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Electromyographic Analysis of Walking in Water in Healthy Humans

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Abstract This study was designed to describe and clarify muscle activities which occur while walking in water. Surface electromyography (EMG) was used to evaluate muscle activities in six healthy subjects (mean age, 23.3±1.4 years) while they walked on a treadmill in water (with or without a water current) immersed to the level of the xiphoid process, and while they walked on a treadmill on dry land. The trials in water utilized the Flowmill which has a treadmill at the base of a water flume. Integrated EMG analysis was conducted for the quantification of muscle activities. In order to calculate the %MVC, the measurement of maximal voluntary contraction (MVC) of each muscle was made before the gait analysis, thus facilitating a comparison of muscle activities while walking in water with those on dry land. The %MVCs obtained from each of the tested muscles while walking in water, both with and without a water current, were all found to be lower than those obtained while walking on dry land at a level of heart rate response similar to that used when walking on dry land. Furthermore, the %MVCs while walking in water with a water current tended to be greater when compared to those while walking in water without a water current. In conclusion, the present study demonstrated that muscle activities while walking in water were significantly decreased when compared to muscle activities while walking on dry land, that muscle activities while walking in water tended to be greater with a water current than without, and that the magnitude of the muscle activity in water was relatively small in healthy humans. This information is important to design water-based exercise programs that can be safely applied for rehabilitative and recreational purposes. *J. Physiol Anthropol Appl Human Sci 23(4): 119–127, 2004* http://www.jstage.jst.go.jp/browse/jpa

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Introduction

Water exercise programs are growing in popularity (Cassady and Nielsen, 1992). Due to the unique physical properties of water (buoyancy, viscosity, warmth and hydrostatic pressure), aquatic physical therapy has been used effectively for a wide variety of patient populations (Kelly et al., 2000). In terms of compressive force, the heavier the individual, the greater the impact stress on the spine and the lower extremities, such as the hip, knee, ankle, and foot (Whitley and Schoene, 1987). However, the buoyant effect of water greatly reduces the weight-bearing stress on muscles and joints (Evans et al., 1978). This could allow for individuals who cannot tolerate mechanical stress on the spine, bones, joints, and connective tissue to perform exercise in an ideal environment. The effects of swimming on the performance and physiological function are well known (Di Prampero et al., 1974; Magel et al., 1975; McArdle et al., 1971; Pendergast et al., 1977; Ruoti et al., 1994), but swimming is probably not suitable for all individuals since the accurate training heart rates (HR) cannot be stipulated and because water immersion may have a detrimental effect on anginal symptoms, HR and blood pressure (Fernhall et al., 1992). Water calisthenics, however, is thought to be a suitable alternative to land exercise for individuals with arthritis, low back pain, and various orthopaedic dysfunctions for whom the weight-bearing components of the land exercise may be problematic (Cassady and Nielsen, 1992). Moreover, the aquatic aerobic training, such as running in water, has been shown to bring about an improvement in fitness on a pair with that produced by land-based training (Frangolias et al., 1996). D'Acquisto et al. (2001) were able to show that during a 40-minute shallow-water exercise session, participants could continuously maintain their ability to produce a cardiovascular response (66–78% of age-predicted HR_{max}) that met the intensity guidelines set by the American College of Sports Medicine (2000) as necessary if an improvement in cardiovascular and muscular fitness is to be achieved. Since the early mobilization has been shown to promote the healing process, walking is regularly included in rehabilitation programs for patients with various lower limb pathologies or injuries (Brukner and Kahn, 2001). Walking in water would seem to be an ideal form of exercise since it involves the total body, and it is both continuous and rhythmic (Whitley and Schoene, 1987). Walking is generally included in water rehabilitation programs since no special skills are required, and also because patients of all ages in whatever medical conditions can participate (Shimizu et al., 1998). Theoretically, the above evidence would seem to indicate that walking in water is a suitable component of rehabilitation and exercise programs. This may have important implications for the design and application of the rehabilitation and exercise programs that include walking in water.

