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Cardiorespiratory of land and water walking on a non motorized treadmill

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Aim. **This study was designed to assess submaximal cardiac and pulmonary demand imposed by walking on a non motorized treadmill in land and in water condition.**
Methods. **Eight healthy young subjects (mean age, body mass and height: 26.5±2.8 years; 66.7±9.60 kg; 172±8.07 cm) performed one maximal treadmill running test on land and a submaximal incremental test (treadmill speed 2, 3, 4 km·h^{-1}; 5 minutes step duration; 15 minutes total duration) in land (L) at 2, 3, 4 km·h^{-1} (L2, L3, L4) and in water (W) at 2, 3, 4 km·h^{-1} (W2, W3, W4). Individual stride frequency at any given submaximal walking speed on land was used to perform comparable water tests. Heart rate (HR) and oxygen consumption ($\dot{V}O_2$) were continuously measured during the tests.**
Results. **Rest heart rate (%max) decreased immediately after water immersion [land HR(%max) 42 b·min^{-1}±3; water HR(%max) 36 b·min^{-1}±5, P<0.05] while the other physiological parameters were comparable between land and water condition [land $\dot{V}O_2$(%max) 9.44 mL·Kg·min^{-1}±1.54; water VO_2(%max) 7.75 ml·Kg·min^{-1}±2.4, p>0.05; land ventilation [$\dot{V}E$(%max)] 8.71L·min^{-1}±2.37; water $\dot{V}E$(%max) 7.67L·min^{-1}±2.79, p>0.05; land respiratory exchange ratio (RER) 0.77±0.5 water RER 0.75±0.07, P>0.05]. During exercise at 2, 3 and 4 Km·h^{-1}, reserve heart rate [HRR (%max)] was higher during water walking (W2 35±10; W3 54±11; W4 76±9 b·min^{-1}) than during land walking (L2 23±5; L3 39±7; L4 58±8 b·min^{-1}, P<0.05). $\dot{V}O_2$ and *VE* were not different.**
Conclusion. **The findings suggest that water walking on a non motorized treadmill elicits similar $\dot{V}O_2$ but higher HR than land walking; this factor should be considered when prescribing exercise intensity in water using heart rate.**

Key words: Exercise test - Oxygen consumption - Heart rate.

It is well known that exercising in water can help overweight and obese to maintain or increase their fitness without incurring in the risk of an overload on the spine or on the knees often associated to running on land and can help injured people to reduce recovery time as it can be performed early after an injures; besides it can be useful to reduce, when appropriate, the gravity load on the spine, ankle, knees and feet.[1] Previous studies [2-5] demonstrated that deep water running simulation produces lower oxygen consumption ($\dot{V}O_2$) and heart rate (HR) than land running. Moreover, shallow water running induces higher cardiovascular and respiratory responses than deep water running,[5, 6] depending on the depth of immersion, because of a closer similarity to land running and because of the lower percentage of body weight reduction. Cardiovascular and respiratory responses to water exercise can also be influenced by water temperature, reflex responses induced by immersion, by individual fitness level and by the exercise modality (on place or with the displacement of the body through the pool).[7]

A number of studies focused on the cardiovascular and metabolic responses of underwater treadmill exercise [8-10] in patients undergoing locomotors rehabilitation protocols. The ergometer (that is positioned at the base of a water flume) allows to reproduce the same biomechanics of land treadmill;[11-13] the device also allows treadmill water flow, belt velocity and exercise intensity to be adjusted. The walking

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exercise, besides, can be performed backward and forward. Information concerning this form of water training is numerous but the cumulative results on the cardiovascular and metabolic responses are still conflicting.[10, 13, 14]

Some authors reported higher HR responses during submaximal backward walking than when walking forward, with contrary water current.[14] Other studies [13] reported the absence of significant differences in $\dot{V}O_2$, HR, ventilation ($\dot{V}E$) between land and water exercise during maximal $\dot{V}O_2$consumption test. Masumoto *et al.*[14] obtained higher $\dot{V}O_2$, HR and rate of perceived exertion (RPE) responses in water than on dry land at the same speed; moreover, Evans *et al.*[15] and Tomoki *et al.*[16] reported that the water speed required to walk at a similar land energy expenditure is approximately half of the speed on land.

