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Biomechanical characteristics of elderly individuals walking on land and in water

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Abstract

In this study, we examined Spatial–temporal gait stride parameters, lower extremity joint angles, ground reaction forces (GRF) components, and electromyographic activation patterns of 10 healthy elderly individuals (70 ± 6 years) walking in water and on land and compared them to a reference group of 10 younger adults (29 ± 6 years). They all walked at self-selected comfortable speeds both on land and while immersed in water at the Xiphoid process level. Concerning the elderly individuals, the main significant differences observed were that they presented shorter stride length, slower speed, lower GRF values, higher horizontal impulses, smaller knee range of motion, lower ankle dorsiflexion, and more knee flexion at the stride's initial contact in water than on land. Concerning the comparison between elderly individuals and adults, elderly individuals walked significantly slower on land than adults but both groups presented the same speed walking in water. In water, elderly individuals presented significantly shorter stride length, lower stride duration, and higher stance period duration than younger adults. That is, elderly individuals' adaptations to walking in water differ from those in the younger age group. This fact should be considered when prescribing rehabilitation or fitness programs for these populations.

Keywords: Gait; Locomotion; Rehabilitation; Physical activity; Ageing

1. Introduction

Professionals in the field of rehabilitation, training and physical activity have typically used a shallow water environment so that exercises other than swimming can be carried out (Bates and Hanson, 1996; Heyneman and Premo, 1992; Prins and Cutner, 1999; Simmons and Hansen, 1996). In such conditions, the shallowness of the water generally varies from between waist to shoulder levels. Individuals who may benefit from such water-based exercises include those requiring reduced weight bearing in the lower extremities due to muscle or joint disturbances (e.g. arthritis (Cochrane et al., 2005) and anterior ligament injury (Tovin et al., 1994)); those with neurological deficits (e.g. multiple sclerosis (Gehlsen et al., 1984) and cerebral palsy (Kelly and Darrah, 2005)), and individuals with balance disorders (Heyneman and Premo, 1992; Simmons and Hansen, 1996), among others. The elderly commonly suffer from these and other pathologies, so aquatic exercises are frequently recommended for them (Bates and Hanson, 1996; Devereux et al., 2005; Simmons and Hansen, 1996; Suomi and Collier, 2003).

From a biomechanical point of view there are two principal reasons why walking in water may be beneficial: the lowering of apparent body weight due to the buoyant force (that is, the larger the submerged part of the human body, the lower the apparent body weight), and the increased resistance to movement due to the drag force exerted by water on the human body (that is, the larger the frontal area and faster the movement of the body, the greater the resistance to movement). Thus, the individual finds it is easier to support the body in water than on land, and movements can be performed more slowly, thus diminishing the impact forces on the musculoskeletal system (Barela

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et al., 2006; Bates and Hanson, 1996; Prins and Cutner, 1999).

Walking may be one of the most common motor tasks in water-based exercise programs because it can be practiced by any age-group and with most medical conditions. For example, unlike swimming practice, it does not require any specific skills. Therefore, the biomechanical characteristics of walking in water have been relatively well investigated (Barela et al., 2006; Harrison et al., 1992; Masumoto et al., 2004; Miyoshi et al., 2004; Nakazawa et al., 1994). We have previously shown that when younger adults select comfortable speeds at which to walk in chest-deep water as well as on land, their speed in water is about 36% of their speed on land (Barela et al., 2006). Their stride lengths are only 10% lower in water than on land while the ranges of motion of the ankle, knee, and hip joints are similar in both conditions (Barela et al., 2006; Miyoshi et al., 2004). As younger adults walk in water, the vertical ground reaction force (GRF) component magnitudes are, on average, about 50% and 25% of body weight, respectively, when walking in waist-deep and chest-deep water (Harrison et al., 1992; Nakazawa et al., 1994). However, when the vertical GRF component from walking on land and in water are normalized, respectively, by the individuals' body weight and the apparent body weight in water (that is, the body weight minus the buoyant force), this component shows similar magnitudes and profiles during walking at comfortable speeds in both conditions (Barela et al., 2006). Finally, lower limb muscle activity is reduced, with less-defined peaks (that is, a flatter pattern), during walking at comfortable speeds in water than on land (Barela et al., 2006; Masumoto et al., 2004).

The above characteristics have been observed for younger adults only. It is widely recognized that the gait of older individuals differs significantly from that of younger people [for a review see Judge et al., 1996; Prince et al., 1997]. Elderly individuals usually present reduced step lengths, walking speeds, ranges of joint motion, and ankle extensor powers (that is, a less vigorous push-off) as they walk on land (Judge et al., 1996; Prince et al., 1997). It is likely that elderly individuals also present these differences as they walk in water.