Previous research has demonstrated the metabolic (McArdle et al., 1976; Town and Bradley, 1991; Young et al., 1995), thermoregulatory (Craig and Dvorak, 1968; McArdle et al., 1992; Shimizu et al., 1998), cardiorespiratory (Avellini et al., 1983; Christie et al., 1990; Hall et al., 1998; Shono et al., 2001), and psychological (Oda et al., 1999) responses to various forms of water-based exercise. Furthermore, several investigators have evaluated muscle activities while the subjects performed exercises in water. Clarys et al. (1985) measured the muscle activity of biceps brachii in water and in air during maximal voluntary contraction (MVC). Kelly et al. (2000) and Fujisawa et al. (1998) studied shoulder muscle activation during water and dry land exercises. The muscle activation during knee exercises in water has been estimated (Pöyhönen et al., 1999, 2001). Moreover, Kaneda et al. (2004) and Kato et al. (2002) reported that the leg muscle activation which occurred while subjects walked in water. However, no previous study has concurrently examined the muscle activities in both lower-extremity and trunk muscles under identical conditions, or the influence of water current on muscle activities, while the healthy subjects walk in water. If a water-based exercise program is to be safely applied for rehabilitative or recreational purposes, and if such a program is to be effective and appropriate for each individual, then a framework is required on which to base the planning of such exercise. Such a framework could be developed from clear scientific evidence of the fundamental neuromuscular function and the hydrodynamic properties of water in healthy individuals.

Many researchers have investigated physiological responses while walking in a swimming pool (Evans et al., 1978; Whitley and Schoene, 1987). It has been methodologically difficult, however, to fix the physical and physiological intensity of walking and jogging in a swimming pool (Fujishima and Shimizu, 2003). An underwater treadmill known as the Flowmill with treadmill at the base of a water flume is currently available. Its major advantage is that the speed of the underwater treadmill and the speed of the water current can be controlled independently. Exercise therefore can be carried out in an ideal environment, while the functional walking patterns and exercise intensity can be adjusted for each individual. Furthermore, Shono et al. (2001) stated that walking in the Flowmill was very similar to walking in a swimming pool. The present study was designed to utilize the Flowmill and thereby perform the trials in water, both with and without a water current, in an effort to ascertain the specific influences of the resistance of water current on muscle activities while walking in water.

A lack of information regarding muscle activity while walking in water, led us to design this study with a view to clarifying such muscle activities, and consequently, muscle activities while walking in water (with and without a water current) and those while walking on dry land were compared within each speed setting of the Flowmill.

Methods

Subjects

A total of six healthy males (age, 23.3 ± 1.4 yr; height, 174.9 ± 5.7 cm; weight, 73.1 ± 12.4 kg; and % fat, 20.9 ± 5.9%; mean±SD, respectively) agreed to participate in this study. Height was measured to the nearest 0.1 cm, and body weight was obtained with a standard clinical balance-beam with the subjects wearing swimsuits. The percentage of the fat was estimated using the impedance method (TBF-410, Toyo Physical, Japan). The subjects were all physically active and in excellent health. However, their fitness levels were not taken into consideration. All the subjects were free from acute or chronic cardiopulmonary and musculoskeletal diseases at the time of the study. The subjects were not participating in any regular exercise at the time of data collection. This study was approved by the Ethical Committee of the Department of Rehabilitation Medicine at Kyushu University Hospital and all subjects were informed about the procedures and potential risks and gave their written informed consent to participate in the study.

