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Comparison of maximal and spontaneous speeds during walking on dry land and water

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ABSTRACT

The aim of this study was to quantify spontaneous and maximal speeds on dry land and in water, in four modalities of walking [forward (F), backward (B) and lateral walking (L)], with chest immersion level. Lateral walking was studied with the upper limbs of the subject alongside the body with hands placed on the lateral face of the thighs (L1) and upper limbs tightened behind the back with the hands joined (L2). 16 males (age 22.8 ± 1.8 years, height 178.1 ± 6.1 cm, body mass 73.5 ± 6.6 kg) and 15 females (age 22.8 ± 2.1 years, height 171.5 ± 5.8 cm, body mass 69.2 ± 9.3 kg) were evaluated using the four modalities of walking on dry land and in water. The speed increments between spontaneous and maximal speeds on dry land for F, B and L1 and L2 were 60.2%, 60.9%, 64.3% and 65.3% for males and 47.3%, 48.3%, 44.5% and 53.1% for females. In the water, these variation values for F, B, L1 and L2 for males were 44.6%, 26.1%, 48.8%, and 42.1%. The values for females were 31.7%, 21.6%, 32.8%, and 34.6%. Spontaneous and maximal speeds of walking were substantially reduced in water with the chest immersed, compared to speeds on dry land for the four modalities and the two genders. These findings may be used by therapists who utilize the various modalities of walking in aquatherapy.

1. Introduction

Walking is a simple means of functional physiotherapy for patients presenting problems with their system of locomotion. Treadmill walking exercises constitute the basis of re-training in cardiac and respiratory therapy. In daily practice, these exercises are mainly carried out on dry land. In this environment, forward walking is the most frequently used modality of walking and thus has been the object of many publications [1,2]. In most cases, slow, normal and fast gait are studied. These studies are principally concerned with the quantification of energy expenditure and space–time parameters in the gait cycle, for young or old people, both females and males. Backward walking and lateral walking are also currently used by physiotherapists but there is a paucity of data characterising such modalities of locomotion.

Backward walking has gained popularity as an adjunct to treatment for patients undergoing rehabilitation for patellofemoral pain syndrome and anterior cruciate ligament injuries [3]. Backward walking decreases the compressive forces at the patellofemoral joint while also preventing overstretching of the anterior cruciate ligament [4].

Data concerning backward walking is less numerous [3–9] than for forward walking and to our knowledge, there is only little data for lateral walking [9]. The authors who compared these different modalities of walking principally studied cardiorespiratory adaptations and metabolic responses. We found no data on spontaneous and maximal speeds for backward and lateral walking.

Specificity of the aquatic media in line with drag forces leads several physiotherapists to propose re-training exercises in the water. With the aim of ensuring an equivalent energy expenditure to exercise performed on dry land, walking in water is performed in xiphoidian immersion at walking speeds half the speed on dry land [10]. Comparisons were made concerning biomechanics parameters [11,12] or the cardio respiratory system [13]. Most studies were carried out using an immersed treadmill [13–18]. Moreover,

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these authors did not try to bring to light gender differences. Furthermore, data on spontaneous and maximal speeds for the different modalities of walking in water is non-existent. Such data could very useful to help physiotherapists in their choice of retraining exercise.

As a result of this lack of data, notably in water, the aim of this study is to determine and compare the spontaneous and maximal speeds of walking forwards, backwards and laterally, on dry land and in water in healthy subjects.

2. Materials and methods

2.1. Participants

Thirty one physiotherapist students (16 males and 15 females) participated in the study after signing written voluntary consent. Their mean age, height and body mass values were 22.8 ± 1.8 years and 22.8 ± 2.1 years, 178.1 ± 6.1 cm and 171.5* ± 5.8 cm, 73.5 ± 6.6 kg and 69.2 ± 9.3 kg for male and female respectively. There is only a significant difference for the height (*$p < 0.05$) between the two genders. None of the subjects presented any impediment to their system of locomotion, or had a previous history of either orthopaedic or neurological problems.

2.2. Experimental procedure

On dry land and in water, the subjects were requested to cover in a randomized order, a distance of 4 m at both spontaneous and maximal speeds employing different modalities: walking forwards (F), walking backwards (B) and walking laterally, on the right-hand side. For forward and backward walking, the subjects were not asked to restrict their movement, including upper limb swing. In order to see the influence of the upper limbs during lateral walking, we studied two positions: upper limbs alongside the body with hands placed on the lateral face of the thighs (L1) and upper limbs tightened behind the back with the hands joined (L2).