Given the lack of biomechanical studies on this topic and that elderly individuals are a commonly targeted group for water-based exercise programs, the present study investigated elderly individuals walking in water. Such investigation will provide a better understanding as to how the elderly behave during such motor tasks. It may also contribute to a more appropriate prescription of walking in water as a rehabilitation or fitness program for this population. Therefore, this study comprises two main components. First, we analyzed qualitatively and quantitatively a complete gait cycle of healthy elderly individuals walking on both land and in water at comfortable, self-selected speeds. In order to compare walking in both conditions we specifically analyzed the common biomechanical variables already used in previous investigations into walking in water (Barela et al., 2006; Harrison et al., 1992; Masumoto et al., 2004; Miyoshi et al., 2004; Nakazawa et al., 1994), but rarely used all together: Spatial–temporal gait parameters; ground reaction force components; joint angles, and muscle activation patterns. Second, based on our previous results (Barela et al., 2006), we conducted a comparison between elderly individuals and younger adults walking in water.

2. Methods

2.1. Participants and procedures

Ten elderly individuals (6 males, 4 females) volunteered for this study. All of them were in community living situations, free from known musculoskeletal, neurological, cardiac, or pulmonary diagnosis, and had normal or corrected to normal vision at the time of testing. At this time, all participants were enrolled for at least one year in a physical activity program for the elderly at our institution. This program comprised twice-weekly low intensity activities. Their mean (± 1 Standard Deviation, SD) age, height, and mass were 70 ± 6 years, 160 ± 9 cm, and 65 ± 13 kg, respectively. All participants signed an informed consent agreement that had been approved by the local ethics committee of the University of São Paulo. The data from 10 healthy adults (mean age, height, and mass (± 1 SD): 29 ± 6 years, 1.65 ± 0.10 m, and 63 ± 10 kg, respectively) reported in a previous investigation (Barela et al., 2006) were used to compare to the elderly individuals.

The participants walked on 10 occasions in bare feet at self-selected, comfortable speeds on both a walkway in the laboratory, referred to as land condition, and on a walkway in the swimming pool, referred to as water condition. The length of both walkways was approximately 6 m, and in both conditions, the participants were instructed to look straight ahead and to walk at a speed with which they felt comfortable. In addition, in the water condition, the participants were instructed to keep their arms out of the water, with elbows flexed. For the water condition, they all walked with the water at the Xiphoid process (at the chest region) level (Fig. 1). The experimental setup was designed to perform a bi-dimensional gait analysis of one stride (gait cycle) of the participants' walking and consisted of the event between two successive right foot contacts with the ground per trial.

The experimental setup and the procedures used to collect and analyze the data were the same as those reported elsewhere (Barela et al., 2006). The participants' movement in the sagittal plane was recorded at 60 Hz with digital cameras (GRDVL-9800U, JVC), in order to obtain kinematic measurements. Passive reflective markers were placed on each participant's right side at the following locations: head of the fifth metatarsal, lateral malleolus, lateral epicondyle of the femur, greater trochanter, and 5 cm below the lateral projection of the Xiphoid process. The positions of markers in the video were later digitized, using APAS software (Ariel Dynamics, Inc.).

During the task, surface electromyographic (EMG) data were collected from tibialis anterior (TA), gastrocnemius medialis (GM), vastus lateralis (VL), long and short head of the biceps femoris (BFLH and BFSH, respectively), tensor fasciae latae (TFL), rectus-abdominis (RA), and erector spinae (ES) at the first lumbar vertebrae (L1 level) muscles of the right side. We used passive disposable dual Ag/AgCl snap electrodes with a 1 cm