Electromyograms

Electromyograms (EMGs) of each muscle were taken using silver-silver chloride surface electrodes (Mini Ag/AgCl Skin Electrode, NT-511G, Nihon Kohden Co. Ltd., Japan) which were 8 mm in diameter, in order to evaluate the activities of the trunk muscles and lower extremity muscles in the subjects during the experimental session. To keep the inter-electrode resistance low ($<5\,k\Omega$), the sites for electrode placement were prepared by shaving the hair and gently abrading the skin using a skin preparation gel (Skinpure, YZ-0019, Nihon Kohden Co. Ltd., Japan), and then these sites were cleaned with alcohol pads to minimize skin resistance. EMG signals were captured from the following muscles on the right side: the gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), the long head of the biceps femoris (BF), tibialis anterior (TA), the lateral head of gastrocnemius (GA), rectus abdominis (ABD), and paraspinal muscles (PA) at the level of L4. A reference electrode was placed on the acromion. In order to minimize cross talk between muscle groups, surface electrodes were placed 2 cm apart over the middle point of the venter longitudinally along the muscle fibres. Accuracy of electrode placement was determined by manual muscle testing, while observing the EMG signals. These procedures were carried out by one particular investigator in order to ensure identical standard record keeping.

The quantifying muscle activity and gathering scientific evidence has been a major challenge in the research field of aquatic exercise, because of the difficulty in fixing surface electrodes to the skin, and the complexity and sophistication of the equipment needed to transmit and to record EMG signals from subjects while they are immersed in water (Piette and Clarys, 1979). We endeavored to clarify muscle activity while walking in water. Although initially hampered by technical considerations, we were able to successfully employ surface electrode and telemetric EMG technology to analyze the muscle activities of subjects while they were walking in water. Waterproof dressings were placed over each of the motor points. The surface electrodes were fixed with the extreme care using adhesive tape (3M Co. Ltd., USA) before being covered with foam pads (Foam Pad, 75A, Nihon Kohden Co. Ltd., Japan) to prevent water from contacting the skin-electrode interface and to prevent electrical leakage during the tests. This method was used because no electrodes or remote telemetry equipment is commercially available for determining muscle activities while walking in water. It was essential that the surface electrodes adhered to the skin surface, because failure to do so would have resulted in considerable movement artifact. Taping was done in a manner that allowed unencumbered movement of the tested muscles and normal gait while performing the trials.

The raw EMG signal was derived with the eight-channel multitelemeter system (WEB-5000, Nihon Kohden Co. Ltd., Japan) and was transferred to an Analogue/Digital converter (MacLab/8c, AD Instruments Pty. Ltd., USA) before being imported into a personal computer (Macintosh PowerBook 3400c, Apple Computer Inc., USA) for later analysis. The raw EMG signal was recorded at the sampling frequency of 1,000 Hz and then the integrated EMG (iEMG) analysis was made using the software, Chart v3.5/s (AD Instruments Pty. Ltd., USA) and Scope v3.5/s (AD Instruments Pty. Ltd., USA). The raw EMG signal was digitally filtered with a second order, using low- and high-pass digital filters, with cut-off frequencies between 20 Hz and 500 Hz. The EMG data were integrated after smoothing.

Measurement of MVC and standardization

Normalization of EMG activity is a procedure that is commonly used for comparing myoelectric activity of different muscles (Ng et al., 2002). The telemetrical appraisal of muscular activity by means of iEMG and the quantitative estimation by reference to the maximum isometric activity appears to be highly reliable (Lewillie, 1973). MVC was used to normalize the EMG magnitude. The measurement of MVC of each tested muscle, essentially following the method of Hishop and Montgomery (1995), was made on dry land before performing gait analysis in order to calculate the percentage of MVC (%MVC), so as to facilitate a comparison between normalized muscle activities evaluated while walking in water and those evaluated on dry land within each experimental session. The entire EMG activity for each muscle was expressed as a %MVC. Such a procedure permitted the comparison of quantitative EMG data for single individuals and between individuals on a relative basis. The duration of the MVC isometric contraction test was set at 5 seconds for each tested muscle. MVC was based on the peak amplitude for each of the 8 tested muscles. The subjects were carefully familiarized with the testing procedure and were trained to produce the maximal force output before each measurement session.

