An Electromyographic Study of Human Gait both in Water and on Dry Ground

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Abstract  The purpose of the present study was to define the degree of muscular activation while walking in water in order to aid rehabilitation therapists in their choice of exercises for daily clinical practice in aquatherapy. This study compares the electromyographic (EMG) activity of the rectus femoris, the soleus of the right lower limb and the contra-lateral lumbar erector spinae, during gait in water and on dry ground. The study was carried out on a group of seven healthy female subjects without past rachidian pathology. EMG recordings in water were taken with immersion to the umbilicus at “comfortable” speed. A total of five recordings were made at this speed, in water and on dry ground, with a one-minute rest between recordings. Integrated EMG results, averaged on eight gait cycles, show, for all the subjects, more erector spinae activity in water than on the ground (p<0.01). Soleus activity is greater during gait on dry ground for the whole group (p<0.01). For four subjects, the electromyographic (EMG) activity of the rectus femoris over the entire cycle is greater than that exhibited on dry ground.

In the two experimental situations, no differences have been found either on amplitudinal peaks or on the shape of the patterns. The speed and gait cycle length are reduced in water (60% and 25%). Walking in water at an umbilical level increases the activity of the erector spinae and activates the rectus femoris to levels near to or higher than walking on dry ground.


Keywords: aquatherapy, electromyography, gait in water, gait on dry ground, retraining

Introduction

Despite the quantity of research existing on walking, this subject continues to interest many researchers in the fields of bioenergetics and biomechanics. Many applications in functional rehabilitation are based on this research, where walking is used as a means of retraining, according to well-codified processes. For example, walking has been proved beneficial in cases of persons suffering from respiratory insufficiency, peripheral arterial disease, and heart disorders.

The water environment has long been used for rehabilitation for its biophysical specificities (Edlich et al., 1987). The effects of aquatherapy have been studied in orthopedics (Raboudin et al., 1987), traumatology, rheumatology (Drouot et al., 1992), neurology (Morris, 1994), pediatrics (Pialoux et al., 1987), and many other areas (Kemoun et al., 1998).

Nonetheless there are relatively few appearances in the literature of studies concerning the way people walk in water. Indeed, Zamparo and Pagliaro’s study (1998) of the bioenergetics of walking in subjects presenting a neurological pathology is worthy of mention. However, it is also important for rehabilitation therapists to know the degree of muscular activation during walking in water, in order to better choose which exercises to employ in their daily practice of aquatherapy. There are few studies on this topic, and those that exist are somewhat contradictory. Dietz et Duysens (2000) found that immersion reduces the activity of the extensor muscles of the lower limbs while Nilsson et al. (1985) showed that resistance of the water to forward movement increases such activity. We decided to measure by surface electromyography the alterations in muscular activity during walking resulting from a change in environment, from dry ground to water.

Materials and Methods

Population studied

The study was carried out on a group of seven young
women volunteers (age: 22.7±2.5 years, height: 163±4 cm, weight: 56.4±4.5 kg). Informed consent was obtained for this experiment. The subjects had no history of spine pathology or any other musculoskeletal disorders. They did not have any contra-indications for immersion.

Materials

The EMG signals were amplified, band-pass filtered (20–500 Hz), digitized, and stored by a data acquisition system (Pro-Comp+ Thought Technology LTD distributed by the Saint Cloud International Company Parc Polaris 85110 Chantonnay France) at a sample frequency of 100 Hz. The integrated EMG (EMGi) analysis was made using the software biograph. The EMG data were exported to Excel software to analyze the power of the signal. The device includes a lightweight box (200 g, 81 mm×122 mm×30 mm) with a total of six EMG recording tracks. The box is linked to the serial port of an independent portable computer by means of a flexible, six-meter, fiberoptic cable.

Specifications of the EMG recording:

- Input impedance: 2 mega Ohms
- Resolution: 0.2 mV
- Accuracy: +/− 5%

The surface of the electrodes was approximately one square centimeter. Made of Ag–AgCl and measuring about 20 mm from center to center, the electrodes were placed on adhesive discs 55 mm in diameter and connected to the box by means of jacks and flexible 1.15 m cables. The signal was preamplified at the source to suppress external noise. In order to prevent the immersion of the box and to allow the person recording to maintain a safe distance from the patient while the device was functioning, we added a 2.60 m cable to the three tracks that were used.

