Chapter 11

Underwater Electromyogram for Human Health Exercise

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Additional information is available at the end of the chapter

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1. Introduction

1.1. Why exercise in water has become popular?

The physical qualities of water are well established and include buoyancy, water drag force, hydrostatic pressure and thermal conductivity [1]. The large difference in these physical qualities, compared to land-based activities, affect the human body in both physiologic and biomechanical aspects. An example of this is buoyancy, which acts vertically against gravity on the immersed object thus decreasing weight of the human body. The buoyancy level is equal to the mass of water displaced by the immersed object and is based on the accepted Archimedean principle. When a human is immersed in water up to the level of pubis around 40% of weight is accounted for, 50% at umbilical, 60% at xiphoid, and almost 80% at the level of axillary [1, 2]. When immersed to their lower limb joint and waist in a water environment, humans can easily move, without gravitational overload, due to the buoyancy effect.

Water drag force is composed of three types of drag; surface drag, form drag and wave drag [3]. Surface drag is affected by viscosity of water and the surface quality of the immersed object. For example, the roughness of the surfaces of the object might increase surface drag, however, this depends on the speed of movement of the object as seen in the decreased drag on a golf ball due to the dimples [3]. Form drag depends on the shape and size of the immersed object, whilst wave drag directly opposes the object's movement through water. Water drag force increases proportionally by the frontal projected area and square of moving velocity [4]. Therefore, humans need to exert a much greater force to overcome water drag force when moving in water due to a greater frontal surface area [3].

Hydrostatic pressure is related to water density and depth. Water density is about 800 times greater than air. When at a water depth of 1 meter, hydrostatic pressure increases about

73.5mmHg [1], which is similar to normal diastolic blood pressure. Hydrostatic pressure causes blood to shift from the lower extremities to the thoracic region [5], and also affects lung, renal and other endocrine functions [6]. Thermal conductivity, which is about 25 times faster than air, also affects the human circulatory system [1]. When a human is immersed in water with a lower than thermo-neutral temperature, peripheral vasoconstriction occurs and increases the blood shift to the thoracic region [7]. This thermoregulation effect has been used for a range of therapeutic practices [1].

As briefly described above, the water physical qualities can be very beneficial for the human body. In addition to those effects, exercising in a water environment is a safe environment and may reduce the incidence of falling [8]. A wide range of people including those who have difficulty moving on land due to obesity, a lower-limb disorder, through to those who are healthy or want to improve their fitness may benefit from utilizing the water environment [8, 9].

1.2. Why knowledge of muscle activity during exercise in a water environment is important?

When exercising in water, the benefits of buoyancy and water resistance mainly occur because these qualities act directly on the exercise motion. For example, weight reduction, due to buoyancy, may contribute to the upward or downward motion, and additional loading by water resistance would strongly affect the motion in any direction. Therefore, the instructors of water exercise need to consider the effect of water specific qualities can play on the human body.

As a method of understanding the loading or offloading effect of water specific qualities on human body, investigation of muscle activity is considered an important tool. This provides information regarding the degree of muscle loading during exercise in water, and also provides a basis to apply health and rehabilitation exercise in a water environment more effectively. It is easily hypothesized that the muscle activity would be changed during exercise in water, compared with the same exercise on land. However, there is a challenge in measuring muscle activity in a water environment.

In consideration of these points, firstly, this chapter focuses on the methodology and its validity of collecting muscle activity data in a water environment, with special mention regarding a waterproofing method. Following this, the muscle activity modality for walking, running and many other exercise forms in water are also featured. Walking and running exercise in water are the most popular and basic exercise forms of water exercise [9]. This chapter focuses on walking, running and other water exercise forms which is based on gait, for example, walking with long step, walking with twisting, walking with kicking and so on. Finally, this chapter provides an informative suggestion for exercise participants and instructors.

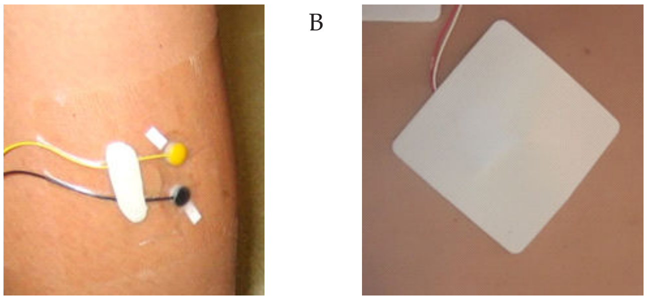
2. How to collect underwater electromyogram (EMG)?

2.1. The methodology for the collection of muscle activity in underwater environment

Measuring muscle activity by EMG method is challenging because most EMG devices are not waterproofed. As with all electronic devices, water immersion can be dangerous. Because of this risk, most research has used silver-silver-chloride surface EMG electrodes as passive surface electrodes [10, 11]. Some researchers who have investigated muscle activity using EMG devices developed their own waterproofing methods [10, 11] of which there are two types. The first type attached a waterproof seal onto the electrodes placed on the local muscle of interest [10, 11], and the second wears a dry suit on the whole body created for EMG collection [10, 12].

Waterproofing the seal onto the electrodes usually involves attaching transparent film and/or a foam pad (Foam Pad, 75A: Nihon Kohden, Tokyo, Japan) and this method has been used successfully in previous research [10, 11]. For even better waterproofing, transparent film and/or foam pad are attached in combination [10, 11]. This is achieved by sealing a small piece of transparent film over the electrodes which are attached on the muscle belly to be studied. Then, fill up the slight gap between electrodes leads and transparent film with putty. Finally, use a large piece of transparent film to cover over the small size film and putty (Figure 1).

A B



A: doubled by transparent films with putty. B: covered by foam pad.

Figure 1. Waterproofing of surface electrodes. [Pictures were taken by the authors]

Even when this strict waterproofing is applied the water can sometimes immerse under the films cause interference with the electrodes. Therefore, when using this method, the EMG signal has to be monitored continuously throughout the experiment to ensure the data is not affected by water intrusion. When water intrusion under the films or electrodes occurs, a high frequency noise and/or baseline fluctuation on the wave data would be observed. If an abnormal data reading is confirmed due to water intrusion, the electrodes attachment has to be removed and re-applied and the experiment procedure should be started over again. In addition to the waterproofing to the electrodes, the code of each electrode should be taped along with body segment to avoid unexpected tension by water resistance and swinging by exercise motion in water which may prevent or interfere with the normal motion (Figure 2). Due to the series of extensive electrode attachments, waterproofing procedures and establishing the settings for collecting data of underwater EMG, the procedure for underwater EMG takes considerably longer to perform compared with testing in the land environment.

