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Research Article

Energy Cost of Water Running in Shallow and Deep Water

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Abstract

Water running is distinguished in two different form, shallow water running and suspended deep water running. Shallow water running is defined as running in water at the hip or breast depth with contact with the bottom of the pool while deep water running is intended as running without contact with the floor supported by a flotation device. They have been prescribed by physician and coaches as an alternative to land-based running as a rehabilitative treatment, as well as supplement to land based training regiments. However, higher metabolic responses have been reported for shallow water with respect to deep water running. Aim of the study was to assess individualized relative exercise intensity of water running at different stride frequency for young active female at the same water level (xiphoid level) once with ground contact in shallow water and once suspended in deep water by a buoyancy belt. In the present study running performed in deep and shallow water induced a similar metabolic expenditure at all exercise intensity. In conclusion, to exercise at a mainly aerobic intensity young active females should run in water at a stride frequency of about 50 cpm, which elicits more or less 35% of both HRmax and VO_2max. While for a mixed aerobic/anaerobic intensity water running should be performed at ~ 60 cpm, where HR corresponds to 50% of HRmax and VO_2 to 41/44% of VO_2max.

Keywords: Water Running; Shallow; Deep Water

Introduction

Water running is a wide spread aerobic training method causing less stress to muscle-skeletal apparatus or impaired structure than running on dry land. This exercise method was developed in the USA by Marines' Track and Field trainer Glenn Mc Water and worldwide used as an effective training alternative in endurance athletes [1-3], or to improve cardiovascular fitness in sedentary [4] as well as for prevention [5] and rehabilitation [6-8].

Water running is distinguished in two different form, shallow water running (SWR) and suspended deep water running (DWR). Shallow water running (SWR) is defined as running in water at the hip or breast depth with contact with the bottom of the pool. It has been prescribed by physician and coaches as an alternative to land based running as a rehabilitative treatment, as well as supplement to land based training regiments. This form of exercise is popular among runners, who tries to proportioning their weekly mileage between land and water running. The technique requires no floatation device and is less threatening to those who fear deep water. DWR is intended as running in deep water (1.80m depth) without contact with the floor, in "head out immersion"; the body is in a vertical position supported by a flotation device (buoyancy vest or belt). DWR enables to eliminate impact with the ground reducing the occurrence of injuries, it can be therefore considered as an appropriate activity for developing fitness [9]. It thus may find many indication and different application. It has been employed more widely for rehabilitation exercise in patients with musculoskeletal ailments or in athletes with surgically, or otherwise treated, lower trunk injuries. It can also be suitable during pregnancy, or recovering from orthopaedics acute injuries, chronic joint diseases, person with knee and hip endoprothesis, chronic back pain, overweight and obesity, disabilities etc.

Even though many author compared the maximal metabolic responses of running on land and DWR Some author compared the metabolic responses of running on treadmill, DWR and SWR at maximal intensities. Literature comparing SWR with DWR reports that SWR elicits higher metabolic responses [10]; Dowzer., *et al*. found higher heart rate (HR) and pulmonary oxygen uptake (VO_2) for SWR and found that DWR caused significantly lower loss in stature [11].

Ainsworth., *et al*. attributed to jogging in water an energetic cost of 8 METs. However, in their compendium water depth, stride frequencies and subject's population were not specified. The value and limitations of using the compendium of physical activities to determine the energy cost of physical activity in adults are well known [12,13].

Aim of the Study

Therefore, aim of the present study was to assess individualized relative exercise intensity of sub maximal water running for young active female. Subjects were tested at the same water level (xiphoid level) once with ground contact in shallow water (SWR) and once suspended in deep water by a buoyancy belt (DWR).

Materials and Methods

Subjects: Nine female students (Mean ± SD age 22.5 ± 2.3, weight 55.5 ± 5.5 kg, stature 161.2 ± 6.3 cm, and 15.29 ± 3.28%) attending the water fitness course of the university of motor sciences, participated in the study. Body composition was assessed by measuring 7 skin fold site according to the formula of Pollock and Jackson [14]. Written informed consent was obtained from each subject before participation.

Protocol: Maximal treadmill test on land (VO_2max) and sub maximal water tests on shallow and deep water were performed in order to measure physiological parameter and to calculate the energy cost. Subjects participated in both experimental conditions using a counterbalanced within subjects design.

