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Effect of stride frequency on metabolic costs and rating of perceived exertion during walking in water

Kenji Masumoto [a,*], Yoshiko Nishizaki [b], Ayako Hamada [b]

[a] Faculty of Integrated Human Studies and Social Sciences, Fukuoka Prefectural University, Tagawa, Fukuoka, Japan
[b] Graduate School of Human-Environment Studies, Kyushu University, Kasuga, Fukuoka, Japan

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ABSTRACT

We investigated the effect of stride frequency (SF) on metabolic costs and rating of perceived exertion (RPE) during walking in water and on dry land. Eleven male subjects walked on a treadmill on dry land and on an underwater treadmill at their preferred SF (PSF) and walked at an SF which was lower and higher than the PSF (i.e., PSF ± 5, 10, and 15 strides min^{-1}). Walking speed was kept constant at each subject's preferred walking speed in water and on dry land. Oxygen uptake, heart rate, RPE, PSF and preferred walking speeds were measured. Metabolic costs and RPE were significantly higher when walking at low and high SF conditions than when walking at the PSF condition both in water and on dry land ($P < 0.05$). Additionally, the high SF condition produced significantly higher metabolic costs and RPE than the equivalent low SF condition during walking in water ($P < 0.01$). Furthermore, metabolic costs, RPE, PSF, and the preferred walking speed were significantly lower in water than on dry land when walking at the PSF ($P < 0.05$). These observations indicate that a change in SF influences metabolic costs and RPE during walking in water.

1. Introduction

Walking is a common type of physical activity for developing and maintaining aerobic fitness [1]. In general, moderate mechanical loading is required for maintaining healthy musculoskeletal system [2]. However, the magnitude of impact forces on the lower extremities when walking on dry land may be problematic in some pathological populations (e.g., obese individuals [3]).

Walking in water has been used as a cross-training alternative to walking on dry land [4]. The buoyancy force of water may reduce the magnitude of impact forces on the lower extremities when walking in water, compared to walking on dry land [5,6]. Furthermore, improvements in aerobic fitness and body composition after completion of a training program that consisted of walking in water have also been reported [4]. These observations indicate that walking in water can be an effective component of exercise programs to improve aerobic fitness and body composition, while reducing impact forces on the lower extremities.

Several studies have investigated metabolic costs (oxygen uptake ($\dot{V}O_2$) and heart rate (HR)) and the rating of perceived exertion (RPE) during walking in water at predetermined speeds [7,8]. Additionally, Masumoto and Mercer [9] have reported that biomechanical responses in water and on dry land are different when subjects walk at their preferred walking speeds (i.e., each subject's preferred stride frequency (PSF)). It has been reported that muscle activity [5,6], vertical ground reaction force (GRF) [5,6], and walking speed [5,6,10,11] when walking in water are lower than when walking on dry land at the PSF. It has also been reported that walking in water produces a flatter muscle activity pattern, although well-defined peaks of muscle activity were observed when walking on dry land at the PSF [5,6]. Furthermore, it was observed that ankle plantar flexion and knee extension moments are lower in water than on dry land when walking at the PSF [11]. However, to the best of our knowledge, no research is available regarding metabolic costs and RPE during walking in water and on dry land at the PSF, while measuring each subject's actual preferred walking speed in water.

Furthermore, it has been reported that a change in SF influences metabolic costs during walking on dry land [12,13]. Holt et al. [12] reported that a low SF condition (e.g., PSF – 15 strides min^{-1}) produces higher $\dot{V}O_2$ than the equivalent high SF condition (e.g., PSF + 15 strides min^{-1}) when walking on dry land at a constant walking speed. Furthermore, a U-shaped curve relationship has been reported with a minimum $\dot{V}O_2$ during walking on dry land at

* Corresponding author at: Faculty of Integrated Human Studies and Social Sciences, Fukuoka Prefectural University, 4395 Ita, Tagawa, Fukuoka 825-8585, Japan. Tel.: +81 947 42 2118; fax: +81 947 42 6171.
E-mail address: masumoto@fukuoka-pu.ac.jp (K. Masumoto).

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the PSF with speed held constant [12,13]. Unfortunately, these relationships have not been investigated while subjects walked in water. Such information about the effect of SF on metabolic costs and RPE during walking in water is important if human locomotion is to be better understood.

The purpose of this study was twofold. Our first purpose was to investigate the effect of a change in SF on metabolic costs and RPE during walking in water. Our second purpose was to compare the metabolic costs, RPE, and walking speeds in water and on dry land when subjects walk at their PSF.

2. Methods

2.1. Subjects

Eleven male subjects (means ± standard deviation (SD): age = 23.8 ± 4.2 years, height = 175.7 ± 7.3 cm, body mass = 68.6 ± 7.0 kg) participated in this study. The subjects were free from any acute or chronic diseases at the time of the study. The study was approved by the University Ethics Committee, and written informed consent to participate in the study was obtained from all subjects.

2.2. Measurements

$\dot{V}O_2$ was measured using a portable, breath-by-breath gas analyzer (K4b^2, Cosmed, Italy). The gas analyzers were calibrated using known ambient air and sample gas references, and the turbine flowmeter of the system was calibrated with a syringe of known volume prior to each test. The $\dot{V}O_2$ data from the final 30 s of each condition were analyzed. HR was recorded with a portable device (Polar Electro, Kempele, Finland), and was analyzed during the final 30 s of each condition. RPE was measured using Borg's 6–20 scale [14] during the final minute of each condition.