A whole body dry suit has been developed for the collection of underwater EMG, specifically for water sports activities to allow full range of motion [10, 12]. This suit consists of waterproof material with the arm, leg and neck openings tightly sealed. Once the electrodes are attached on the subject, the electrodes and its leads are well covered from the water due to the fully enclosed suit. The advantages of this suit include less set up time than waterproofing and

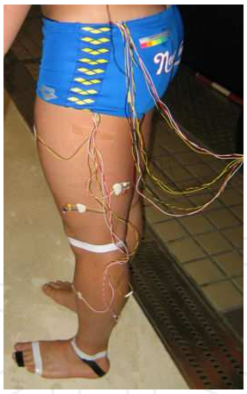


Figure 2. Electrodes and its codes attachment for underwater EMG experiment. [Picture was taken by the authors]

enable longer EMG data collection periods due to increased comfort the suit provides in the water environment. However, the suit would disadvantage subjects who do not fit the standard size of the suit, and this waterproof method still requires further refinement to limit water intrusion at the openings [10, 12].

2.2. The effect of human water immersion on EMG data

The other issue for EMG recording in a water environment is whether the EMG data is affected by water immersion, even if the electrodes are waterproofed. However the EMG data seems to have little attenuation from water immersion if the waterproofing is completely implemented [10, 13-16]. There are numerous studies regarding the influence of water immersion for EMG data collection using waterproofed and non-waterproofed electrodes attached on human muscles [10, 13-16]. Rainoldi et al. [13] investigated the effect of EMG recording by using surface electrodes attached on Biceps Brachii in conditions of dry land, in water with waterproofed or not. The subjects conducted 50% of isometric maximal voluntary contraction (MVC) as determined by a load cell. The results showed that there was no attenuation on EMG recordings in averaged rectified value (ARV) and root mean square (RMS) value with waterproofed condition, whilst the non-waterproofed condition showed significant reduction of the EMG data. In addition to that, the same circumstances were seen in the signal spectrum analysis. The authors concluded that waterproofing was required for EMG recording in water environment to avoid large signal artifacts, to ensure constant recording conditions for the whole experimental session duration, and to avoid time consuming alternative correction technique to remove low frequency artifacts. Pinto et al. [14] investigated the effect on surface EMG recording of isometric MVC between on land and in water. The EMG was recorded from Biceps Brachii, Triceps Brachii, Rectus Femoris and Biceps Femoris. The results showed that the EMG data of each muscle was not affected by water immersion, however the force production of the hip extension decreased significantly in water. This study also reported a significant intra-class correlation coefficient from moderate to high (0.69-0.92) for the EMG recording and the authors concluded that the environment did not influence the EMG data in MVC. With respect to a reduction of EMG data without waterproofing in water environment, Carvalho et al. [15] reported that the reduction was around 37.1-55.8% in the water condition without waterproofing compared with the land or the water with waterproofing in both MVC and 50% of MVC trials. Recently, Silvers et al. [16] reported the validity and reliability of EMG recording by waterproofing in water exercise suggesting future EMG studies should conduct MVC testing in water for data normalization and confirm the post-exercise verification of EMG recording. It can be then assumed due to the body of previous research that the collection of EMG data during water environment is not influenced by water immersion if the electrodes were waterproofed, however, it might be more reliable to verify post-experiment EMG recordings and/or normalization in water MVC.

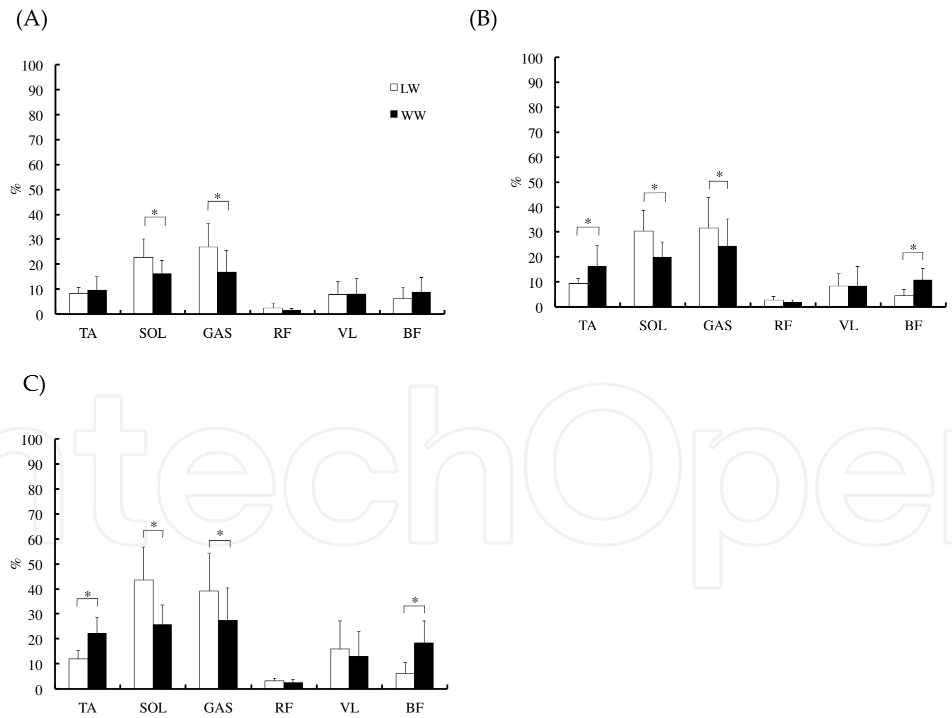
3. The characteristics of muscle activity during walking in water

3.1. Muscle activity in lower limb muscles

One of the most basic forms of exercise in water is walking gait. Walking in water provides significant changes on your body. A number of investigations have been conducted on the physiological aspects of water walking [17, 18, 19], and more recently, biomechanics and kinesiology research has been published [11, 20-25]. Research into muscle activity has focused mainly on lower limb muscles due to the fact that walking exercise in water is generally conducted at the waist depth or deeper [8, 9, 18, 19]. Research of the lower limb muscles activity during walking in water has been reported by the authors at subject's self-selected slow, moderate and fast speed in comparison to those same selected speeds for land walking [11, 20]. Subjects included nine young men and they walked along the swimming pool deck for the land trial and in a 1.1m deep swimming pool. The EMG data was collected from Tibialis Anterior (TA), Soleus (SOL), Medial Gastrocnemius (GAS), Rectus Femoris (RF), VastusLateralis (VL), and Long Head of Biceps Femoris (BF) on subject's left side with 2000Hz sampling rate. The EMG data was normalized by MVC on land in each muscle. Data processing involved the raw EMG data being filtered using 4^{th}-order low-pass and high-pass filters with cut-off frequencies of 500 Hz and 10 Hz, respectively. And then, the filtered EMG data was transferred to digital data, and the root mean square (RMS) of each phase calculated on a 100-ms window of data (i.e. 50 ms both before and after the data point of interest), and expressed as percentages of MVC (%MVC). This study evaluated the muscle activity in each cycle phase as to a stance phase from a heel contact to a toe-off, and a swing phase from the toe-off to the next heel contact. A paired Student's-t-test was applied for a statistical comparison between two conditions. Figure 3 and Figure 4 showed the result of the study.