Muscular potentials recorded for five-selected representative and consecutive gait cycles were subjected to full-wave rectification. For each subject and each muscle, the iEMGs (mV · s) of the five selected representative and consecutive gait cycles were divided by the time required for each of the gait cycles in order to calculate the iEMGs per second (mV). Then, the iEMGs were averaged in order to yield iEMGs per gait cycle. After excluding the noise, the peak 1-sec EMG signal (mV) during MVC measurements was selected as a normalizing value (100%). In order to calculate the %MVC, each of the iEMGs per second (mV) was divided by the peak amplitude of MVC per second (mV) for standardization.

Experimental protocol

The measurements were performed in the Institute of Health Science at Kyushu University (Fukuoka, Japan). Each subject completed all the exercise tests within a single day. Initially, after excluding the noise identified by the submaximal EMG recording, subjects completed MVC measurement on dry land. Verbal encouragement by the instructors was provided to motivate the subjects in the achievement of their maximal contraction levels. Then, they underwent a treadmill test on dry land, and finally they were required to enter the water flume in order to perform the trials in water. Before initiating the actual trials in water, a few submaximal EMG recordings were repeated to ensure that the electrodes had not migrated and that dampening of the signal due to water leakage had not occurred. The multitelemeter system was secured dorsally to the subject's waist while performing the trials on dry land, and was secured to the side of the underwater treadmill while performing the trials in water. This set-up enabled the transmitter to be secured without placing undue tension on the leads or interfering with the gait.

The tests consisted of walking on dry land, walking in water with a water current, and walking in water without a water current. Subjects walked on a treadmill (ELG-2, Woodway, USA) on dry land and on an underwater treadmill (Flowmill, FM-1200D, Japan Aqua Tech Co. Ltd., Japan), immersed to the level of the xiphoid process. The newly developed underwater treadmill, the Flowmill, comprises a treadmill at the bottom of a water flume, and water temperature, depth, walking speed, and water current can each be controlled independently. Throughout the laboratory experiment, the water temperature of the Flowmill was maintained at 31.0±0.1°C (Evans et al., 1978), a level assumed to be thermoneutral for exercising humans (Sheldahl et al., 1984). The air temperature of the laboratory during the study was set at 26.6±0.1°C to ensure similar skin temperatures between the wet and dry conditions (Poyhonen and Avela, 2002).

Before testing, all the subjects practiced walking in water and on dry land at various speeds until they felt confident and appeared safe. Additional practice was performed if the subject or investigators deemed it necessary. Each subject completed three consecutive 1-minute exercise bouts for each condition (on dry land, in water with a water current, and in water without a water current), with a 1-minute rest between each speed setting. None of the subjects had engaged in walking in water regularly, prior to the experiment. Walking in water was performed at three speeds (30 m/min, 40 m/min and 50 m/min), and walking on dry land was also performed at three speeds (60 m/min, 80 m/min and 100 m/min). The speeds of the water current were 30 m/min, 40 m/min and 50 m/min, in line with the speeds of the underwater treadmill. The range of three walking speeds was chosen to represent slow, moderate and fast speeds. Evans et al. (1978) reported that approximately half the speed was required to work at the same level of energy expenditure while walking and jogging in water, as compared with exercising in air. Accordingly, we reduced the speed of movement while subjects walked in water by half, in order to induce an energy expenditure equal to that which would have been expended while walking on dry land. Subjects were encouraged to maintain their walking pace throughout each exercise session. No specific instructions were made regarding their walking modality so that the subjects were free to walk in water. Throughout the experimental sessions, the subjects wore swimsuits.

For all tests, HR responses were monitored continuously by a telemetry method (ST-30, DS-501, Fukuda-Denshi Co. Ltd., Japan) and recorded every 10 seconds: the value at the middle of each exercise bout (30 seconds) was used for statistical analysis. Waterproof electrodes (Vitrode D-90, Nihon Koden Co. Ltd., Japan) were used to estimate HR while walking in water.