2.3. Experimental procedures

Subjects performed tests in water and on dry land on different days, with at least a 2-day break in between. Before commencing the actual tests, all subjects practiced walking on a treadmill on dry land (ELG-2, Woodway, USA), as well as walking on an underwater treadmill (Flowmill, FM-1200D, Japan Aqua Tech, Japan; Fig. 1), at various walking speeds. The underwater treadmill comprises a treadmill at the bottom of a water flume, and provides the ability to control the water depth and the speed of both the underwater treadmill and the water current independently [7–9].

Following the practice session, the PSF was obtained during walking in water and on dry land [12]. In order to obtain the PSF, each subject was asked to walk on a treadmill on dry land and on an underwater treadmill and to direct the investigator to increase or decrease the walking speed until their most comfortable pace was obtained [12]. The subjects were not allowed to see the actual walking speeds when obtaining the PSF in water and on dry land [12]. This procedure was repeated until the subject was consistent in identifying exactly the same walking speed over three consecutive trials while measuring the subject's preferred walking speed and PSF for each of the water and dry land conditions. The three PSF values for each of the water and dry land conditions were averaged. The average PSF value for each subject was used for each of the actual PSF conditions during walking in water and on dry land.

After obtaining the PSF, the subjects were asked to rest in a seated position for 10 min, both in water immersed to their chest level, and on dry land. Then, resting metabolic data were obtained in water and on dry land for 5 min, prior to beginning the actual tests. The SF conditions consisted of both walking in water and on dry land at PSF ± 5, 10 and 15 strides min^{-1} [12]. A digital audio metronome was used to control each SF condition. Walking speeds in water and on dry land were kept constant through all the SF conditions at the speeds originally obtained as the subject's preferred walking speeds for the PSF [12].

During the tests in water, the subjects were immersed to the level of the xiphoid process. The speed of the water current was set at the same speed as the walking speed of the underwater treadmill. Throughout the experiment, the water temperature of the underwater treadmill and the room temperature were maintained at 31 °C and 26 °C, respectively.

Each subject completed a 4 min exercise at each of the SF conditions. A randomized testing order (both modes of exercise and SF conditions) was used. The subjects wore swimsuits but did not wear shoes throughout the experimental sessions.

2.4. Statistical analysis

Data are presented as mean ± SD. All parameters were analyzed using a 2 (mode) × 7 (SF) repeated measures analysis of variance. When an interaction effect was observed, Bonferroni's post hoc tests were conducted to compare the means. A paired *t*-test was used to compare preferred walking speeds, PSF and resting metabolic variables between water and dry land conditions. Statistical significance was set at $P < 0.05$.

3. Results

There was no significant difference in the $\dot{V}O_2$ (6.0 ± 1.8 and 6.0 ± 1.9 ml kg^{-1} min^{-1} for water and dry land conditions, respectively, $P > 0.05$) and HR (65.2 ± 8.8 and 66.2 ± 9.1 beats min^{-1} for water and dry land conditions, respectively, $P > 0.05$) between water and dry land conditions at rest.

Metabolic costs and RPE for each of the SF conditions are presented in Figs. 2 and 3, respectively. Metabolic costs ($\dot{V}O_2$, $P < 0.001$; HR, $P < 0.001$) and RPE ($P < 0.001$) were influenced by the interaction of mode and SF.

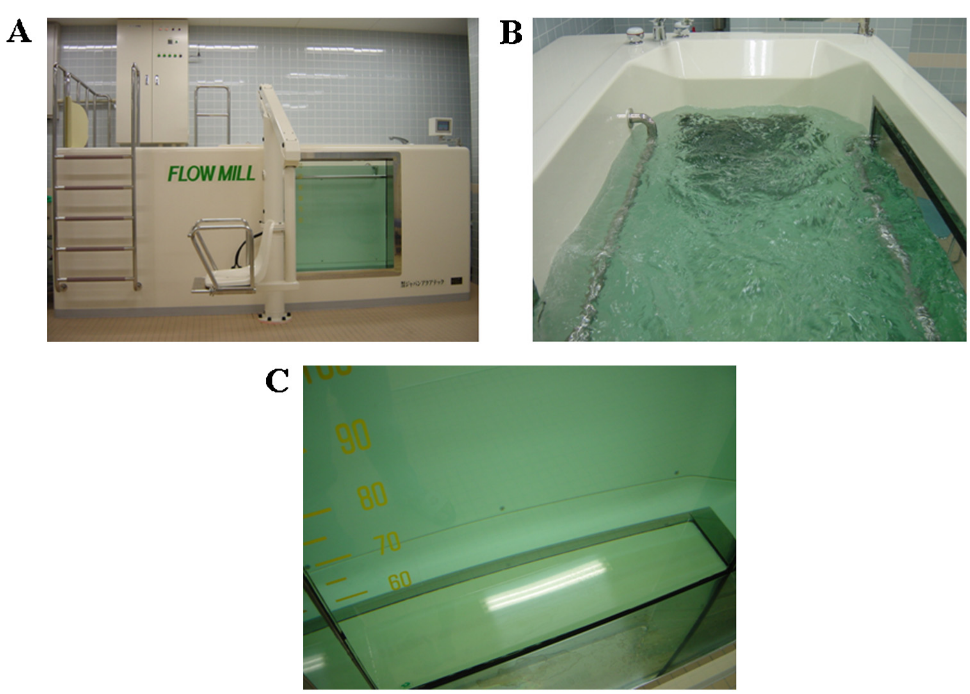

Fig. 1. Side view of the underwater treadmill (A), water current (B), and the treadmill in water (C).