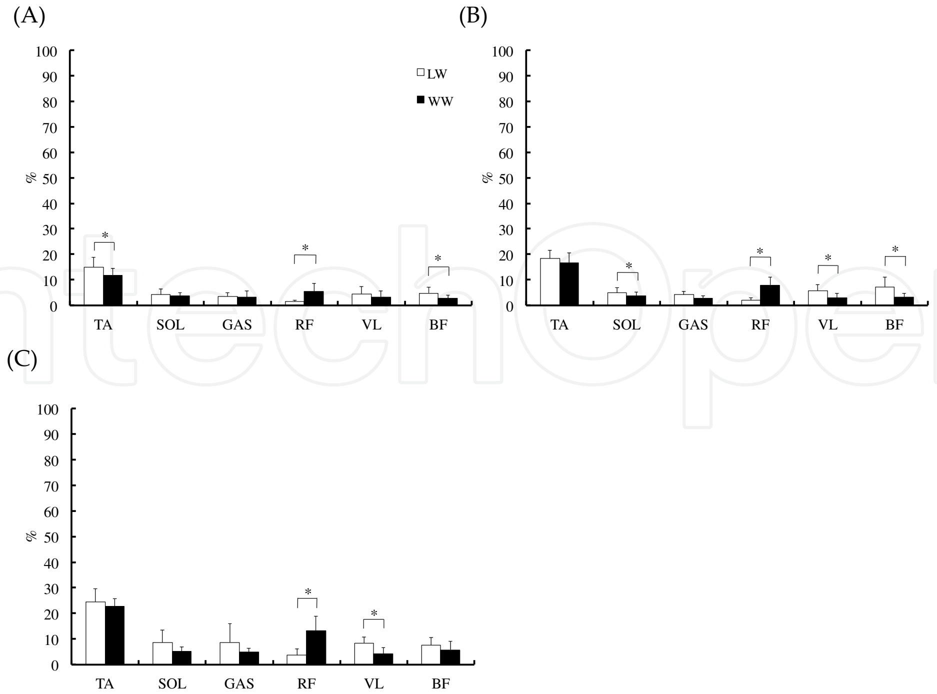
As a result of the stance phase (Figure 3), significantly lower %MVC were observed during water-walking compared to land-walking in the SOL and GAS muscles at all speeds ($P < 0.05$). On the other hand, the TA and BF were significantly higher during water-walking than land-walking at normal and fast speeds ($P < 0.05$). In the swing phase, RF was significantly higher during water-walking than land-walking at all speeds, but the other muscles tended to be lower during water-walking than land-walking at all speeds especially in the TA (slow), SOL (moderate), VL (moderate and fast) and BF (slow and moderate) as significance (Figure 4).

Muscle activity during walking is not dramatically large if it is expressed in %MVC regardless of the condition. Basically, TA seems to activate during stance phase to stabilize the ankle joint against the water resistance added to whole body during water walking [21]. This may explain why the TA activity was significantly higher during water-walking in moderate and fast speeds (Figure 3). There was no phase where the TA had to stabilize the ankle joint during swing phase, resulting in lower TA activity during water-walking than land-walking. However, Nakazawa et al. [22] concluded that the inter-subject and intra-subject variability were higher in the TA response during water-walking. Therefore, more precise investigation of TA during water-walking is required. The muscle activity of SOL and GAS dramatically decreased during water-walking due to a reduction of weight bearing by buoyancy. Further investigation of these muscles by Miyoshi et al. [23] reported a different role of SOL and GAS muscles during water-walking. They concluded that the SOL was affected by walking speed and gravity stress, while the GAS was affected by only walking speed. In BF, more activation is needed to generate propulsive force against water resistance force by extending hip joint during stance phase. A larger hip joint extension moment during water-walking throughout the stance phase than that during land-walking was confirmed by Miyoshi et al. [24]. In the swing phase, the RF muscle activates more during water-walking than land-walking to overcome water resistance force for forwarding lower limb [21]. Interestingly, the %MVC of the other muscles decreased during water-walking compared to land-walking. It is presumed that this is due to a lack of or smaller impact force in water than that on land, reducing the need for VL and BF muscles to prepare for shock absorption at heel contact. As described above, lower limb muscle activity shows different modalities depending on walking style.



A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking.
*: significant difference between water-walking and land-walking (P < 0.05).

Figure 3. The mean ± standard deviation (SD) of %MVC value in each lower limb muscle at each speed during stance phase. [Modified from reference 11]



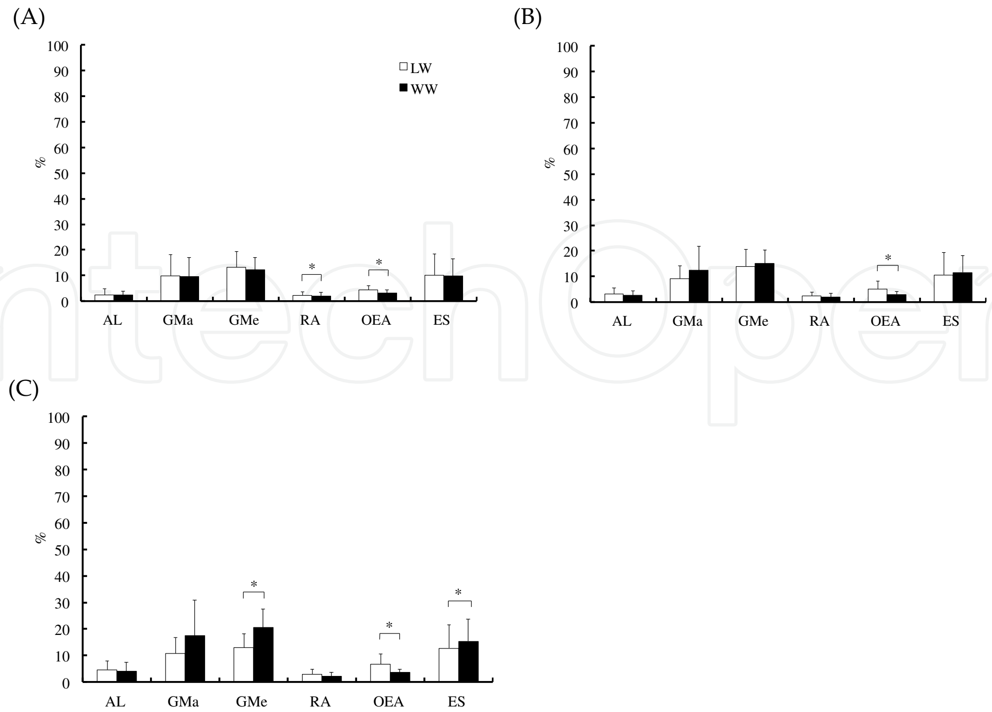
A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking.
*: significant difference between water-walking and land-walking (P < 0.05).

Figure 4. The mean ± standard deviation (SD) of %MVC value in each lower limb muscle at each speed during swing phase. [Modified from reference 11]

3.2. Muscle activity in hip and trunk muscles

There are a limited number of studies investigating hip and trunk muscle activity during water-walking, and the EMG data around hip and trunk muscles during water and land based walking [25, 26]. In the author's investigation [25], the surface electrodes were attached to the subject's left side and the muscles studied included Adductor Longus (AL), Gluteus Maximus (GMa), Gluteus Medius (GMe), Rectus Abdominis (RA), Obliquus Externus Abdominis (OEA), and Erector Spinae (ES, the position of L2). The data reduction methods were also applied with the same method as mentioned in lower limb analyzes. The EMG data collected by 2000Hz sampling rate was normalized by MVC (%MVC) on land in each muscle with 4th-order 500Hz low-pass and 10Hz high-pass filters, and the root mean square (RMS) on a 100-ms window of data applied. Figure 5 and 6 showed the results of the Student-t's-t-test.