Recently, a new form of water walking or running training has been developed which consists on walking or running on a non motorized treadmill, maintained at an inclined position. To walk forward only the human kinetic movement is needed; this results in a higher energy expenditure compared to walking/running on a motorized treadmill, for a given speed; however, to the best of our knowledge no study investigated the cardiovascular and metabolic demands of passive treadmill exercise in land and water condition.

The aim of this study was to investigate the pulmonary and cardiovascular responses induced by submaximal walking on a non motorized treadmill, in land and in water condition, at different speeds in a group of young, healthy people.

Materials and methods

Subjects

Eight healthy young subjects volunteered for this study. The mean age (SD), body mass and height were 26.5±2.8 years; 66.7±9.60 Kg; 172±8.07 cm. The study was approved by the Local Ethical Committee and all subjects signed an informed consent prior to participation.

Experimental design

All subjects performed one maximal incremental treadmill test (Technogym, Cesena, Italy) and two incremental submaximal tests, one on a non motorized treadmill (BSQ MAG TR 1000, High Power Srl, San Marino, Italy) and one on a non motorized water trekking (OKeo s.r.l. Carasco (GE) – Italy). One pre-experimental session was provided to familiarize all subjects to land and water tests. The three tests were performed in separate sessions, with at least 24 hours interval in between the maximal test and the submaximal tests. The submaximal land test (LT) and the maximal treadmill test (TT) were performed at a room temperature of 23.4±0.9 °C. The water test (WT) was performed in a swimming-pool with a water temperature of 29.7±0.2 °C; all subjects were immersed in water at umbilicus level. The LT always preceded the WT; test order was not randomized because LT was used to fix exercise intensity during WT test. During both tests subjects were asked to grasp the treadmill hand bars.

TT

after a 3 minutes warm up at a self selected velocity, 1-min steps were performed during which the gradient of the treadmill was kept constant at 1%, and the velocity was increased by 1 $Km \cdot h^{-1}$ every minute until exhaustion. The $\dot{V}O_{2max}$ was considered achieved when at least two of the following criteria were met: 1) the $\dot{V}O_2$ obtained in two consecutive steps did not increase by more than 1.5 mL·kg; 2) the HR reached at least 90% of the maximal theoretical HR (220-age); 3) RER equal or higher than 1.1. All subjects were verbally encouraged to achieve their maximum possible effort.

LT

Subjects performed five minutes at 2 $km \cdot h^{-1}$ (L2), five minutes at 3 $km \cdot h^{-1}$ (L3) and five minutes at 4 $km \cdot h^{-1}$ (L4). The velocity was visualized and controlled directly on the screen of the treadmill. During the test, two investigators were instructed to count the stride frequency of each stage for each subject.

WT

Subjects performed 5 minutes at the stride frequencies corresponding to the three velocities of the LT (W2, W3, W4 $Km \cdot h^{-1}$). The stride frequency was dictated by a metronome. Cardiopulmonary resting values were recorded for 5 minutes before starting each test.

Oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), breathing frequency (f) and pulmonary ventilation ($\dot{V}E$) were measured breath by breath by using a portable metabolimeter (K4b² – Cosmed, Italy); prior to each test, the gas analyzers were calibrated with gases of known concentration (16.06 oxygen, 5.02 carbon dioxide) and the turbine flowmeter was calibrated using a 3-liter syring. During the LT the metabolimeter (0.8 Kg weight) was fixed on the back of the subject; during the WT the measuring apparatus was placed inside a waterproof bag. The HR was recorded by using a heart rate monitor (Polar, Finland). Data were transmitted to a telemetric receiver placed 5 m from the subject in both conditions and visualized on-line on the screen of a portable computer and saved for subsequent analysis. The respiratory exchange ratio (RER), i.e. the ratio between $\dot{V}CO_2$ and $\dot{V}O_2$, was also calculated. The stride frequency was measured as the number of footfalls per minute and was recorded during the last 30 seconds of each stage of the striding walking (Figures 1-3).