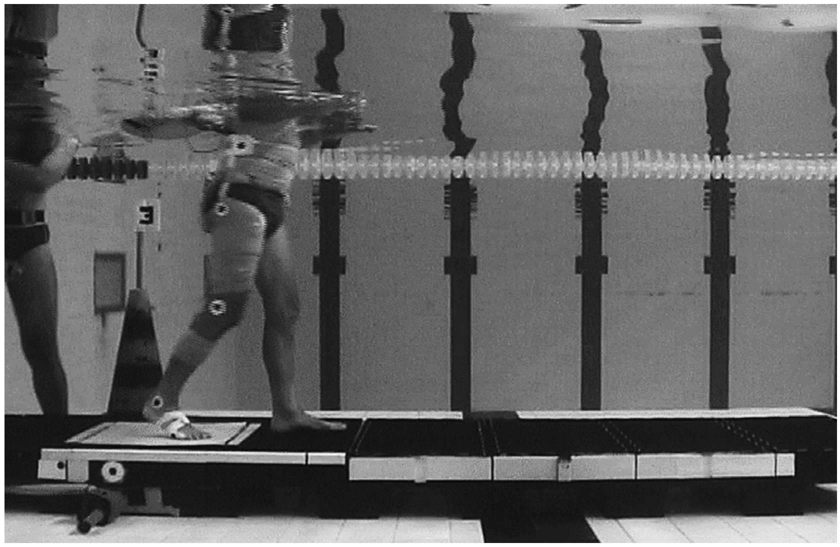

Fig. 1. Partial view of an elderly individual walking with the water at the Xiphoid process level.

diameter of each circular conductive area and a 2 cm center-to-center spacing (dual electrode #272, Noraxon). Extreme care was necessary to insulate electrodes for the water condition trials. For these we used a 10×12 cm^2 transparent dressing (Tegaderm, 3M), and placed it over the electrode and the cable connection near the electrodes. The body segments adjacent to the electrode areas and cables were lightly bandaged with elastic bands to avoid cable movement. The EMG signals were registered with an 8-channel telemetric EMG system (Telemyo 900, Noraxon), which had a gain of 1000 times, bandwidth (−3 dB) of 10–500 Hz, and common mode rejection ratio >85 dB.

The vertical and anterior–posterior components of the ground reaction force (GRF) were recorded using two different force plates embedded in each of the walkways (AMTI OR6-2000 and AMTI waterproof OR6-WP-1000). GRF and EMG signals were sampled at 1000 Hz using the APAS software and these signals were synchronized with the video images using a homemade trigger. Prior to data acquisition, the participants performed practice trials in each condition until they felt comfortable with the experimental situation. They were not aware of the force plate's position because it was under a thin rubber rug in both conditions.

2.2. Data analysis

We analyzed one gait stride per occasion of each participant for a total of at least eight strides in each condition for each participant. The data analyses were performed using Matlab software (version 6.5, Mathworks, Inc.). The reconstruction of the real coordinates of the kinematic data was performed using the direct linear transformation (DLT) procedure in the land condition, and a localized two-dimensional DLT procedure in the water condition to account for refraction in the underwater video. All the data were digitally filtered using a fourth order and zero-lag Butterworth filter. Kinematics data were low-pass filtered at 8 Hz for the trunk and hip markers and at 10 Hz for the knee, ankle, and foot markers. GRF data were low-pass filtered at 50 Hz. The EMG data were band-pass filtered at 20–400 Hz, and subsequently full-wave rectified and low-pass filtered at 5 Hz to obtain the linear envelope. These cut-off frequencies were based on the analysis of the signal and noise contents present in the data (Winter, 2005). Kinematic data were referenced by the participants' neutral angles as measured during quiet standing trials in the land condition. GRF data were normalized by the participants' own body weight in each condition, measured during the quiet standing trials. For the water condition, the measured vertical GRF during quiet standing in water is a result of the body weight minus buoyancy, which will be referred to as 'apparent body weight.' The EMG data of each muscle were normalized by the mean value of the EMG data during the stride cycle in order to obtain the average pattern across participants.

All the stride cycles were normalized in time from 0% to 100%, in steps of 1%. These cycles were then averaged to obtain the mean cycle for each participant and the same process was repeated to obtain the mean cycle among participants. Based on previous investigations (Barela et al., 2006; Harrison et al., 1992; Masumoto et al., 2004; Miyoshi et al., 2004; Nakazawa et al., 1994) about walking on land and in water to quantify the kinematic, kinetic, and EMG data, a number of variables were selected and are described next.

From the kinematics data, we measured the following variables: stride length and duration, speed, support period duration, ankle, knee, and hip joints' range of motion (ROM) during each stride, and ankle, knee, and hip joint angles at both initial contact and initial swing, that were defined as instants when the foot contacted the force plate and lost contact from the force plate, respectively. From the GRF vertical component, we investigated the magnitudes of the two peaks and the impact force, calculated as the slope of a linear fit by least squares of the first 100 ms of the vertical GRF versus time curve. From the anterior–posterior component, the impulse was calculated as the area under the force versus time curve during the support period.