In the stance phase (Figure 5), the OEA was significantly lower %MVC during water-walking than that during land-walking in all speeds (P < 0.05). The RA showed significantly lower %MVC during water-walking than land-walking only in slow speed. A significantly higher %MVC was seen during water-walking than land-walking in the GMe and ES at fast speed. In the swing phase, the AL and ES showed significantly higher muscle activity during water-walking than that during land-walking at all speeds, however, all other muscles activity were lower during water-walking than land-walking in the OEA at all speeds, the GMa and GMe at moderate, and the GMa and RA at fast with significant level (P < 0.05), respectively.



A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking.
*: significant difference between water-walking and land-walking ($P < 0.05$).

Figure 5. The mean ± standard deviation (SD) of %MVC value in each hip and trunk muscle at each speed during stance phase. [Modified from reference 25]

Similar to the %MVC of lower limb muscle, the %MVC of hip and trunk muscles were also not as large during each walking style. The highest level of the %MVC in the hip and trunk muscles is around 20%. In addition to that, the mean differences in some muscles were very small, for example, the RA in both phase, the GMa and GMe in the swing phase. This should be taken into account for a more precise interpretation when applied to an actual exercise situation. Regardless of the fact, there are many noticeable changes when walking in water, compared with walking on land. Adductor Longus muscle appears to activate to stabilize pelvis and thigh segment [27, 28] during swing phase and does not fluctuate by water resistance force. Moreover, one of the important functions of AL is hip joint flexion matched to swing phase, during which relatively larger water resistance force added to lower limb. In respect to the stability during walking, GMe would act to increase stability of pelvis on the femur [28] against large water resistance force especially in the fast speed. Obliquus Externus Abdominis acts in body twisting yet the activity of OEA seems to decrease throughout walking in water compared with walking on land. Considering the results of the muscle activity, trunk twisting during water-walking might be less than that during land-walking. However, there is no evidence about movement in the transverse plane, and further research is needed to clarify this. Despite the fact that ES also acts in body twisting as well as OEA, the results showed higher activity in the ES during water-walking than that during land-walking. It is suggested that ES is compelled to activate against increased water resistance force on trunk during

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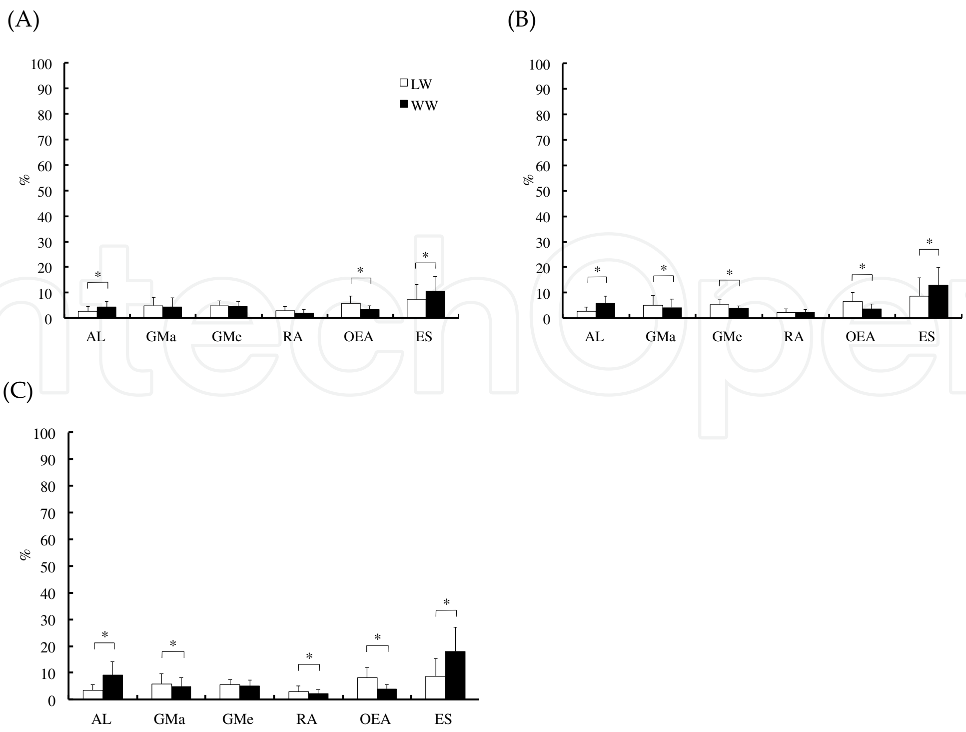
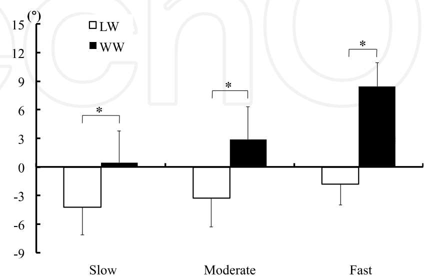


A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking.
*: significant difference between water-walking and land-walking (P < 0.05).

Figure 6. The mean ± standard deviation (SD) of %MVC value in each hip and trunk muscle at each speed during swing phase. [Modified from reference 25]

propulsion of the body. As evidence for this, the trunk forward inclination angle is larger during water-walking than land-walking (Figure 7), which is a counteractive reaction to deal with increased frontal water resistance force.



LW: land-walking, WW: water-walking
*: significant difference between water-walking and land-walking (P < 0.05)
Positive: forward inclination
Negative: backward inclination

Figure 7. Trunk inclination angle during walking. [Modified from reference 25]

Trunk muscles show different muscle activity between water and land based walking, as well as lower limb. However, when humans walk on a treadmill apparatus, most muscle activity decreased during water compared with land in both lower limb and trunk area [29]. In this case, the walking speed was set as one-half to one-third of the land walking in reference to the oxygen consumption [17]. Furthermore, muscle activity during treadmill water-walking without water flow further decreased muscle activity than with flow set to the same speed to the walking speed [29]. The differences between with or without treadmill may be due to the treadmill function moving the leg backward automatically without force generation during stance phase. Further, it would be possible that the displacement of the lower limb moves through less distance on treadmill walking than without treadmill in swing phase since human would be at the same position during treadmill walking. Although no previous research has clarified the biomechanical difference between walking with and without treadmill in water, researchers, exercise instructors and participants should pay attention to the differences of the muscle activity modality to determine more appropriate exercise and specific prescription according to water-walking style selected.