Before any measurement, participants performed several trials to get used for the tasks for each modality of walking. Three trials per modality were recorded and averaged values of the variables measured are considered for the analysis. To avoid the onset of fatigue, a breather period of 30 s was imposed between trials, both on dry land and in water.

- dry land walking: trials were performed in a corridor of 15 m. Photoelectric cells (Brower Timing Systems, USA) were fixed on the wall, 4 m apart, in the middle of the corridor, enabling the measurement of the time spent to cover the 4 m. Walking speed was then obtained from the ratio between the distance and the time measured.
- walking in water: the trials were performed in a swimming pool 6 m × 6 m and 1.30 m deep. Such as depth allowed the subjects to be immersed up to the chest level, approximately and according the height of males and females, at 5–10 cm upper the xiphoid process. The temperature of the water was set at 30 °C. Photoelectric cells were placed on the edges of the swimming pool, 4 m apart in the middle of the pool. For forward and backward walking, the subjects were not allowed to leave their upper limb from the water.

2.3. Statistical analysis

Mean and standard deviation were used to represent the average and the typical spread of values of the studied variable. A Student's *t*-test was used to analyse the anthropometric differences between males and females with significance being accepted at $p < 0.05$. The normal Gaussian distribution of the data was verified by the Shapiro Wilk's test. A three-way (2 environments (air/water); 2 speeds (spontaneous/maximal), and 4 modalities (forward, backward, lateral (2)) repeated-measure ANOVA was carried out. To detect significant difference, post hoc HSD Tukey was used. The threshold for significance was set at the 0.01 level of confidence. This statistical analysis was made using the STATISTICA 6.0 PC software.

3. Results

The speeds for spontaneous and maximal walking, on dry land and in water for forward, backward and lateral walking are presented in Table 1, for males and females respectively.

Fig. 1 shows the differences between the modalities of walking according to speed and environment.

3.1. Walking on dry land

The speed increments between spontaneous and maximal speeds for males were respectively 60.2% (F), 60.9% (B), 64.3% (L1) and 65.3% (L2). The values for females were 47.3% (F), 48.3% (B), 44.5% (L1) and 53.1% (L2). At the spontaneous speed, the speeds measured for F were higher than B ($p < 0.01$). The spontaneous speeds for F and B were significantly higher than the two modalities for lateral walking (L1 and L2) ($p < 0.01$). Finally, spontaneous and maximal speeds were not significantly different between L1 and L2. During walking at maximal speed, we obtained the same order of speeds according to the modalities of walking as during walking at spontaneous speed.

3.2. Walking in water

The speed increments between spontaneous and maximal speeds for males were respectively 44.6% (F), 26.1% (B), 48.8% (L1), and 42.1% (L2). The values for females were 31.7% (F), 21.6% (B), 32.8% (L1), and 34.6% (L2).

Respectively, at spontaneous and maximal speeds, no significant differences were found between the four modalities of walking.

3.3. Effect of environment on walking speed

The spontaneous speed values decreased from dry land to water by 68.4% (F), 61.6% (B), 50.7% (L1) and 50% (L2) for males and 70.1%, 65.4%, 52.8% and 54% for females. For the maximal speed values, the reductions were respectively 71.5% (F), 69.9% (B), 55.3% (L1), and 57% (L2) for males and 73.3%, 71.6%, 56.6%, and 59.5% for females.

4. Discussion

We measured spontaneous and maximal walking speeds in adults according four modalities (F, B, L1, L2) in two environmental conditions (on land and in water), at chest immersion level. The interest of our study was to quantify data on speeds in these modalities and notably in modalities which were not usual on land (B, L). We chose to quantify the forward, backward and lateral speed of walking because these exercises are frequently used in rehabilitation and in aquatherapy. These exercises are easy to set up, they require no material and the choice among the different modalities of walking avoids monotony. Another interest was to

Table 1
Results of forward, backward and lateral walking on dry land and in water at spontaneous and maximal speeds (Lateral 1: hands alongside the body, Lateral 2: hands behind the back).