Statistical analysis

The %MVC from each tested muscle and the HR for each experimental condition were averaged, and standard deviations (SD) were calculated. The parameters obtained while walking in water (with and without a water current) were compared to those obtained while walking on dry land within each speed setting. A one-way factorial analysis of variance (ANOVA) was performed within each speed setting for each muscle activation and HR, in order to determine whether there were any statistically significant differences between values which were obtained while walking in water (with and without a water current) and those obtained while walking on dry land. *Post hoc* analysis was performed using a Fisher's PLSD multiple-comparison test. The level of statistical significance was set at $P<0.05$. Statistical analyses were performed using StatView version 4.54 software (Abacus Concepts Inc., USA).

Results

HR responses

A summary of HR responses in each experimental session is shown in Table 1. There was no significant difference between HR response obtained while walking in water (with and without a water current) and that obtained while walking on dry land within each speed setting.

%MVC

Figure 1 represents the typical raw EMG data from the tested muscles while performing the trials at moderate speed. Typically, reduced raw EMG activities from the tested muscles were observed while walking in water (both with and without a water current) compared to those observed while walking on dry land.

The %MVCs from each of the muscles while walking in water (with and without a water current) and while walking on dry land at slow, moderate, and fast speeds are presented in Figures 2, 3, and 4, respectively.

Figure 2 depicts muscle activities while walking in water (with and without a water current) and while walking on dry land at slow speed. The %MVCs calculated from the iEMGs per gait cycle obtained from the tested muscles while walking in water with a water current were significantly lower than those obtained while walking on dry land ($p<0.05$), although there was no significant difference in muscle activity from the GA or the BF. The %MVCs from all the tested muscles while walking in water without a water current were significantly lower than those obtained while walking on dry land ($p<0.05$).

Figure 3 demonstrates a summary of the %MVCs in each experimental session at moderate speed. The %MVCs obtained from the tested muscles while walking in water with a water current were significantly lower than those obtained while walking on dry land ($p<0.05$), although there was no significant difference in muscle activity from the BF. The %MVCs obtained from the tested muscles while walking in water without a water current were significantly lower than those obtained while walking on dry land ($p<0.05$), although

Table 1 Heart rate responses while walking in water and on dry land (beats/min).

Speed	Dry land	Water+Cur	Water−Cur
Slow	80.3±5.9	79.5±5.2	74.8±4.1
Moderate	91.3±8.2	88.7±7.0	83.8±4.4
Fast	93.2±8.2	94.7±5.1	87.5±5.8

Water+Cur, in water with current; Water−Cur, in water without current. Values are mean±SD.