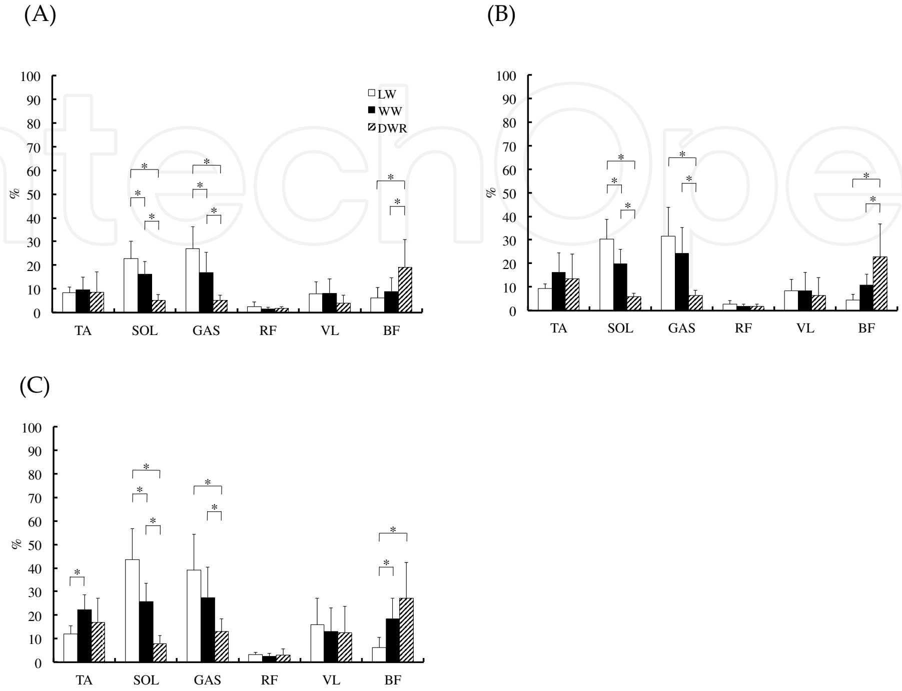
4. The characteristics of muscle activity during deep-water running

4.1. Muscle activity in lower limb and trunk

Deep-Water Running (DWR) is one of the unique exercise forms in water environment. Using a floatation device around the waist (Figure 8), people move their feet as if running without touching the bottom of the swimming pool.

Figure 8. Aqua Jogger (Excel Sports Science Inc., Japan) used for DWR exercise. [Picture was taken by the authors]

This exercise form has been widely used for aerobic training and cross training for performance enhancement in athletes [30], and rehabilitation training [31]. Previous studies have investigated muscle activity during DWR by the authors and compared this with water-walking and land-walking [11, 20, 25]. The results of %MVC level in lower limb muscles and hip and trunk muscles during those exercises are presented in Figure 9, 10 and 11. The measurement procedure, environment settings and the analysis methods were the same as the previous investigation comparing water-walking and land-walking by the authors [11, 20, 25]. In the DWR, the data was collected for one cycle from a maximal knee flexion to a maximal knee extension during the backward swing phase, and from the maximal knee extension to the next maximal knee flexion during the forward swing phase. These phases represent the stance and swing phase in walking exercise, respectively. One-way repeated measures analysis of variance (ANOVA) with Tukey's post-hoc test was applied for the statistic comparison.

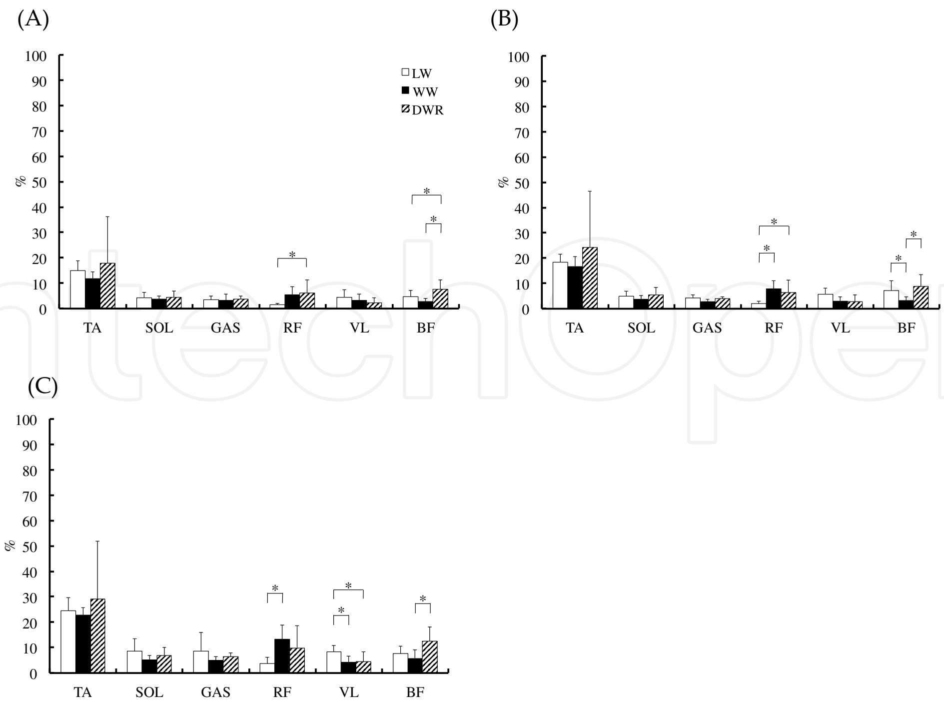


A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking, DWR: Deep-Water Running
*: significant difference (P < 0.05).

Figure 9. The mean ± SD of %MVC value in each lower limb muscle at each speed during backward swing phase. [Modified from reference [11]

As seen in Figure 9 and 10, the characteristics of the DWR, %MVC of the SOL, GAS in the backward swing phase, and the VL in the forward swing phase were dramatically decreased compared with water- and land-walking (P<0.05). This is likely a result of the non-contact phase during DWR compared to land walking. On the other hand, %MVC of the BF in both swing phases, and the RF in forward swing phase were much higher than land- and sometimes water-walking (P<0.05). The knee and hip joint range of motion (ROM) was increased during DWR when comparedto both land- and water-walking (Figure 12), which would cause the higher %MVC in the RF and BF. Similarly this increased ROM of the hip would also result in higher %MVC of the GMa, AL and GMe during the DWR than during water- and land-walking. Increased ROM directly indicates that thigh and knee extension and flexion muscles receive greater water resistance force. Further, it is likely that the AL and GMe activated to stabilize the pelvis against femur during an unstable floating situation as in DWR [25].

Interestingly, the %MVC of the RA, OEA and ES were higher during DWR than water- and land-walking throughout one-cycle (P<0.05, Figure 11). The authors speculated that maintaining forward inclination during DWR would increase the RA and OEA muscles activation



A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking, DWR: deep-water running
*: significant difference (P < 0.05).

Figure 10. The mean ± SD of %MVC value in each lower limb muscle at each speed during forward swing phase. [Modified from reference 11]

(Figure 13). However, it is important not to lean forward excessively which would explain the ES muscle activity needed to maintain forward inclination posture.