Statistical analysis

The statistical package (v18, 2011 SPSS Lead Technologies Inc., Chicago, Illinois, USA) was used for this analysis. Data were presented as mean values and standard deviations; statistical significance was set at alpha level of P=0.05. Prior to the study the Kolmogorov test was applied to test the normal distribution of the data. For each of the three variables reserve heart rate (HRR)%max, net oxygen consumption (net $\dot{V}O_2$)%max, net pulmonary ventilation (net $\dot{V}E$)%max) a within-subjects repeated measures analysis of variance (ANOVA) was used to test differences for environment (Land, Water) and intensity level (2, 3, 4 Km*h). In order to control

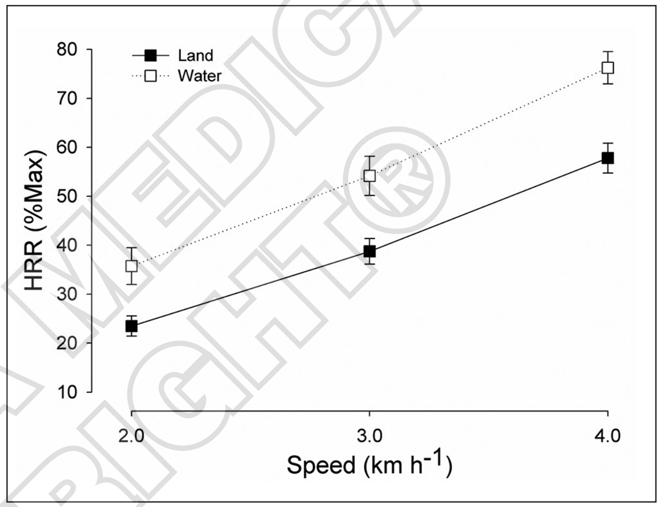

Figure 2.—Relationship between HRR(%max) during land (full squares) and water (open squares) walking.

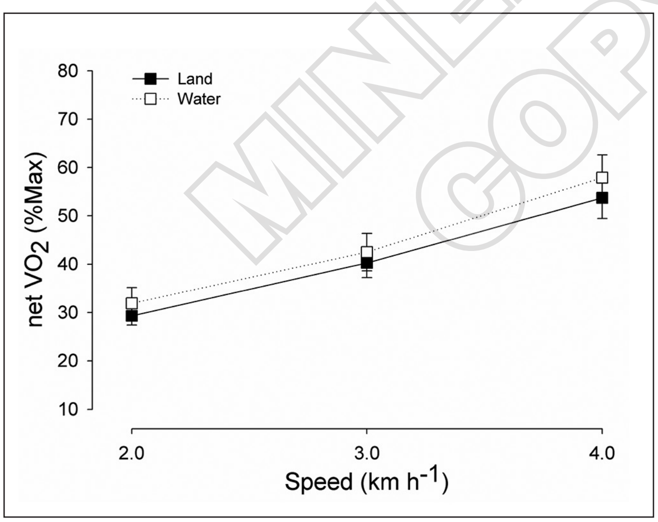

Figure 1.—Relationship between net $\dot{V}O_2$(%max) during land (full squares) and water (open squares) walking.