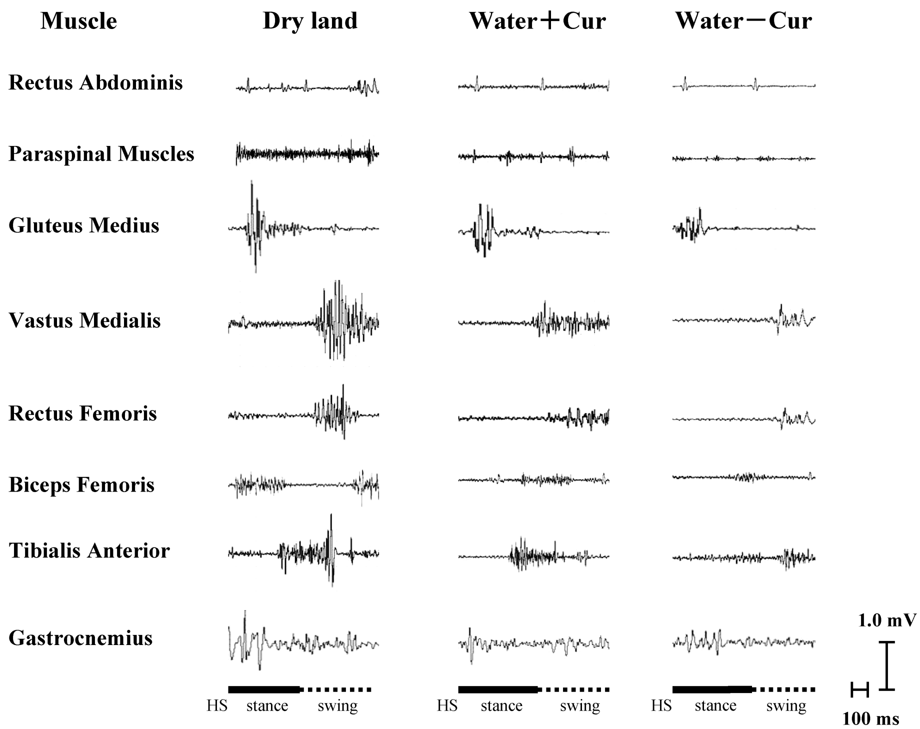

Fig. 1 Typical EMG data per gait cycle of a subject performing trials at moderate speed. HS; heel strike. Water+Cur; walking in water with a current. Water−Cur; walking in water without a current.

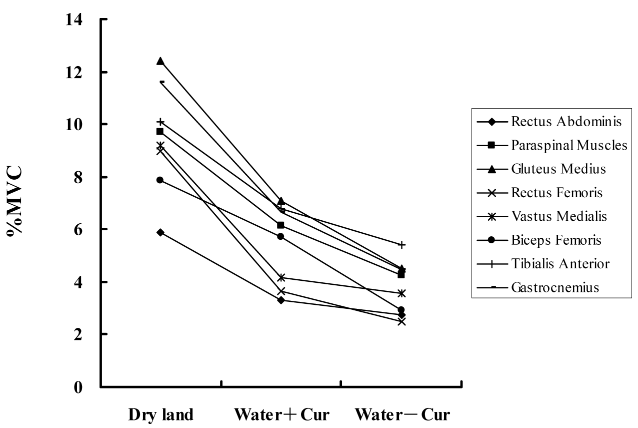

Fig. 2 EMG activities while walking in water (with and without a water current) and on dry land at slow speed. At slow speed, the %MVCs obtained from the tested muscles while walking in water (with or without a water current) were lower than those obtained while walking on dry land. Water+Cur; walking in water with a current. Water−Cur; walking in water without a current.

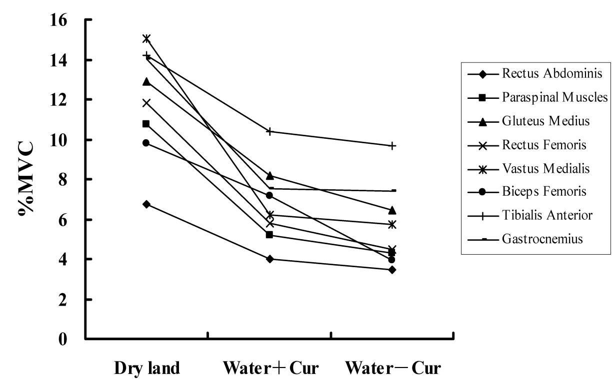

Fig. 3 EMG activities while walking in water (with and without a water current) and on dry land at moderate speed. At moderate speed, the %MVCs obtained from the tested muscles while walking in water (with or without a water current) were lower than those obtained while walking on dry land. Water+Cur; walking in water with a current. Water−Cur; walking in water without a current.

there was no significant difference in muscle activity from the TA.

Figure 4 characterizes a summary of the %MVCs in each experimental session at fast speed. The %MVCs obtained from the tested muscles while walking in water with a water current were significantly lower than those obtained while walking on dry land ($p<0.05$), although there was no significant difference in muscle activity from the RF, BF, TA or GA. The %MVCs obtained from the tested muscles while walking in water without a water current were significantly lower than those obtained while walking on dry land ($p<0.05$), although there was no significant difference in muscle activity from the BF and the TA.