The DWR seems to use muscles of the hip and trunk more than water- and land-walking. Muscle activity comparing running on land and DWR was studied by Masumoto et al. [32]. This study reported the EMG data of the DWR in comparison with running on land treadmill for TA, GAS, RF and BF muscles. Masumoto et al. [32] revealed that TA and GAS muscle activity; when calculated as the average EMG; was clearly lower in DWR than land treadmill running for the same rating of perceived exertion (RPE). Similarly, RF and BF muscles tended to be lower in DWR than land treadmill running. Further investigation comparing running and DWR is necessary for more detailed understanding of muscle activity behavior during DWR.

4.2. Muscle activity difference between two types of deep-water running

There are various styles of DWR depending on the type of floatation device and its usage. Previous research has investigated muscle activity during DWR using aqua pole (Pole Running: PR, Figure 14), and compared this with the DWR using an aqua belt (Belt Running: BR, Figure 8). Subjects sat on the aqua pole with one leg either side instead of using upper body (Figure 15). The results showed the mean ± SD value of the EMG data as %MVC during one cycle in the TA, SOL, GAS, RF, VL, BF, AL, GMa, GMe, RA, OEA and ES muscles (Figure 16 and 17).

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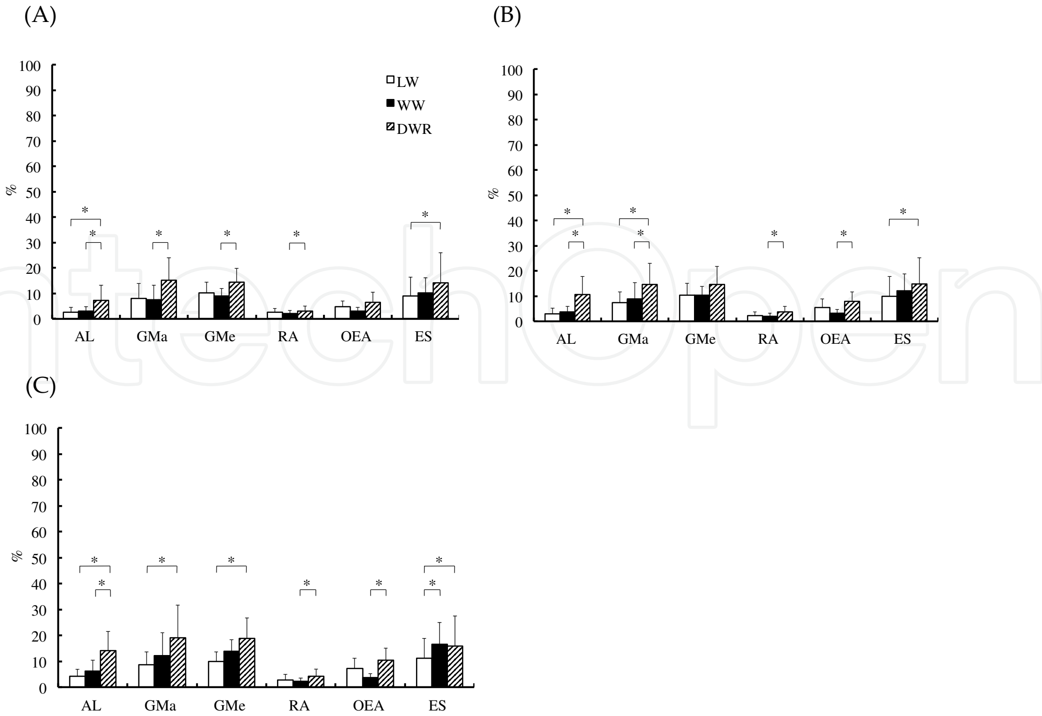
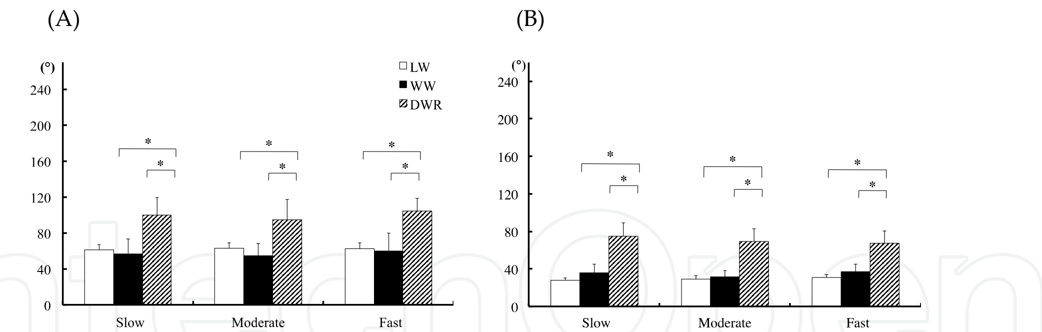


A: slow, B: moderate, C: fast.
LW: land-walking, WW: water-walking, DWR: deep-water running
*: significant difference (P < 0.05).

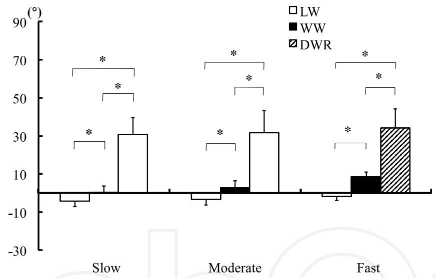
Figure 11. The mean ± SD of %MVC value in each hip and trunk muscle at each speed during one cycle. [Modified from reference 25]



LW: land-walking, WW: water-walking, DWR: deep-water running
A: knee joint, B: hip joint
*: significant difference (P < 0.05)

Figure 12. The mean ± SD of the knee and hip joints ROM during each exercise. [Modified from reference 25]

In summary, the muscle activity during both Belt Running and Pole Running reported similar values. However, the SOL tended to be higher activity during Pole Running than Belt Running, whilst the VL tented to be higher activity during Belt Running than Pole Running. The reasons for the difference in the SOL activity is difficult to determine, however, the different activity level in the VL which acts on knee extension motion, was considered to be due to the different



LW: land-walking, WW: water-walking, DWR: deep-water running
*: significant difference ($P < 0.05$)
Positive: forward inclination
Negative: backward inclination

Figure 13. The mean ± SD of the trunk inclination angle during each exercise. [Modified from reference 25]

Figure 14. Aqua Pole (Footmark Corp., Japan) used for DWR exercise. [Picture was taken by the authors]