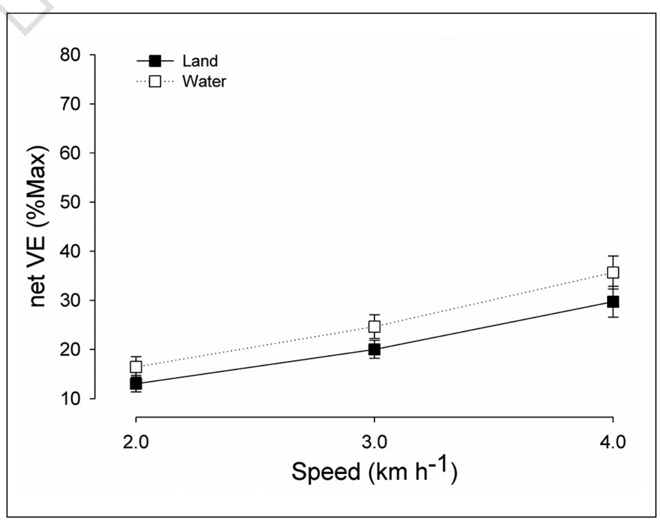

Figure 3.—Relationship between net $\dot{V}E$(%max) during land (full squares) and water (open squares) walking.

for assumptions which must be met in this kind of analyses the Mauchly's test for the sphericity, was performed. For statistical tests that used multiple comparisons post-hoc Fisher protected least significant difference comparisons with Bonferroni corrections were used. To provide meaningful analysis for significant comparisons from small groups, the Cohen's effect sizes (ES) between groups were calculated. An ES <0.2 was considered trivial, from 0.3 to 0.6 small, <1.2 moderate and>1.2 large.

The relationship between HRR(%max) and net $\dot{V}O_2$(%max) during land and water walking was estimate using a Pearson product-moment correlation as well as the coefficient of correlation (*r*=correlation coefficient; R^2=coefficient of determination).

Results

Table I shows the mean (±SD) maximal values recorded during the maximal treadmill test.

Table II shows the mean (±SD) of resting values recorded prior to land walking test and prior to water walking test and the mean (±SD) of the submaximal values recorded during the land walking test at 2, 3, 4 km·h-1 and during the water walking test at 2, 3, 4 km·h-1. Resting HR in water was statistically lower (P<0.01) than in land condition, while $\dot{V}O_2$ and $\dot{V}E$ were not different. During the walking water test, HR was statistically higher with respect to the land walking test at 2 Km·h-[1] (P<0.01), at 3 Km·h-[1](P=0.00), at 4 Km·h-[1](P=0.01). All the other considered parameters were not different between land and water condition.

$\dot{V}O_2$ increased linearly with the speed and there were no significant differences between $\dot{V}O_2$ during land test and during water test at each velocity (Figure 1).

Heart rate increased linearly with the increment of the velocity in both condition; the HR water test values were statistically higher than the HR land test values for each velocity (P<0.05) (Figure 2).

$\dot{V}E$ increased linearly with the increment of the velocity; there were no significant differences between $\dot{V}E$ during water test and during land test (Figure 3).

A linear relationship is always present in both land and water condition (r^2 land=0,825; r^2 water=0.7528). $\dot{V}O_2$/HR relationship during water walking is less than that during land walking, denoting a lower oxygen pulse (Figure 4).

TABLE I.—*$\dot{V}E_{max}$, $\dot{V}O_{2max}$, HR_{max}, RER_{max} during maximal treadmill test. Data are expressed as mean (±SD) among all subjects and at the net of the rest values.*

Maximal test - Treadmill	
$\dot{V}O_{2max}$ (ml·kg·min-1)	45.7±5.4
HR_{max} (b·m-1)	107±8.7
$\dot{V}E_{max}$ (L·m-1)	116.7±33.1
RER_{max}	1.35±0.1

$\dot{V}E$: pulmonary ventilation; $\dot{V}O_2$: oxygen consumption; HR: heart rate; RER: Respiratory Exchange Ratio.