The muscle activities from the BF at slow speed while walking in water with a water current were significantly greater than those while walking in water without a water current ($p<0.05$). Although a significant difference was not found, the remaining muscle activities while walking in water with a

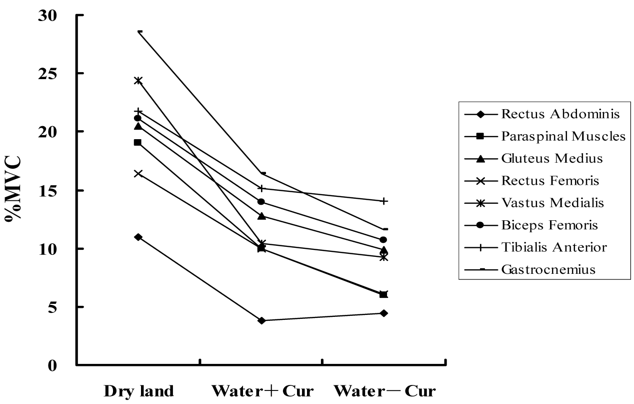

Fig. 4 EMG activities while walking in water (with and without a water current) and on dry land at fast speed. At fast speed, the %MVCs obtained from the tested muscles while walking in water (with or without a water current) were lower than those obtained while walking on dry land. Water＋Cur; walking in water with a current. Water－Cur; walking in water without a current.

water current also tended to be greater when compared to those while walking in water without a water current.

Discussion

This study represents the first attempt to investigate muscle activities concurrently in both lower-extremity and trunk muscles, and the influence of a water current on muscle activities, while healthy subjects walk in water.

The HR response while walking in water (with and without a water current) did not differ significantly from that while walking on dry land (Table 1). This indicates that the HR response while walking in water was similar to that while walking on dry land. Accordingly, all the remaining EMG data from the three types of exercise were found to be comparable.

This investigation was set up primarily to test for differences in the %MVC of each muscle when performing trials in water, both with and without a water current, and when performing trials on dry land, within each of three speed settings. The major findings of the present study indicated that while walking in water with a current, the amount of muscle activity from the ABD, PA, GM, RF, VM and GA was approximately 40 to 60%, while that from the BF and TA was approximately 70% of that observed on dry land. Moreover, the level of muscle activity while walking in water without a water current from the ABD, PA, GM, VM, BF and GA ranged from approximately 30 to 50%, while that from the TA was approximately 60% of that observed on dry land. The present biomechanical data therefore clearly demonstrate dramatically decreased muscle activity while walking in water (with or without a water current) compared to that measured while walking on dry land (Fig. 2, Fig. 3, and Fig. 4). It is of interest to note that all the tested muscles were activated below 20%MVC while walking in water in the present study, and since Monad (1985) found that 15% to 20% of MVC was the highest level at which the sustained activity can be performed without fatigue, it seems unlikely that the fatigue had any bearing on the level of muscle activity measured while walking in water in this study.

The present study demonstrated decreased muscle activities while walking in water. These findings were in agreement with previously reported findings showing that the EMG activity during underwater exercises was decreased compared to that during similar exercises performed on dry land. (Clarys et al., 1985; Fujisawa et al., 1998; Kaneda et al., 2004; Kelly et al., 2000; Pöyhönen et al., 1999). The amount of recorded EMG activity should be interpreted as an indicator of muscle activity level (Fujisawa et al., 1998). The decreased EMG amplitude is directly associated with the decreased muscle activity and force generation (Kelly et al., 2000). The current study noted the decreased EMG amplitudes in water, which may have been due to the effect of the weightless on the neuromuscular system. Harrison et al. (1992) demonstrated that, when the human body is immersed to the anatomical levels of C7, the xiphoid process or the ASIS (anterior superior iliac spine), the percentage of weight-bearing is 85%, 71%, and 57%, respectively. Accordingly, in the case of the current study, it is thought that the subjects experienced approximately 70% of weight-bearing while walking in water, since they were immersed to the level of the xiphoid process. It is therefore possible that the decreased muscle activity while walking in water was largely attributable to the effect of water buoyancy, which suggested that the subjects minimized their efforts while walking in water, which would have resulted in reduced resistance. An alternative explanation for the decreased muscle activity which was noted during exercise in water could have been the effect of the weightless on the muscle spindles and proprioceptive systems within the neuromuscular system (Pöyhönen et al., 1999). Pöyhönen et al. (1999) reported that Dietz et al. (1989) had found that the activation of pressure receptors controls reflex and proprioceptive mechanisms. Similarly, Avela et al. (1994) had found that during unexpected gravity conditions muscle spindle activity might be reduced. Pöyhönen and Avela (2002) concluded that the head-out immersion induced deterioration in neuromuscular function, perhaps by triggering the inhibitory mechanisms. Furthermore, the findings from the micro-gravity simulations suggested that the decreased effect of gravity during immersion is associated with the reduced stimulation of the gravireceptors in muscles, the vestibular system and the skin (Grigoriev and Egorov, 1996; Pöyhönen and Avela, 2002). Accordingly, the mechanism of the decreased muscle activities could revolve around the effects of the partial weightless, although the hydrostatic pressure also needs to be considered (Pöyhönen and Avela, 2002). Moreover, since the lower stride frequencies (Frangolias and Rhodes, 1995; He et al., 1991; Newman et al., 1994; Shono et al., 2001) and a reduction in ground reaction force (Newman et al., 1994) have been demonstrated in water, it is possible that kinematically different movements may be yet another explanation for the decreased muscle activities noted in subjects as they walked in water.