Sensor characteristics:

- Size: 36 mm×37 mm×12 mm
- Weight: 25 g
- Input impedance: 1 Mega Ohms
- Accuracy: +/− 5% +/− 0.3 micro-Volts

Sensitivity: <0.1 micro Volts

The time between two points 5 meters apart was measured on dry ground and in the water, at natural speed, after a training period of walking in the pool to set a comfortable speed.

Protocol

Muscles chosen for assessment

Activity on the right soleus and rectus femoris and on the contralateral erector spinae was recorded. These muscles are typical target muscles in walking assessment because of their function and their accessibility for surface EMG. The choice of the contralateral erector spinae was made because of their crossed activation during walking (Thorstensson et al., 1982).

Placement of the electrodes

After the skin was shaved, disinfected, and de-greased with ether, the electrodes were placed on each subject, respectively on the left lumbar erector spinae, the right rectus femoris and the right soleus (Fig. 1). A thin layer of conductive gel was applied to the receiving part of the electrode. At each placement, the muscular activity was recorded in order to verify the correct placement of the electrodes as described below for each muscle.

Our bone reference mark was a straight line drawn along the top of the iliac crests at the level of the vertebral disc, L4 L5. According to the morphology of the subject, the electrodes were placed 2 or 3 centimeters from the line of the spinous process, on the fleshiest part of the muscle, lengthwise in relation to the muscular fibers. In order to highlight these rachis extensor muscles, and thus verify the placement of the electrodes, we asked the standing subject to lean forward slowly and then to stand up straight again.

Our bone reference mark was the line from the anterior superior iliac spine and the base of the patella. The electrodes were placed halfway between these two points. When the subject, lying flat, extended her leg against resistance at the knee, the rectus femoris stood out clearly, thus permitting us to verify the placement.

Fig. 1  Illustration of electrode placement.
In order to make the soleus appear clearly, the subject, standing on one foot with the knee bent, stood on tiptoe, again permitting us to verify placement. After locating the muscle, the electrodes were placed on the medial side of the leg, under the gastrocnemius medialis and halfway from the head of the fibula and lateral malleolus. Accuracy of electrode placement for the erector spinae, rectus femoris and soleus was determined by observation of the EMG signals while performing manual testing.

**EMG recording out of the water**

First of all, the subject was asked to walk barefoot for a distance of ten meters along the edge of the pool. Our visual marking system indicated each time the right heel struck the ground, using the space bar of a computer to mark the beginning of a new cycle. A preliminary test was made at spontaneous speed to familiarize the subject with the surroundings and with the experimental device. Then, the subject was asked to walk at a "comfortable" speed, holding her hands behind her back so that she would not use her arms while walking. A total of five recordings were made with a one-minute rest between recordings.

**EMG recording in the water**

To protect the electrodes, sensors, and cables, we used Opsite®, a transparent, waterproof, adhesive film (10 cm × 1 m). (Smith and Nephew Medical Ltd, Hull HU3 2BN England).

Recordings in the water were performed in the smaller of two public swimming pools. The pool was a square with sides of 15 meters, with a gradual increase in depth from 0.7 m to 1 m. The shape of the pool allowed us to present each subject with identical conditions immersed to the umbilicus. The umbilical level for immersion reduces by half the weight and induces fewer alterations of the posture and less turbulence than a deeper immersion.

The instructions given to the subject were the same as those given for the previous recordings. One test was performed in order to familiarize the subject with the environmental changes. As with the earlier recordings, five tests were carried out at a comfortable speed, with a one-minute rest between recordings.

**Data analysis of the EMG recordings**

The first cycles are not representative of the activity (Yang et al., 1985). That is why we eliminated the first three cycles of walking from each test to study the muscle activity. For each subject and each muscle, the EMG (mV/s) of the eight representative gait cycles among the five recordings, in the water as well as on dry ground, were divided by the time required for each of the gait cycles. Then the EMG were averaged in order to yield EMG (gait cycle). The power of the signal (relation energy/time) and the activity peaks were also analyzed. The ratio between the EMG activity on dry ground (EMG) and in the water (EMG in water) was calculated.