Discussion

This study aimed at establishing the pulmonary and cardiovascular demands induced by submaximal intensity exercise performed in air and in water while walking on a non motorized treadmill (Figure 5). This is a device that has been recently included in aerobic training programs; to walk forward, only the human kinetic movement is needed; this, probably make it better in terms of the overall workout/calories burned and allows people to train at low speed, avoiding the risk of orthopaedic trauma often experienced with running.[1]

It is well known that the immersion in non thermoneutral water induces a decrement of the heart rate;[7, 17] the amount of this reduction is dependent on

TABLE II.—*$\dot{V}E$, $\dot{V}O_2$, HR during submaximal land and water walking in the rest condition and at 2, 3, 4 km·h-1. Data are expressed as mean (± SD) among all subjects and as net and percentage of the treadmill maximum values.*

	LandRest	Land2	Land3	Land4	WaterRest	Water2	Water3	Water4
$\dot{V}O_2$ (ml·kg·min-1)	9.4±1.5	29.3±1.1	40.3±2.7	53.7±3.6	7.7±2.4	31.2±9.1	43.2±11	57.5±13.3
HR (b·m-1)	42±3*	23±5**	39±7***	58±8****	36±5*	35±10**	54±11***	76±9****
$\dot{V}E$ (L·m-1)	8.7±2.4	14.4±4.7	22.0±5.2	32.8±8.9	7.7±2.8	18.2±5.9	27.1±6.9	39.2±9.5

Rest: rest condition; 2: 2 km·h-1; 3: 3 km·h-1; 4: 4 km·h-1; $\dot{V}O_2$:oxygen consumption; HR: heart rate; $\dot{V}E$: pulmonary ventilation. *differences between LandRest and WaterRest; **differences between Land2 and Water2; ***differences between Land3 and Water3; ****differences between Land4 and Water4.

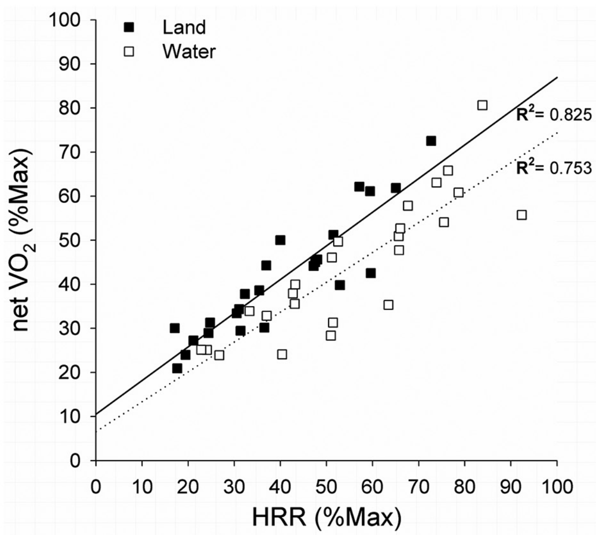

Figure 4.—Relationship between HRR(%max) and net $\dot{V}O_2$ (%max) during land (full squares) and water (open squares) walking.

the level of immersion and on the water temperature and derives from an increase in vagal activity as a consequence of the stimulus of skin cold receptors. The activation of the parasympathetic nervous system induces the decrease of the rhythm of sino-atrial node and slows down the transmission of the cardiac impulse to ventricles. Besides, the compression of lower limbs induces an increase in venous return, which, in turn, increases the ventricular contraction (Starling law), thus maintaining the cardiac output. Data from this study confirmed that during rest condition, HR decreased immediately after water immersion. All subjects were immersed at hip level and the amount of the decrement is in accordance with that reported by Farhi and Linnarson.[18]

In contrast rest $\dot{V}O_2$, $\dot{V}E$ and RER were not affected by water immersion.

During exercise, net $\dot{V}O_2$, HRR, net $\dot{V}E$ and RER increased linearly with speed during both land and water training. At 2, 3, 4 Km*h-1 HRR was significantly higher in water than in the land condition, while the net $\dot{V}O_2$, the net *VE* and the RER did not change (Table II).