For all variables, data from at least eight occasions under each condition were averaged for each participant. Five multivariate analyses of variance (MANOVA) were employed, having as factors the two groups (elderly individuals and younger adults) and the two conditions (land and water), the last factor considered as repeated-measure. The analyses comprised dependent variables; stride length, duration, speed, and stance period duration for the first MANOVA; ankle, knee, and hip joint ROM for the second

MANOVA; ankle, knee, and hip joint angles at initial contact and at initial swing for the third and fourth MANOVAs, respectively; and first peak, second peak, and impact of the GRF for the fifth MANOVA. A univariate analysis of variance (ANOVA) was employed for the dependent variable impulse. When applicable, Tukey *post hoc* tests were employed. An alpha level of 0.05 was used for all statistical tests, which were performed using SPSS software (version 10.0, SPSS Inc.).

3. Results

The elderly individuals were able to walk at self-selected comfortable speeds on land and in water at the Xiphoid process level. Following are the results of Spatial–temporal gait parameters, joint angles, GRF components, and muscle activation patterns for the elderly individuals and younger adults. Since the results for the younger adults have been presented previously, only the figures for the elderly group will be included here. In order to compare stride duration in both conditions, additional horizontal axes were also added in each figure (upper portion) to indicate the mean non-normalized values of stride duration in each condition. In Table 1 it is shown the mean (±1 SD) values of all the investigated variables and the statistical results of the comparisons.

3.1. Spatial–temporal gait parameters

There were no differences between elderly individuals and younger adults for stride duration when they walked

Table 1
Mean (± SD) values for elderly individuals and younger adults (Barela et al., 2006) during the stride cycle on land and in water conditions

Spatial–temporal	Land		Water		*F* ratio *p* value		
	Mean ± SD		Mean ± SD		Group	Condition	Interaction
	Elderly	Adults	Elderly	Adults			
Duration (s)	0.99 ± 0.10	0.95 ± 0.01	2.02 ± 0.28	2.41 ± 0.25	5.7	609	17.7
					0.028	*0.000*	*0.001*
Length (m)	1.17 ± 0.09	1.32 ± 0.13	0.97 ± 0.16	1.19 ± 0.15	17.3	16.3	0.7
					0.001	*0.001*	0.404
Speed (m/s)	1.20 ± 0.16	1.39 ± 0.14	0.49 ± 0.06	0.50 ± 0.07	7.4	476	6.3
					0.014	*0.000*	*0.022*
Stance period duration (%)	63.4 ± 1.5	61.9 ± 1.9	63.4 ± 3.5	60.4 ± 2.2	6.8	1.3	1.3
					0.018	0.260	0.060
Joint angle ROM							
Ankle (°)	26.2 ± 4.7	32.9 ± 4.1	25.9 ± 4.7	32 ± 12	7.2	0.07	0.01
					0.015	0.800	0.947
Knee (°)	59.9 ± 5.5	61.4 ± 4.6	52.6 ± 5.8	56.4 ± 8.7	1.9	*8.7*	0.3
					0.182	*0.009*	0.602
Hip (°)	30.1 ± 5.6	29.3 ± 7.0	31.4 ± 4.1	29.6 ± 3.5	0.4	0.4	0.2
					0.514	0.529	0.687
Joint angle at IC							
Ankle (°)	5.3 ± 2.2	3.8 ± 5.1	−1.6 ± 4.7	−2.8 ± 5.1	0.6	42	0.01
					0.437	*0.000*	0.922
Knee (°)	4.4 ± 3.9	7.0 ± 5.0	16.0 ± 5.6	8.1 ± 8.8	1.3	20	14
					0.270	*0.000*	*0.002*
Hip (°)	18.2 ± 3.9	18.2 ± 5.7	22.1 ± 3.9	18.5 ± 4.4	1.3	2.8	2.2
					0.265	0.112	0.160
Joint angle at IS							
Ankle (°)	−5.4 ± 4.8	−15.34 ± 5.6	−8.3 ± 4.2	−19 ± 11	15	4	0.5
					0.001	0.059	0.820
Knee (°)	40.8 ± 5.6	42.4 ± 8.4	42.5 ± 3.6	35.3 ± 5.7	1.7	2.8	7.3
					0.205	0.112	*0.015*
Hip (°)	−1.5 ± 7.1	−1.0 ± 3.0	8.2 ± 4.7	1.9 ± 3.9	2.7	22	6.5
					0.120	*0.000*	*0.020*
GRF							
1st peak (BW)	1.12 ± 0.10	1.27 ± 0.13	0.96 ± 0.05	1.03 ± 0.08	11.7	48	1.8
					0.003	*0.000*	0.193
2nd peak (BW)	1.12 ± 0.06	1.20 ± 0.14	1.01 ± 0.05	1.01 ± 0.10	1.5	*35*	1.9
					0.230	*0.000*	0.183
Impact (BW/s)	8.1 ± 1.8	10.3 ± 1.9	3.7 ± 1.6	5.4 ± 1.7	10	89	0.3
					0.005	*0.000*	0.622
Impulse (BW.s)	0.00 ± 0.00	0.00 ± 0.01	0.14 ± 0.04	0.20 ± 0.06	6.7	*218*	5.9
					0.019	*0.000*	*0.025*