One of the primary purposes of the present study was to focus on the specific influences of the resistance of water (water current) on muscle activities while walking in water. The muscle activity of the BF while walking in water was significantly greater with water current than without current at slow speed. This is thought to be attributable to the increased propulsive force due to the effect of water resistance. The data from the present study demonstrated that the two different experimental conditions have specific effects on neuromuscular function. The remaining muscle activities while walking in water also tended to be greater with a water current than without, albeit the differences were not statistically significant. One possible explanation for the insignificant differences in muscle activities between those two experimental sessions may be the limited number of subjects investigated.

In this study, adiabatic foam pads were used in order to prevent water infiltration into the sites of the electrode during the tests. In addition, the submaximal EMG was recorded prior to initiating the trials in water to ensure that dampening of the signal due to water leakage had not occurred. Accordingly, in the case of the current study, it can be concluded that water had no disturbing effects on the electrodes. Moreover, we were sure that both the water temperature and the air temperature were maintained within the thermoneutral range (Sheldahl et al., 1984). It can therefore be assumed that the immersion-related changes in electromechanical factors that affect the measurement techniques or detected signals were in fact neglible. In addition, no noticeable difference in walking modality between the subjects was observed in this study. No structural attempts were made in this investigation to have the subjects fully adapted to walking in water, however, we are of the opinion that our results are a true reflection of what happened in practice. They should be applicable to individuals who are not familiar with walking in water, and who may perform it for the first time for the rehabilitation or training purposes. Further investigations into this question utilizing biomechanical analysis would be helpful before a definitive conclusion can be derived.

Many physicians, physical therapists, and sports instructors who have recommended walking in water have habitually reported positive benefits in both their patients and their exercisers. Unfortunately, few scientific studies have been carried out to ascertain the precise biomechanical responses that take place in muscles while walking in water. Our results were able to clarify the neuromuscular basis for the positive findings that has been observed in cases where there was a clinical application of walking in water. Although these results do not directly guarantee the safety and efficacy of walking in water as a rehabilitative or recreational means, they undoubtedly provided crucial information. It is thus important to carry out further well-designed scientific research relating to this field of study. The methodology presented here can be further applied to evaluate muscle activities for different modes of water-based exercise. Furthermore, research techniques utilized in the current study should enable a comparison of the normal and pathological gait patterns in water and on dry land to be made. This is perhaps a possible pointer for future research in the field of the rehabilitation medicine and exercise physiology.

In conclusion, the present study demonstrated that muscle activities while walking in water both with and without a water current were significantly decreased when compared to the muscle activities while walking on dry land, and that the magnitude of muscle activity in water was relatively small at a level of similar HR response in healthy humans. Furthermore, this study has shown that the muscle activities while walking in water tended to be greater with a water current than without a water current. The present findings should provide valuable information that will help with the design of water-based exercise programs that can be safely applied for the rehabilitative and recreational purposes.

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