Maximal oxygen consumption assessment: Participants underwent a treadmill incremental exercise protocol to exhaustion on dry land (ergometer Runrace, Technogym, Italy). Following a 15 min warm up the subject was equipped for breath by breath gas analysis (K4 b^2, Cosmed, Italy), expired gas was passed through a mixing chamber and analysed continuously. Gas analyser were calibrated immediately before and after each test with a known concentration of oxygen and carbon dioxide and the flow meter was calibrated with a 3-l syringe. HR was continuously monitored (Sport Tester, Polar Electro, Kempele). Blood lactate determination from the earlobe at rest and at the third, sixth, and ninth minutes of the recovery phase, was carried out immediately after the collection (Accusport Lactate Analyser Roche, Basel, Switzerland). At the start of the test, the treadmill belt reached the first speed of 7 km/h in less than 5 s. The load was increased by 1 km/h every minute until volitional exhaustion. Verbal encouragement was given to the subject during the last minute of the test to give his maximal effort. Beyond to volitional exhaustion attainment, the achievement of VO_2max was also ensured by one of the following criteria: a VO_2 change less than 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ between workloads, heart rate reaching ± 5 bpm of the age adjusted maximal, respiratory exchange ratio higher than or equivalent to 1.15, and blood lactate accumulation higher than 8 mM. VO_2max was considered as the highest value obtained from the VO_2 data averaged over 30s. Treadmill and the water running tests were performed 1 week apart.

Water submaximal tests: An indoor swimming pool with 1.20 meters shallow water and 5 meters depth and with water temperature of about 24°C, was used. All the students were able to swim and were familiarized in shallow and deep water running with buoyancy belt. The same coach also carefully instructed the subjects of appropriate jogging and of deep water running techniques and approved the running technique of all students. Subjects were allowed to move forward as they run both in deep and shallow water.

For the deep water running technique with the buoyancy belt worn around the waist (Soft Touch Hydrobelt Okeo, Italy), the following advice were given: to maintain the head above the water straight ahead with the mouth out of the water, to held the trunk upright slightly foreword of vertical (2 - 3 degrees) with the spine in a neutral position, to held the elbows flexed at 80 - 90 degrees, the hands relaxed or slightly clenched, to perform the upper extremity motion with each arm swinging forward contemporary with the opposite leg, to move the leg with the thigh forward and up (approximately 70 degrees hip flexion) with the knee at 90 degrees and the ankle dorsiflexed, then to extend the hip and the knee and the ankle plantarflexed as in a push-off in land running.

For shallow water running an experienced coach choose the appropriate water depth in order for the subjects to be submerged to the xiphoid level and checked that the correct submersion depth was maintained all over the test. The running technique performed was the same as in deep water running, with the only difference that the lower limbs were actually pushing off the bottom of the pool.

On the test day all participants received oral and written instructions of the exercise procedure. In order to assess the relative exercise intensity of sub maximal water running for each subjects tests were performed at different stride frequencies below the 4 mM lactate threshold. The tests for both shallow and deep water running, consisted of water running at stride frequencies of 30, 40, 50, and 60 cycles per min^{-1} (cpm^{-1}) given by an acoustic preregistered signal, on a separate day in a random order. Each stride frequency was performed for 5 minutes with 1 minute rest. During the rest period blood lactate concentration was measured collecting blood samples at the earlobe. For the immediately after collection determination an Accusport Lactate Analyser with a 0.992 single-trial interclass reliability (Roche, Switzerland) was used. In case the 4 mM blood lactate concentration ([La]b) was over mounted subjects did not undergo the following step. The correctness of blood lactate values was later ensured by a laboratory apparatus (Ebio plus, Eppendorf, Germany).

Rating of perceived exertion (RPE), using Borg's 6- to 20-point scale [15], were scored during the last 15s of each step of exercise by pointing to a number of the scale, verbally reiterating it, and then starting any verbal anchor expressing their feeling (e.g. "13-somewat hard"). Prior to testing, participants were instructed in the use of the Borg scale, utilizing the standardized instructions [15], to ensure familiarity with the verbal anchor used.

Along every test and pre-test gas exchanges and heart rate were continuously recorded. Expired air was collected through a mouthpiece designed for use during swimming and attached to a lightweight helmet (Aquatrainer, Cosmed, Italy) connected to a portable gas analyzer (K4 b^2, Cosmed, Italy). The subject run along the side the swimming pool and gas analyzer contained on a water resistant bag was loaded on a rack located immediately over the head of the participant and carried by one person closely following the runner. At the end of the swimming pool, the subject made a pre-instructed outward turn. At every breath gas exchanges were recorded by a open-circuit oxygen uptake measurement system. Heart rates were continuously recorded (S810, Polar Electro, Finland).