ROM = range of motion; IC = initial contact; IS = initial swing; GRF = ground reaction force; BW = body weight. *N* = 10 for each group.

on land, and the elderly group presented significantly shorter stride duration than younger adults in water. Also, elderly individuals walked significantly slower than younger adults on land, and both groups walked at the same speed in water (see Table 1).

3.2. Joint angles

Fig. 2 represents the mean (±1 SD) stride cycle of ankle, knee, and hip joint angle patterns of the elderly individuals walking on land and in water. Qualitatively all the joints seemed to have roughly similar patterns in both conditions. The ankle was more plantar flexed during the stance period (approximately the first 60% of the stride cycle), and at the end of the swing period (approximately the remaining 40% of the stride cycle), in water than on land (Fig. 2, upper panel). In water, instead of touching the ground with the heel at the point of ground contact as on land, the foot was approximately parallel to the ground. The knee joint was more flexed at the beginning and at the end of the gait stride in water than on land (Fig. 2, middle panel). In the remaining stages of the stride cycle, the knee joint pattern was similar in both conditions. Finally, during the entire stride cycle the hip joint pattern seemed to be more flexed in water than on land (Fig. 2, bottom panel).

Regarding the joint ROM, elderly individuals presented significantly smaller ankle ROM than adults and both groups presented significantly smaller knee ROM in water than on land (see Table 1).

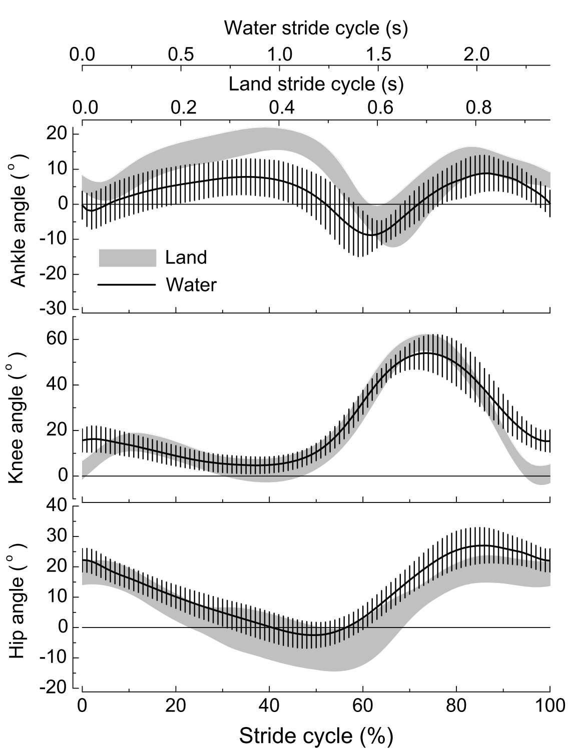

Fig. 2. Mean (±1 SD) stride cycle of joint angles for the participants walking on land and in water. Positive values denote ankle dorsiflexion, knee and hip flexion; negative values denote ankle plantar flexion, knee and hip extension ($N = 10$).

Regarding the angle joints at the initial contact event, both groups presented ankle plantar flexion on land and ankle dorsiflexion in water. Elderly individuals and younger adults presented the same for knee joint at the initial contact phase when they walked on land and elderly individuals presented significantly more flexion for this joint than younger adults in water. On the other hand, younger adults presented the same for knee flexion in both conditions and elderly individuals presented significantly more flexion in water than on land at the initial contact phase (see Table 1).

Finally, regarding the angles of the joints at the initial swing event, the elderly individuals presented significantly lesser ankle dorsiflexion than adults. Elderly individuals did not present any difference in the knee angle between land and water conditions while younger adults presented significantly more knee flexion on land than in water at the initial swing. On the other hand, both groups presented the same values for hip joint position on land and elderly individuals presented significantly more hip flexion than younger adults in water at the initial swing (see Table 1).