These results suggest that water exercise elicits the same pulmonary responses of land training and, in contrast, a higher cardiovascular effort.

It has been reported that the physiologic responses induced by exercising in water are influenced by the level of immersion and by the water temperature,[12] by the modality of displacement,[7, 15, 19] by the presence or not of a water current,[11] by walking backward or forward.[14]

Previous studies,[16, 19] compared treadmill walking on land and in water and suggested that for a given metabolic load ($\dot{V}O_2$) speed in water is approximately half that on the land. During exercise, the belt speed and the water flow increased; the presence of a contrary water current enhanced the drag force exerted by the water on the lower limb [11] thus increasing the energy expenditure. Masumoto *et al.*,[20] stated that the cardiorespiratory responses are higher in water.

Harrison and Bulstrode [21] measured the percentage of body weight unloading for several levels of immersion; they reported that immersion at anterior superior iliac spines (ASIS) gives a body weight unloading of about 50% (this is, approximately, the level of the body's centre of gravity). The 50% bodyweight unloading may counterbalance the added resistance to the movement imposed by water with respect to that of land walking. Gilbert *et al.*,[12] found that the slope of HR/$\dot{V}O_2$ was significantly less during waist water walking with respect to land walking and with respect to other water depth (ankle, knee and midthigh), the lower oxygen pulse indicating that HR must be higher to achieve the same $\dot{V}O_2$. In addition, authors found that exercising in water at waist level, at water temperature of 30.5, induced an HR response greater for any increase in $\dot{V}O_2$ and that this effect was more relevant at the water temperature of 36.1. They suggested that to reproduce the same oxygen consumption during underwater walking at waist level, the water temperature must be lower than that they used in their study.

In accordance with these findings, our data on the dynamic phase show a statistically higher HRR, while the $\dot{V}O_2$, the RER and the $\dot{V}E$ is unaltered. The linear relationship between HRR%max and net $\dot{V}O_2$%max (Figure 4) was significant during both land and water walking but is shifted to the right denoting a higher cardiac effort, for each of the three speed, for any oxygen consumption. The increased HR could be due to the necessity to dissipate heat by the body, instead of an increased request of oxygen from the muscles.

Our subjects performed the water walking at hip level in water at 29.5±2 °C and at a air temperature of 30±2 °C, with humidity of 50%.

Exercise in a warm environment, promotes a gradual decrease in stroke accompanied by an increase in heart rate. This is frequently accompanied by a rise in body temperature. As a greater amount of blood is sent to the skin to cool, the body decreases the volume of blood returning to the heart. All these phenomena cause a lowering of central venous pressure, which in turn leads to decreased venous return to the right side of the heart and reduces diastolic volume canvases, and this in turn decreases the volume of systolic discharge. The HR increased to offset the decline in the volume of systolic discharge, in an attempt to maintain cardiac output. These findings are in accordance with Gilbert *et al.*[12] and Hall *et al.*[10] that reported an increase in heart rate at increased water temperature.

Onodera *et al.*,[22] reported that the water depth is related to the oxygen consumption, which decreases when the water level increases from the knee to the waist, suggesting that the buoyancy offset the effect of water resistance.

Conclusions

Considering the findings from the present study it is reasonable to suppose that the water training at hip level, in warm water and in warm air environment, performed at the same speed of land training, is not a sufficient stimulus to improve the aerobic capacity in non impaired subjects; besides, the water environment can hardly influence the cardiac adjustment, making it a high impact activity on the heart.

It must be taken into account when prescribing exercise intensity in water by heart rate monitoring.