Speed ($m\ s^{-1}$)	Dry land (spontaneous)		Water (spontaneous)		Dry land (maximal)		Water (maximal)	
	Males	Females	Males	Females	Males	Females	Males	Females
Forward	1.35 ± 0.20	1.35 ± 0.17	0.43 ± 0.08	0.40 ± 0.06	2.17 ± 0.29	1.98 ± 0.17	0.62 ± 0.08	0.53 ± 0.08
Backward	1.13 ± 0.12	1.10 ± 0.17	0.43 ± 0.06	0.38 ± 0.05	1.81 ± 0.22	1.63 ± 0.22	0.55 ± 0.07	0.46 ± 0.07
Lateral 1	0.80 ± 0.11	0.84 ± 0.15	0.40 ± 0.05	0.40 ± 0.05	1.32 ± 0.13	1.22 ± 0.14	0.59 ± 0.05	0.53 ± 0.05
Lateral 2	0.82 ± 0.12	0.84 ± 0.13	0.41 ± 0.05	0.39 ± 0.05	1.35 ± 0.15	1.28 ± 0.15	0.58 ± 0.07	0.52 ± 0.07

evaluate maximal speeds; indeed, there are few reports which investigate this type of data [19].

4.1. Walking on dry land

The speed values results of this study are identical to those found in the literature for spontaneous [11,19–22] and maximal [20] speeds concerning forward walking on dry land.

As for the backward walking, it appears that both spontaneous and maximal speeds are lower than those measured during the forward walking. This lower speed can be explained by the fact that backward walking is not a usual mode of locomotion. According to Thorstensson [23]: (i) both swing and stance duration of the phases are decreased in comparison with the forward walking; (ii) a massive activation of the knee extensors occurred during the stance phase; these muscles contract during shortening and there is no possibility to utilize elastic energy stored in muscle during a stretch-shortening cycle as in forward walking [24]. Moreover, backward walking required an increased in neuromuscular demand when compared to forward walking [25–27].

In most studies which concern backward walking, speeds are imposed. But we can still notice that some of these speeds values are identical with the spontaneous [3,5,7] and maximal speeds [3,5,6] measured in our study. At an imposed speed (107.2 m min^{-1} = 1.78 m s^{-1}), Flynn [6] found a greater energy cost for backward walking when compared with forward walking. This speed value corresponds to our maximal speed measured for backward walking and to an intermediate speed between our spontaneous and maximal speed in forward walking. This greater energy cost could be explained by the fact that the subjects walked at their maximal speed for backward modality.

The speeds data measured during lateral walking are the lowest in the four modalities as well in spontaneous as in maximal speeds. It can be also noted that the positioning of the upper limbs behind the back or alongside the body had no effect on the speed in spontaneous or maximal lateral walking, even if, at the start, it might have been thought that the upper limbs could hinder the advancement of the lower limbs at maximal speed.

In the literature, data for lateral walking are less numerous than for backward walking. At our knowledge, only one research is available concerning this modality of walking [9]. These authors investigated energy cost and the speeds were imposed to the subjects. At 80.45 m min^{-1} (=1.33 m s^{-1}), the highest energy cost is for lateral walking and the weakest for forward walking. For