Data analysis

VO_2 and VCO_2 were recorded every breath and than averaged every 15s. Gross energy cost (GEC) in ml/kg/min was calculated as the VO_2 mean value of the last 2 min of each step. The net increase of lactate ([[(Δ[La]b) was obtained by subtracting the resting value from that attained during the recovery phase. When Δ[La]b exceeded 4 mM its contribution to the GEC was measured as follows: [(Δ[La]b x 3) x kg] for each minute of exercise [16], and the resulting value in VO_2 (ml/kg/min) was added to GEC. Energy cost of exercise was also calculated in kcal/min by the caloric equivalent of a liter of oxygen corresponding to the appropriate respiratory exchange ratio (RER). Finally, the multiple of the resting metabolic rate (MET), equivalent to 3.5 ml O_2 kg/min, was calculated. HR values were averaged every 5s. HR was calculated as mean value of the last 2 min of each step. It has been reported as absolute value and as percentage of HRmax measured during the exhaustive test (HR% HRmax).

Cpm, VO_2, VO_2% VO_2max HR and HR%HRmax were extrapolated at the intensity corresponding to the accumulation of 2mM of blood lactate (AT) and of 4 mM of blood lactate (AnT).

Statistical analysis

Data are presented as a mean ± sd and percent of maximal values. ANOVA for repeated measures has been performed to evaluate statistical significance among strides and between DWR and SWR in metabolic parameters. Tukey's post-hoc analysis was carried out when appropriate. The level of significance was set at $P < 0.05$.

Results

During the maximal oxygen consumption assessment, peak measured values were 46.6 ± 6.1 $ml.kg^{-1}.min^{-1}$ for VO_2max and 189 ± 11 for bpm HRmax.

For what the water submaximal tests are concerned, since every subject reached 4 mM ([La]b) during the 50 cpm^{-1} step, none of them performed the 60 cpm^{-1} step in both running conditions.

Tables summarize the average data calculated for each stride frequencies in deep and shallow water during the sub maximal test.

Results show that there are no statistically significant differences between SWR and DWR at the three SF in La, RER, MET, VO_2 as percentage of VO_2max and VO_2 at the intensity estimated to produce 2 mM (aerobic threshold: AT) and 4 mM (anaerobic threshold: AnT) of lactate accumulation, HR, HR value relative to measured maximal HR and HR relative (HR%HRmax) at AT and AnT.

A difference was instead found for RPE with significantly higher values during DWR at 40, 50 (and 60 steps).min^{-1}, but not at the lowest intensity of 30 steps.min^{-1}.

A 30 40 50

ΔLa,	**30**	**40**	**50**
SWR	-0.01 ± 0.44	1.01 ± 0.91	1.44 ± **2.32**
DWR	-0.20 ± 0.67	0.93 ± 0.60	2.54 ± 0.89
RER	**30**	**40**	**50**
SWR	0.81 ± 0.05	0.86 ± 0.06	0.82 ± 0.29
DWR	0.84 ± 0.10	0.92 ± 0.09	1.05 ± 0.13
MET	**30**	**40**	**50**
SWR	2.6 ± 0.5	4.2 ± 1.6	6.8 ± 2.9
DWR	2.9 ± 1.1	4.4 ± 1.9	6.6 ± 2.6
VO_2 % VO_2max	**30**	**40**	**50**
SWR	20.2 ± 4.0	30.0 ± 9.6	48.2 ± 15.2
DWR	21.8 ± 9.1	31.8 ± 13.2	46.6 ± 16.4
HR	**30**	**40**	**50**
SWR	96 ± 15	115 ± 13	147 ± 23
DWR	98 ± 17	116 ± 20	141 ± 21
HR % HRmax	**30**	**40**	**50**
SWR	52 ± 9	61 ± 8	78 ± 13
DWR	52 ± 10	62 ± 13	75 ± 14
RPE	**30**	**40**	**50**
SWR	6 ± 0	7 ± 1 *	11 ± 2*
DWR	7 ± 2	10 ± 2	13 ± 3

Table 1: * = P < 0.05.