3.3. Ground reaction force components

Fig. 3 represents the mean (±1 SD) stride cycle of vertical and anterior–posterior GRF components for elderly

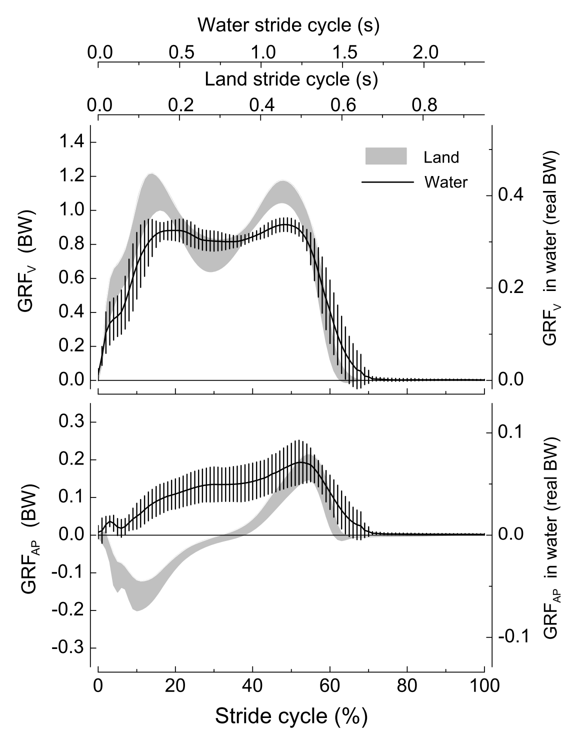

Fig. 3. Mean (±1 SD) stride cycle of the vertical (GRF_V) and anterior–posterior (GRF_{AP}) ground reaction forces for the participants walking on land and in water. The left axis indicates the forces measured in units of body weight (BW, apparent body weight for the water condition). The right axis indicates the forces in water measured in units of real body weight ($N = 10$).

individuals walking on land and in water. The magnitudes of the data were normalized by the body weights of the respective participants (apparent body weight for water condition). The data from water condition were also normalized by the body weight and are indicated in Fig. 3 by the right vertical axis.

From the vertical GRF component pattern (Fig. 3, top panel), one can observe a typical pattern of two well-defined peaks and a valley when participants walked on land, and a flatter curve with almost no distinction between the two peaks and the valley when they walked in water. The anterior–posterior GRF component, on the other hand, presented a different pattern between conditions and contrary to the typical anterior–posterior GRF pattern observed while walking on land (Fig. 3, bottom panel), where one negative phase is followed by one positive phase, each with about the same areas, an always-positive curve was observed in water.

For the GRF components, the first peak of the vertical GRF was significantly lower for the elderly individuals than for the adults in both conditions and it was lower in water than on land for both groups. On the other hand, the second peak of the vertical GRF was significantly lower in water than on land for both groups. In terms of impact force, elderly individuals presented significantly lower impact than adults in both conditions and both groups presented significantly lower impact in water than on land. Finally, regarding the horizontal impulse, it was significantly lower on land than in water and while there were no group differences on land, elderly individuals presented significantly lower impulse than younger adults in water (see Table 1).