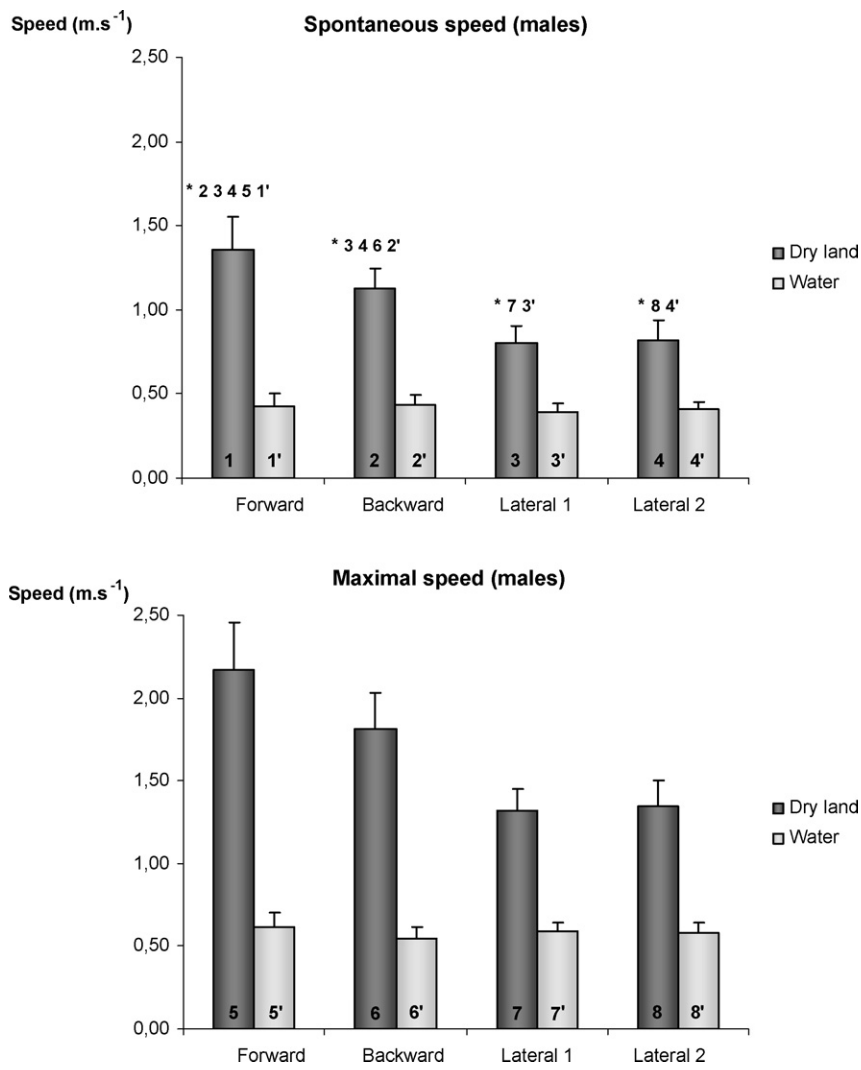

Fig. 1. Comparison of spontaneous speeds (1,1′,2,2′,3,3′,4,4′) and maximal speeds (5,5′,6,6′,7,7′,8,8′), on dry land (1–8) and in water (1′–8′) for forward walking, backward and lateral with hands alongside the body (lateral 1) and hands behind back (lateral 2), for males and females (mean ± SD). *Significant difference with corresponding modality $p < 0.01$.