**Results**

The "comfortable" velocities registered for all subjects were 1.81 m/s ± 0.03 on dry ground and 0.75 m/s ± 0.21 in the water.

**EMG recordings over several gait cycles, in the water and on dry ground**

Figures 2 and 3 provide sample EMG recordings of a subject walking barefoot, immersed in water up to the umbilicus (Fig. 2) and on dry ground (Fig. 3), at a comfortable speed. The vertical lines mark the moment in each cycle when the right heel hits the ground. The wavy lines show the simultaneous EMG recordings of the erector spinae, the rectus femoris, and the soleus over eight continuous cycles in the water (Fig. 2) and six continuous cycles on dry ground (Fig. 3). The two situations produced identical patterns by the beginning of the fourth gait cycle.

The erector spinae present two bursts of activity during a
single cycle on dry ground: the first takes place when the right heel hits the ground and the second about halfway through the cycle. In the water, however, these muscles produce more continuous activity, with amplitudinal peaks similar to those produced on dry ground.

The rectus femoris also shows two bursts of activity during the cycle on dry ground. The first burst precedes that of the erector spinae at the instant when the right heel makes contact; the second arrives in the second phase of the cycle. In the water, on the other hand, the most intense activity takes place just before the heel hits the ground, with the second burst coming when the foot touches the ground.

The soleus is active in the first phase of the cycle in both situations; the first burst of activity comes when the heel touches the ground and is followed by a second one of greater amplitude. The overall pattern of the lines indicates that the gait cycle is longer in the water.

**Average muscular activity measured over 8 gait cycles**

*Erector spinae*

On average, the EMG recordings of the erector spinae show similar patterns, whether in the water or on dry ground (Fig. 4). In both conditions, there is activity before and after heel contact, as well as midway through the gait cycle. In the water, however, the activity recorded is continuous.

**Rectus femoris**

Both in the water and on dry ground, the rectus femoris produces a first burst of activity at the beginning of the gait cycle (Fig. 5). A second burst of activity peaks halfway through the gait cycle. The first burst is greater on dry ground; however, during the greater part of the second phase of the gait cycle, the rectus femoris produces greater activity in the water than on dry ground.

**Soleus**

As Fig. 6 shows, the pattern of the EMG recordings for the soleus is exactly the same in the water as on dry ground. It shows double activity in the first part of the gait cycle. The soleus is inactive during the swing phase. There appears to be no discernable difference in the patterns recorded for this muscle, whether in the water or on dry ground.

**Integrated EMG, signal power (relation energy/time) and amplitudinal peaks**

Table 1 recapitulates the statistical means of the integrated EMG, the signal power, and the amplitudinal peaks, as recorded over 8 cycles for each subject.

The erector spinae and the soleus muscles exhibited significantly different levels of activity depending on the environment in which the activity was recorded. The integrated EMG and the signal power were greater in the water for the erector spinae (EMGw/EMGd = 2.05), but on dry ground for the soleus (EMGd/EMGw = 1.78). In addition, though there appeared to be no significant difference in terms of the entire group, the values of the integrated EMG...
and the signal power for the rectus femoris were higher in the water for four of the subjects (EMGi water/EMGi ground = 1.25). No significant differences in amplitudinal peak were found in the three muscular groups tested.

Discussion

Our purpose was not to make a precise analysis of the activity of the erector spinae, rectus femoris, or soleus muscles when walking on dry land and in water, so a precise marking of events during the walking cycle was not carried out. Neither was the purpose here to consider the variations in cardiorespiratory parameters linked with the change in environment. This has been the subject of other studies, for example that of Hall et al. (1998). These authors showed that energy cost, cardiac frequency, and stride length are different on land and in water at the same given speed.

In order to stress the differences in activity of the muscles studied, the subjects walked on dry ground and in water. A comfortable speed was imposed in both environments. Indeed, it was considered advisable to base our study on spontaneous speeds such as those used in aquatherapy. The standard deviation calculated for the speeds in water is to be put in relation with the individual variations of speed for each subject linked with different motor strategies. An examination of individual EMGi values of the group of muscles studied shows different motor schemas from one subject to another. These differences are to be put in relation with different strategies of progressions according to the subject.