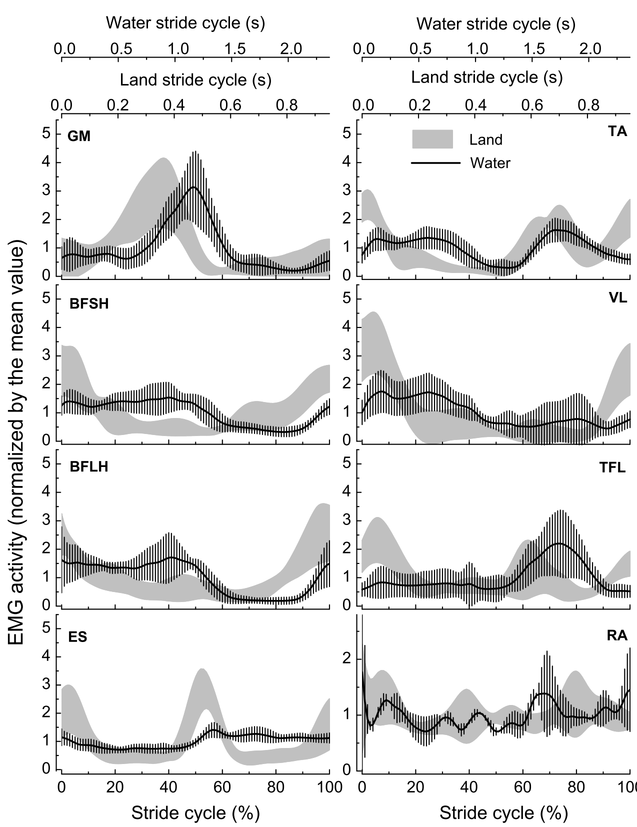

Fig. 4. Mean (±1 SD) stride cycle electromyographic (EMG) activity normalized by its respective mean value of the muscles for the participants walking on land and in water. GM = gastrocnemius medialis, TA = tibialis anterior, BFSH = short head of the biceps femoris, VL = vastus lateralis, BFLH = long head of the biceps femoris, TFL = tensor fasciae latae, ES = erector spinae at L1 level, RA = rectus-abdominis. Note: for the land condition, $N = 7$ for RA; for the water condition, $N = 8$ for EE and $N = 2$ for RA; and $N = 10$ for the remaining muscles in both conditions.

3.4. Muscle activation pattern

Fig. 4 represents the mean (±1 SD) stride cycle of the surface electromyographic (EMG) activation patterns from the eight selected muscles of the elderly individuals walking in both conditions. The EMG activation patterns were different for most of the investigated muscles between water and land. For the water condition, the GM muscle was the only one that presented a very similar pattern to the land condition, but the peak activity in water was delayed at about 10% on land. While the TFL muscle seemed to be more activated in water during the swing period, the BFSH, VL, and BFLH seemed to be more activated during the stance period. On the other hand, the TA muscle was activated in most stages of both periods. The ES muscle was more activated at the end of the stance period and remained during the swing period. The RA muscle seemed to be more activated at points of foot contact (extremes of the stride cycle). However, it was only possible to acquire data for this muscle from two participants in a few trials for the water condition.

4. Discussion

The main differences found in this study were that while walking in water at self-selected speed elderly individuals walked significantly more slowly, with a shorter stride length, reduced vertical ground reaction force (GRF), increased horizontal impulse, reduced knee range of motion (ROM), and increased ankle extension and knee flexion at the stride's initial contact than when walking on land. These findings can be attributed primarily to buoyancy and drag forces and the way in which elderly individuals adapted to walking in water. Generally, the findings for the elderly individuals are in agreement with those previously found for younger adults walking in water (Barela et al., 2006; Harrison et al., 1992; Masumoto et al., 2004; Miyoshi et al., 2004).

4.1. Elderly individuals walking on land and in water

Walking in water at self-selected comfortable speed did not affect the temporal organization of the gait stride compared to walking on land; that is, the relative durations of the stance and swing periods were not altered. It is known that a decrease in speed increases the duration of the stance period during walking on land (Kirtley et al., 1985). In the present study, we observed that the walking speed in water was about 36% of the walking speed on land, but surprisingly no effect on the duration of the stance period (this finding has also been observed for younger adults (Barela et al., 2006)). It is also known that the stance period duration decreases as the percentage of bodyweight unloading increases during treadmill walking (Therlkeld et al., 2003). In the present study, the buoyant force produced the bodyweight unloading that resulted in an approximately 63% reduction of the apparent body weight in water. However, no effect on the duration of the stance period was observed. In this way, it is reasonable to think that while the stance period duration would increase in water due to the reduction in speed, the same stance period duration would decrease in water due to the increase in bodyweight unloading. Consequently, it is possible that both effects cancelled each other and the temporal organization of the gait stride was about the same in both conditions.

As was previously found for younger adults (Barela et al., 2006; Nakazawa et al., 1994), the observed lower peaks of the vertical GRF and the lower impact force value during walking in water support the notion that this activity generates less impact on the locomotor system of elderly individuals. The anterior–posterior GRF presented very different patterns for walking on land and in water conditions. The observation of an always-positive curve for the anterior–posterior GRF while walking in water is supported by other studies (Barela et al., 2006; Miyoshi et al., 2004). To maintain a constant speed when walking in water, it is necessary to generate an impulse to overcome the drag force in the horizontal direction exerted on the body by the water (Barela et al., 2006). This factor also led to changes in the pattern of kinematics of the subjects while walking in water. The joint angles presented major differences between walking on land and in water at both the initial contact (knee) and the initial swing events (ankle, knee, and hip).