A 2 e 4 mM

2 mM	**SWR**	**DWR**
Cpm	48 ± 6	47 **± 5**
VO_2	16.7 ± 5.1	15.8 ± 3.8
VO_2 % VO_2max	35.6 ± 8.1	34.2 ± 8.4
HR	140 **± 6**	135 **± 5**
HR % HRmax	74 ± 3	71 ± 2
4 mM	**SWR**	**DWR**
Cpm	59 ± 6	58 ± 6
VO_2	24.9 ± 8.9	22.0 ± 5.0
VO_2 % VO_2max	52.5 ± 13.9	47.4 ± 9.8
HR	167 ± 8	159 ± 7
HR % HRmax	88 ± 6	84 ± 4

Table 2

Discussion

In the last decade water running has become popular as alternative training and rehabilitation means and it is considered therapeutically beneficial for older individuals is also a viable form of conditioning for those who are afflicted with orthopedic disabilities [17]. Furthermore, for overweight person the dual effect of buoyancy and resistance create an environment that requires higher levels of energy expenditure with relatively little strain on low-joint extremities.

The water's gravity-minimizing properties reduce compressive joint forces providing a better exercise environment for patients with arthritis, back pain osteoporosis, or other medical condition that may restrict training on land.

The results of the present study indicate that to exercise at a mainly aerobic intensity (around 2 mM of [La]b accumulation) young active females should run in water at a stride frequency of about 50 cpm, which elicits more or less 35% of both HRmax and VO_2max. While for a mixed aerobic/anaerobic intensity (around 4 mM of [La]b accumulation) water running should be performed at ~ 60 cpm, at this exercise intensity HR corresponds to 50% of HRmax and VO_2 to 41/44% of VO_2max. In the present study running performed in deep and shallow water induce a similar metabolic expenditure at all exercise intensity. This result could be explained by the same water level immersion of the subjects (xiphoid level).

The updated recommendation from the American College of Sports Medicine and the American Heart Association sustains that to maintain health all healthy adult (18 - 65yr.) need moderate intensity aerobic physical activity for a minimum of 30 min on five days each week or vigorous-intensity aerobic activity for a minimum of 20 min on three days each week [18]. Physical activities are classified by MET: light lower than 3,0 METs; moderate from 3 to 6 METs and vigorous higher than 6 METs. The result of the present study indicates that, for young female running in water submersed at the xiphoid's level at a stride frequencies of 30 cpm^{-1}, is a light activity, at 40 cpm^{-1}, is considered moderate and for exercising at a vigorous intensity the stride frequencies should achieve 50 or over cpm^{-1}.

In the present study RPE was the only parameter showing significant difference between deep and shallow water at 40 and 50 cycles per min^{-1} (cpm^{-1}). At this regard it has to be taken into account that running was performed once with ground contact in shallow water (SWR) and once suspended in deep water by a buoyancy belt (DWR). Moreover, the student participating at the study were not trained runners nor experienced water jogger. Indeed, subjects unaccustomed to DWR might be required to utilize their muscles in an unfamiliar fashion, muscle recruitment pattern might be different. The propulsive muscles of the lower limb (Gastrocnemius and Soleus), analyzed by surface electromyography, are less recruited in DWR compared to walking in water, due to the lack of ground reaction force [19]. Moening., *et al*. suggested that in deep water running the joint angle of hip maximum flexion in the knee drive is greater than during walking on land and at the knee joint, the range of motion from the back swing of the knee drive was grater during DWR than treadmill running [20]. Hip and knee joint flexion and range of motion were greater during DWR than treadmill running. However, Dowzer., *et al*. found that RPE did not differ between running on land, on deep or shallow water [11].

During water immersion the thermoneutral temperature while at rest, is 33 - 35°C [21]. Nielsen and Davies stated that a minimal exercise intensity corresponding to a VO_2 of 1.2 l.min^{-1} was adequate to maintain rectal temperature close to values recorded on land [22]. Indeed, thermoneutral temperature during water immersion is lower during moderate- to high-intensity exercise compared with the thermoneutral temperature when resting immersed in water. In the present study, subjects did not complain of cold discomfort even at very low intensity (30 cpm), probably due to the short duration of the test. Therefore, for exercise training or rehabilitation water temperature should be considered.

Conclusion

In conclusion, for young active female water running both with ground contact and suspended in deep water can be performed at light intensity up to 30 cpm; at moderate intensity between 30 and 50 cpm and at vigorous intensity higher 50 cpm. Results of this study are restricted to this specific subject group; therefore, further study could focus on different populations.

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