Sportsmed* 12: 27-29
- Shimizu T, Kosaka M, Fujishima K (1998) Human thermoregulatory responses during prolonged walking in water at 25, 30, and 35°C. *Eur J Appl Physiol* 78: 473-478
- Town G, Bradley SS (1991) Maximal metabolic responses of deep and shallow water running in trained runners. *Med Sci Sports Exerc* 23: 238-241
- Takaoka I, Ohnishi T, Okamura S, Suzuki D (1999) The physiological responses and RPE to different water flow and belt velocities during "flowmill" walking in water. *Jour Health Sports Sci Juntendo Univ* 3: 61-67 (in Japanese with English abstract)
- Whitley JD, Schoene LL (1987) Comparison of heart rate responses; water walking versus treadmill walking. *Phys Ther* 67: 1501-1504

Received: March 6, 2000

Accepted: May 24, 2000

Correspondence to: Tomiki Shono, Beppu Women's Junior College, Chuo-machi, Kamegawa, Beppu, Oita 874-8567, Japan

e-mail address: t_shono@mizobe.ac.jp