The main findings in this study show that the general form of the patterns of EMG activity on the erector spinae, rectus femoris, and soleus was maintained both on dry ground and in water.

In our study we observed a decrease in the electrical activity on the soleus, an identical EMG activity on the rectus femoris, and an increased activity on the erector spinae while walking in water compared with the same on dry ground. The data recorded during this study concerning the activity of the erector spinae in water or on dry ground concur with the results obtained by others studying "fast" walking (Murray et al., 1984). At low speeds, the erector spinae stabilize the trunk in the frontal plane, with alternate contractions of muscles to the right and left. They also stabilize in the sagittal plane during fast walking and running, as Waters and Morris (1972) observed. We also noted in our study that the general aspect of these patterns was similar for the two types of walking, even though the amplitude and duration of the electrical activity increased.
Indeed, when in water, the para-vertebral muscles were active during the entire cycle, indicating that the trunk was in a permanent state of flexion, contrary to the situation on dry ground. This flexed posture was observed in all the subjects as they moved forward. The first burst of activity coincided with the striking of the right heel. The second burst occurred halfway through the cycle, when the other heel struck the ground, and could be superimposed on the activity of the contralateral rectus femoris. These results concur with those of Thorstensson et al. (1982), which showed that the activity of the spinal ipsilateral is synchronous with the activity of the contralateral quadriceps. This consistency in the pattern form was also observed by Thorstensson et al. (1982) and by Yang and Winter (1985) in other situations, for example, when walking speed increased and when the gait changed from walking to running. Such consistency seems to indicate that the motor strategy of these muscles is not modified, regardless of the situation or environment.

Our study shows an increased activity in the rectus femoris, appearing just before the increased activity of the erector spinae, instants before the heel hit the ground. The rectus femoris exhibited greater activity during the second phase of the gait cycle in a water environment. This activity corresponds to the moment when the leg was extended and is explained by the need to increase muscular mobilization in order to overcome the resistance of the water. This increased activity was observed in all of the subjects during the second part of the walking cycle in water. The general form of the activity patterns was identical with that found in the literature, where the rectus femoris presents a first activity at 0% of the gait cycle, to stabilize the knee, during walking and, in an uneven manner, a second activity, weaker at the end of the first part of the cycle, at the start of the oscillation phase. This second burst of activity is of variable duration, depending on the subjects (Blanc, 1994). The rectus femoris is inactive at low speeds and its activity appears with an increase in speed (Prilutsky et al., 1998).

The comparison may be made with the results of Pöyhönen et al. (1999) for quadriceps activity. In a study comparing the maximal isometric force of the quadriceps in water and on dry ground, these authors showed a decrease in EMG activity and conservation of maximal isometric force, whereas we found no difference for the electric activity of the rectus femoris in the two environments. With the subject having to overcome the resistance of the water, the activity was greater. These results seem to concur.

The activity recorded in our study for the soleus muscle conforms to the activity described by Yang and Winter (1985) for a variety of gait rates. The patterns of our recordings, both in the water and on dry ground, are similar, despite the fact that the soleus exhibited less activity in the water for the entire group studied. The soleus is active during the first phase of the cycle, an activity that Plas et al. (1989) described as hampering the forward motion of the tibia by controlling the knee. These findings are confirmed by Murray et al. (1978) in a study of a patient deprived of the triceps surae; their results present an increase in the activity of the rectus femoris in order to stabilize the knee during walking. In the second phase of the cycle, the burst of activity corresponds to the lifting of the heel. Given that the soleus must overcome water resistance during immersion, one would expect the soleus activity to be greater. However, our results did not confirm this expectation, leading us to think that, in this particular situation at least, the soleus does not provide propulsion.

**Conclusion**

Walking in water at an umbilical level, the hands held behind the back, increases the activity of the erector spinae for all subjects, activates the rectus femoris to levels near to standard walking, and requires less of the soleus than normal walking on dry ground. These data should be taken into account by physiotherapists when designing a rehabilitation programme.

Other studies on the same topics, with various immersion levels and arms positions, will be useful, as they may change muscle activation.

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**References**


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