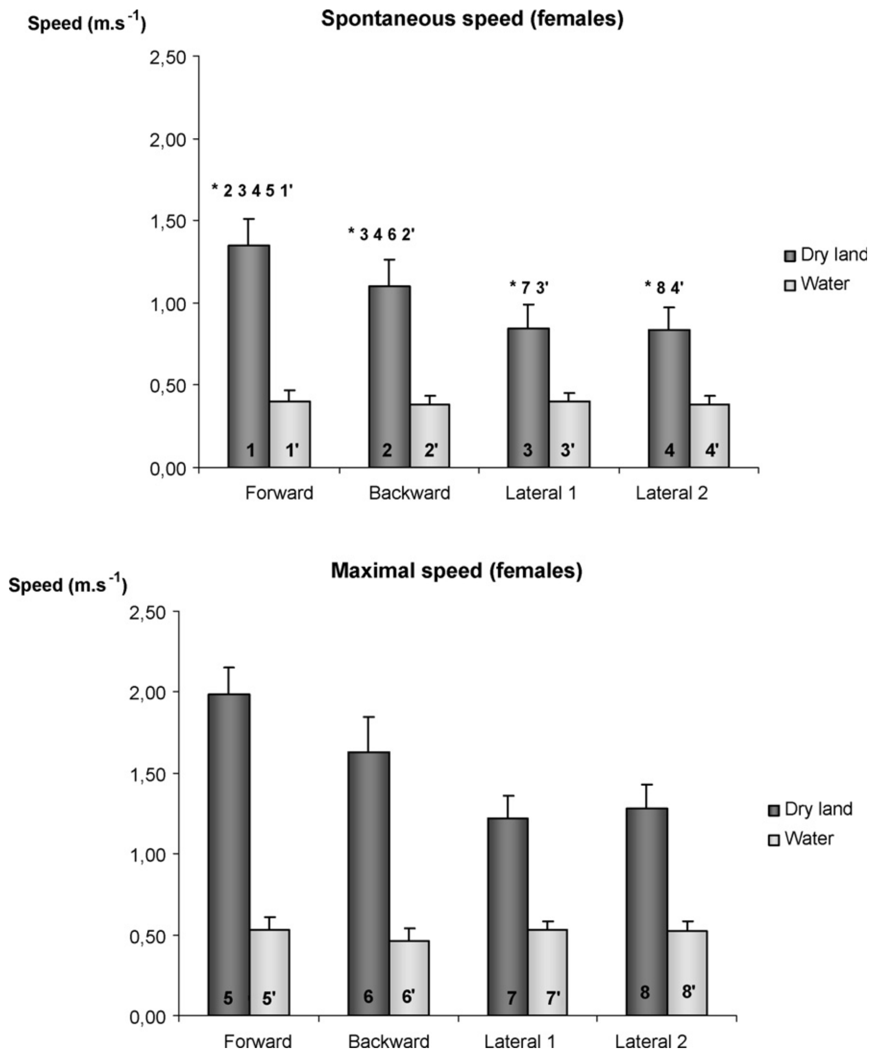

Fig. 1. (*Continued*).

Williford et al. [9], lateral walking is an unfamiliarity and inefficiency modality of walking; their results can be explained by the fact that, at 1.33 m s^{-1} and according to our data, the subjects are walking at a maximal speed in lateral walking and at a spontaneous speed in forward walking.

4.2. Walking in water

Water walking speeds are lower than land walking speeds because of the water resistance as mentioned by Kaneda et al. [28]. Resistance to movement in water increases as the square of speed [29]. It may be also attributed to the water drag force and the lower apparent body weight in water [11]. The main interest of our study was to investigate data in a swimming pool, in real walking conditions.

It seems difficult to compare our data with those of the literature as far as most of the studies were realized on immersed treadmills [30] or on immersed treadmills water-flow [13–17]. Indeed, walking in a swimming pool is quite different from walking on treadmill, because the body must actually move through the water [31]. Walking in a swimming pool is more similar to walking on an immersed treadmill water-flow [32], but most of the time, on treadmills, the walking speed is imposed to the subjects. In the present study, we observed that the spontaneous speed in forward walking in water was about 30% of the walking speed on land, which is close to the results of Barela et al. [11] (0.50 ± 0.07 m s^{-1}), for which the participants walked at self-selected comfortable speeds, on a walkway in a swimming pool. This speed is slightly higher than the one we found; this difference may be explained by a lower level of immersion since their subjects were immersed at the xiphoid process level (5–10 cm below our chest level immersion) and had to overcome a lower resistance. Yet, we chose the chest immersion level, because it is one of the most frequently used level in aquatherapy. This is also agreed with the results of Evans et al. [10], who found that one-half to one-third of the speed is needed to walk in water at the same level of energy expenditure than on land. It is from this report that Shono et al. [33], Matsumoto et al. [18,34,35] and Hotta et al. [14–17] imposed their speeds. The increments between spontaneous and maximal speed in water are lower compared to those on dry land; this may be attributed to water properties as explained above and by hydrodynamic resistance [29].

The present study showed no differences between spontaneous speeds in the four modalities. This lets suppose that specific characteristics for every pattern of walking cannot express themselves here and would be masked by the reduced weight-bearing and the water resistance [11,36].

The same explanation could be advanced for the maximal speeds for which there is either no significant difference between the four modalities. Moreover, the little difference between the spontaneous and maximal speeds can certainly be attributed to the difficulty in generating propulsive forces because of the high level of immersion and the important weightlessness of the subjects walking in the water.

In lateral walking, the square metre surface of the body is reduced which reduces resistance to progression compared to forward walking [29]. So, it could be thought that this reduction would allow reducing the difference between the speeds and would be a supplementary explanation. Concerning the two modalities of lateral walking, there was no difference, even if it could be thought that the increase in square metre of surface with hands placed behind the back would increase the resistance to progression.

5. Conclusion

On dry land, spontaneous as well as maximal speed was higher during forward walking than during backward walking and lateral displacements. In water, no significant differences were found between the four modalities of walking, either at spontaneous or maximal speed. Standardisation of speeds when comparing walking on dry land and in water is therefore difficult as the resistance of the water increases as the square of the speed and depends of the immersion level. According to our data, it would be advisable to choose mean speed values for males and females close to the following values: 31% of spontaneous speed on dry land for forward walking, 36% for backward walking and 49% for lateral walking. As for maximal speed used in water, values close should be close to 28% of maximal speed on dry land must be chosen for forward walking, 29% for backward walking and 43% for lateral walking. Assessment of spontaneous and maximal speeds in both conditions seems also suitable for such studies.

Conflict of interest

Alain Chevutschi, has no proprietary, financial, professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in or the review of the present article.

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