References

1. Bushman BA, Flynn MG, Andres FF, Lambert CP, Taylor MS, Braun WA. Effect of 4 wk of deep water run training on running performance. Med Sci Sports Exerc 1997;29:694-9.
2. Frangiolas DD, Rhodes EC. Metabolic responses and mechanism during water immersion running and exercise. Sports Med 1996;22:38-53.
3. Dowzer CL, Reilly T, Cable NT, Nevil A. Maximal physiological responses to deep and shallow water running. Ergonomics 1999;42:275-81.
4. Mc Ardle WD, Toner MM, Magel JR, Spina RJ, Pandolf KB. Thermal responses of men and women during cold water immersion: influence of exercise intensity. Eur J Appl Physiol 1992;65:265-70.
5. Town GP, Bradley SS. Maximal metabolic responses of deep and shallow water running in trained runners. Med Sci Sport Exerc 1991;23:238-41.
6. Reilly T, Dowzer CN, Cable NT. The physiology of deep water running. J Sports Sci 2003;21:959-72.
7. Conti A, Rosponi A, Dapretto L, Magini V, Felici F. Cardiac and metabolic demands of in place shallow water running in trained and untrained men. J Sports Med Phys Fitness 2008;48:183-9.
8. Greene NP, Lambert BS, Greene ES, Carbuhn AF, Green JS, Crouse SF. Comparative efficacy of water and land treadmill training for overweight or obese adults. Med Sci Sports Exerc 2009;41:1808-15.
9. Fujishima K, Shimizu T. Body temperature, oxygen uptake and heart rate during walking in water and on land at an exercise intensity based on RPE in elderly men. J Physiol Anthropol Appl Human Sci 2003;22:83-8.
10. Hall J, Macdonald IA, Maddison PJ, O'Hare JP. Cardiorespiratory responses to underwater treadmill walking in healthy females. Eur J Appl Physiol 1998;77:278-84.
11. Masumoto K, Takasugi S, Hotta N, Fujishima K, Iwamoto Y. Muscle activity and HR responses during backward walking in water and on dry land. Eur J Appl Physiol 2005;94:54-61.
12. Gilbert WG, Nicholas JA. Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. Am J Sports Med 1989; 17 n°2.
13. Silvers WM, Rutledge ER, Dolny DG. Peak cardiorespiratory responses during aquatic and land treadmill exercise. Med Sci Sports Exerc 2007;39:969-75.
14. Masumoto K, Takasugi S, Hotta N, Fujishima K, Iwamoto Y. A comparison of muscle activity and heart rate response during backward and forward walking on an under water treadmill. Gait Posture 2007;25:222-8.
15. Evans BW, Cureton KJ, Purvis JW. Metabolic and circulatory response to walking and jogging in water. Res Q Exerc Sport 1978;49:442-9.
16. Shono T, Fujishima K, Hotta N, Ogaki T, Masumoto K.Cardiorespiratory responses to low-intensity walking in water and on land in elderly women. J Physiol Anthropol Appl Human Sci 2001;20:269-74.
17. Bonde-Petersen F, Schultz-Pedersen L, Dragsted N. Peripheral and central blood flow in man during cold, thermoneutral, and hot water immersion. Aviat Space Environ Med 1992;63:346-50.
18. Farhi LE, Linnarsson D. Cardiopulmonary readjustments during graded immersion in water at 35 degrees C. Respir Physiol 1977;30:35-50.
19. Migita T, Muraoka Y, Hotta N, Ogaki T, Kanaya S, Fujishima K *et al.* Cardiorespiratory responses during water and land walking. Kurume J Health Phys Education 1994;2:25-30.
20. Masumoto K, Shono T, Hotta N, Fujishima K. Muscle activation, cardiorespiratory response, and rating of perceived exertion in older subjects while walking in water and on dry land. J Electromyogr Kinesiol 2008;18:581-90.
21. Harrison R, Bulstrode S. Percentage weight-bearing during partial immersion in the hydrotherapy pool. Physiotherapy Practice 1987;3:60-3.
22. Onodera S, Miyachi M, Kimura K, Yonetani S, Nakamura Y. The effect of viscosity and depth of water on energy expenditure during water treadmill walking. Descente Sports Science 1993;14:100-4.

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