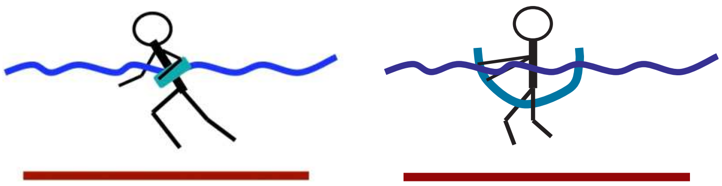
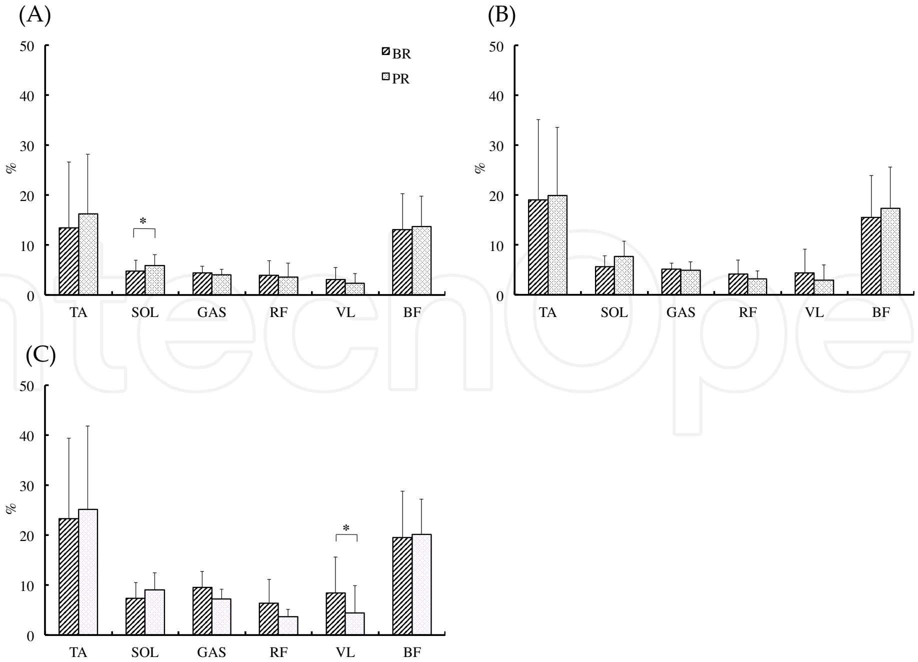


Figure 15. Belt Running (BR) and Pole Running (PR). [Pictures were created by the authors]

knee joint ROM during exercise, where the ROM of Belt Running was greater than that of Pole Running (Figure 18).

In hip and trunk muscles, the AL, RA and OEA muscles tended to have higher activation during Belt Running than Pole Running. The reason for this result is that the exercise style where subjects place aqua pole between their legs in Pole Running may require AL muscle to be less involved in the movement as the subject legs are wider apart during Pole Running than Belt Running. The higher muscle activity of RA and OEA muscles during Belt Running may be due to the trunk inclination angle being larger than that used in Pole Running (Figure 19). Thus, Pole Running is comparably a more upright position compared to Belt Running, which may explain the slight differences of muscle activity during the two forms of exercise. Researchers, instructors and participants can design a variety of exercise styles by simply varying the type of floatation device used in the activity.



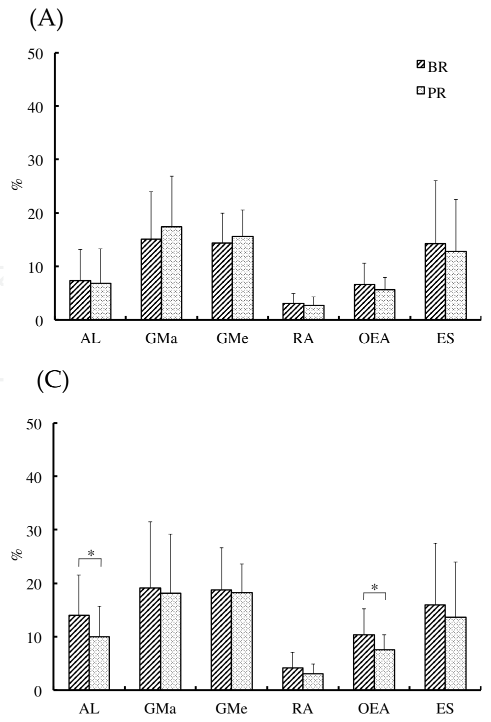
A: slow, B: moderate, C: fast.
BR: Belt Running, PR: Pole Running.
*: significant difference (P < 0.05).

Figure 16. The mean ± SD of %MVC value in each lower limb muscle at each speed during Belt Running and Pole Running. [Unpublished data]

There is still a limited amount of research published on muscle activity during DWR as well as running in water. When determining the most suitable style or type of activity in DWR for rehabilitation and cross training, further insight into muscle activity during the running would be a very useful regardless of running style.

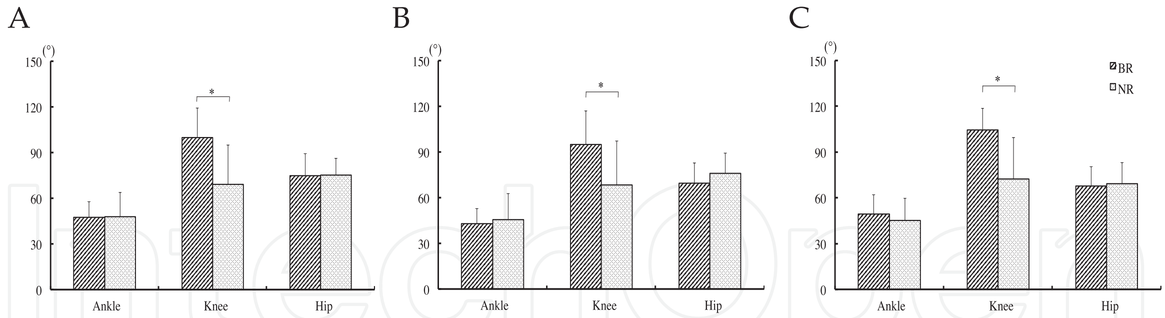
5. Insight into muscle activity during various exercises in water

There are many types of exercise in the water environment and walking and running in water are representative of the common forms. The authors reported the effect of buoyancy and water resistance during exercise in water and categorized exercises by its movement direction [33]. The exercise category was reported as follows: forward walking and backward walking as a horizontal movement, squat and calf raise as a vertical movement, and leg range and leg pendulum motion as a both horizontal and vertical included movement. Nine male subjects were involved in this study, where muscle activity of TA, SOL, GAS, RF and BF was measured. Each exercise was conducted both in water and on land conditions at the same pace. The data was collected at 1000Hz, and calculated integrated EMG (IEMG). Time constant was 0.03sec that is equal to 5.3Hz high pass filter. Results showed IEMG values during each exercise were dramatically decreased in the water condition compared with the land condition. Predominantly the agonist muscles were active in the vertical movement and both horizontal and



A: slow, B: moderate, C: fast.
BR: Belt Running, PR: Pole Running.
*: significant difference (P < 0.05).