The EMG activation patterns for most selected muscles differed between walking on land and in water. There are two main biomechanical differences between walking on land and walking in water. On the one hand, the apparent body weight is reduced (due to the buoyant force) and there is less need to activate the muscles to support the body against gravity. On the other hand, there is more need to keep muscles activated in water to overcome the drag force as the body moves forward. In this way, how muscles are activated will depend on how much the apparent body weight is reduced and on how fast one walks in water.

Peaks in the EMG profiles at self-selected comfortable walking speed were generally, with the exception of the gastrocnemius medialis muscle, less evident in water than on land and this observation is in accordance with data from previous investigations for younger adults (Barela et al., 2006). These findings suggest that the expected increase in muscle activation to overcome the water resistance was, in fact, lower than the expected decrease in muscle activation due to the reduction of the apparent body weight. Certainly, one would observe an increase in muscle activation if the individuals had walked faster in water or with less reduction of the apparent body weight (shallower water). In particular, the gastrocnemius medialis was the only muscle which presented a well-defined pattern, similar to that observed for walking on land, but its peak was later in the stance period. It seems that even with the reduction of the apparent body weight, the increased resistance to movement in water required that the ankle plantarflexor muscles were relatively more recruited than the other investigated muscles to propel the body forward. This supposition is consistent with the observation of the always-positive horizontal force in the stance period.

4.2. Comparison of elderly individuals and younger adults walking in water

In order to better understand the characteristics of elderly individuals walking in water, we compared this age group with our previously published results for younger adults (Barela et al., 2006). The age-related changes during walking on land are already established and are beyond the scope of the this study (for review, see Prince et al. (1997)). In the present study, we have restricted the presentation of the discussion to the alterations in the water condition only.

Note that both groups presented the same self-selected comfortable speed walking in water. This fact allows us to conduct a direct comparison of the analyzed gait variables. In this way, we verified that elderly individuals presented significantly shorter stride length, lower stride duration, and higher stance period duration than younger adults in water. There was no group difference for ankle joint ROM. However, at the initial contact, the elderly individuals flexed their knee significantly more than the younger adults and, at the initial swing, they dorsiflexed their ankle significantly less and flexed their knee and hip significantly more than younger adults. There were other minor differences in some of the variables resulting from the GRF components, and the EMG patterns were similar for most muscles in both groups.

Elderly individuals did not show many more differences between walking on land or in water than younger adults. Indeed, most of the verifiable differences for walking on land between both groups were also present in water walking. However, the elderly individuals adopted a slightly different strategy to walking in water from that of younger adults. Since elderly individuals may present a decrease in ankle plantar flexor power while walking on land (Prince et al., 1997) and the drag force in water decreases the ease of mobility, we would expect that the walking speed of the elderly individuals would also decrease in water. However, this was not the case and the reason for this is not clear. One possible explanation is that due to the reduction of the apparent body weight and the self-selected slow speed in water, less ankle extension power was in fact necessary in the water environment. Finally, what each group judged to be a comfortable walking speed might have varied across conditions.

It has been suggested that elderly individuals are more cautious than younger adults while walking on land (Kerrigan et al., 1998), but it is unknown whether the same is true for walking in water. It is reasonable to assume that there is less need for elderly individuals to take care while walking in water, since falling is not an issue. The fact that while walking in water the ankle joint ROM did not decrease in the elderly individuals compared to the younger adults might be beneficial, particularly for rehabilitation of the ankle joint function in the elderly population. Since it is expected that higher propulsive forces are required in order to walk faster in water, both ankle joint ROM and power could be trained accordingly if the elderly individuals were requested to walk at varying speeds.

Our study has some limitations that are important to mention. Given that we studied only 10 subjects per group, such small sample size may have compromised some of the statistical results observed. In addition, some specific characteristics of walking were not captured by our bi-dimensional analysis.

In conclusion, the present findings indicate that for elderly individuals there are a number of differences between walking on land and in water. When combined with previous results (Barela et al., 2006), the study revealed that elderly individuals adopted strategies different from those of younger adults to walking in water. This fact should be considered when a rehabilitation or fitness program is prescribed to these populations.

Future research should estimate the joint moments during walking in water, taking into account the buoyancy and the drag forces, to better understand the mechanical load and the neuromuscular demand in water. It is also necessary to investigate subjects with locomotor impairments who perform rehabilitation in the shallow water environment to understand how they move in water and how exactly they may profit from this environment.

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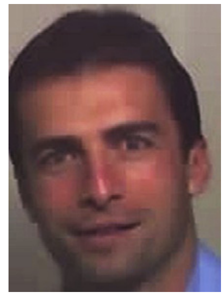

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