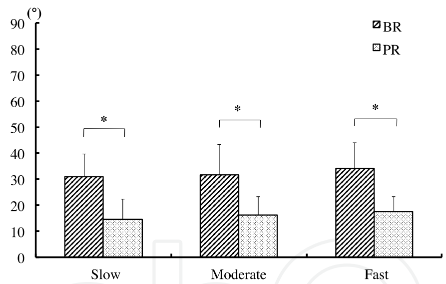
Figure 17. The mean ± SD of %MVC value in each hip and trunk muscle at each speed during Belt Running and Pole Running. [Unpublished data]



BR: Belt Running, PR: Pole Running
A: slow, B: moderate, C: fast.
*: significant difference (P < 0.05)

Figure 18. The mean ± SD of the lower limb joint ROM during each exercise. [Unpublished data]

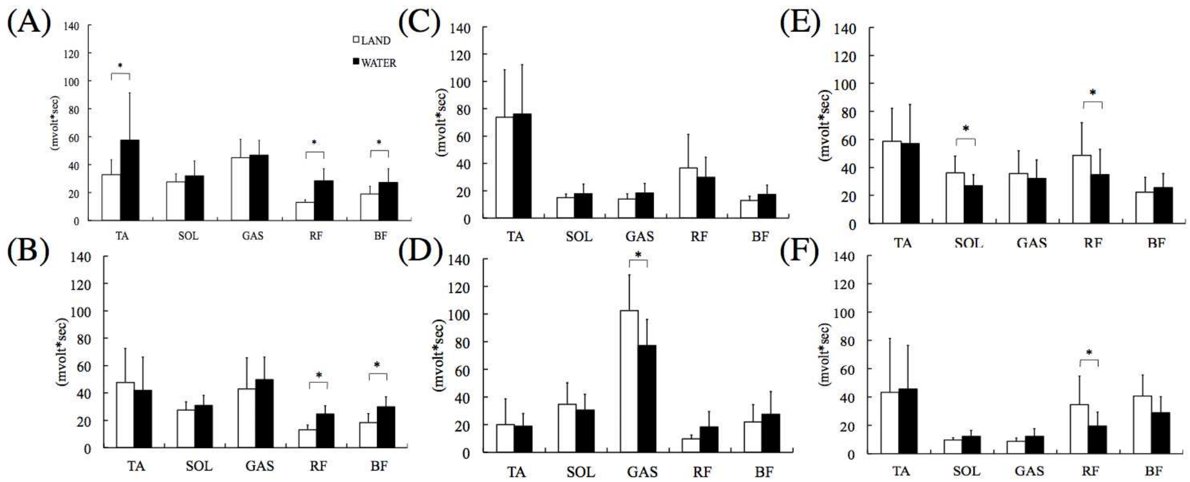
vertical included movement, for example, RF in the squat, GAS in the calf raise, RF in the leg range, and RF and BF in the leg pendulum motion (Figure 20). In contrast, the EMG values were more increased in the water condition than the land condition in the horizontal movement especially for the thigh muscles (Figure 20). It can be said that the only horizontal movement in water environment gives higher muscle stimulus than the same exercise on land.



BR: Belt Running, PR: Pole Running
*: significant difference (P < 0.05)
Positive: forward inclination

Figure 19. The mean ± SD of the trunk inclination angle during Belt Running and Pole Running.

Therefore, it was suggested that vertical and both horizontal and vertical included movement in water environment are useful for rehabilitation training from injury or disability due to the lower levels of stress in water activity than on land.

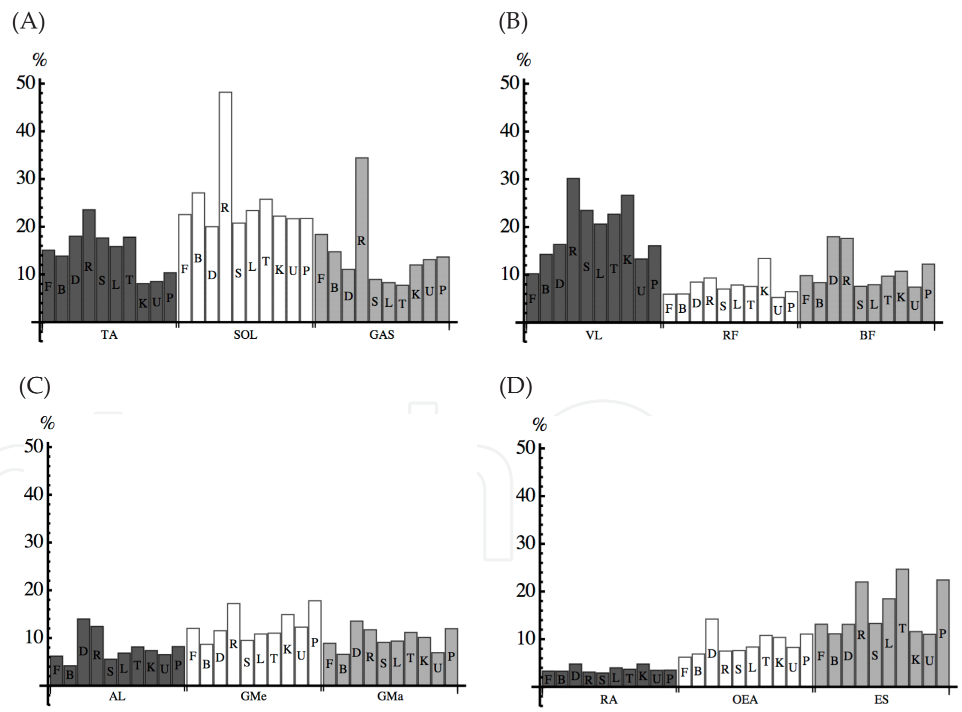


A: forward walking, B: backward walking, C: squat, D: calf raise, E: leg range, F: leg pendulum motion. [Modified from reference 33]
*: significant difference (P < 0.05)

Figure 20. The mean ± SD of the lower limb muscle activity during water and land exercise.

Further research by the authors has investigated lower limb and trunk muscle activity in ten kinds of water exercise [Unpublished data]. The mean EMG values of each muscle were shown in Figure 21. The data was collected at 1000Hz, and the mean EMG values were calculated from %MVC of RMS values with 100ms window of the data applied during one cycle of each exercise form. The exercises performed in this study were: forward walking, backward walking, DWR, normal running, side walking, walking with long step, walking with trunk twisting, walking with kicking, walking with knee-up, walking with elbow-knee alternative touching. These exercises are considered basic variations of walking exercise in water which are often implemented in practical exercise sessions.

As seen in the figure 21, normal running in water stimulated every muscle except the RA and the OEA muscles compared to the other exercise forms. This indicates normal running provides a high intensity activity for these muscles. The DWR was apparently an effective exercise for the BF, AL, RA and OEA muscles, especially abdominal muscles as seen in the comparison with water- and land-walking in the former section. The walking with kicking exercise clearly activated the VL and RF because those muscles were the agonist muscle for the walking with kicking motion, and this exercise stimulated abdominal muscles slightly more when compared to the other exercises. The VL muscle activity was comparably higher in the normal running, side walking, walking with long step, walking with trunk twisting and walking with kicking than the other exercises which may be due to those exercises requiring the body to be immersed deeply or require stronger extension of the knee joint during this motion. The walking with knee up exercise could be said to be of a low intensity exercise as it showed lesser EMG values than the others in every muscle. The walking with elbow-knee alternative touching exercise tended to show a high muscle activity especially in the hip and trunk muscles. It was speculated that the muscle activity for this exercise happened during standing phase in measured muscles resulting from the attempt to stabilize against upper body motion moving dynamically. As just described, the figure showed the features of the muscle activity modality during several exercises in water, but further video analysis investigation would be needed for understanding the cause of the muscle activity more precisely.



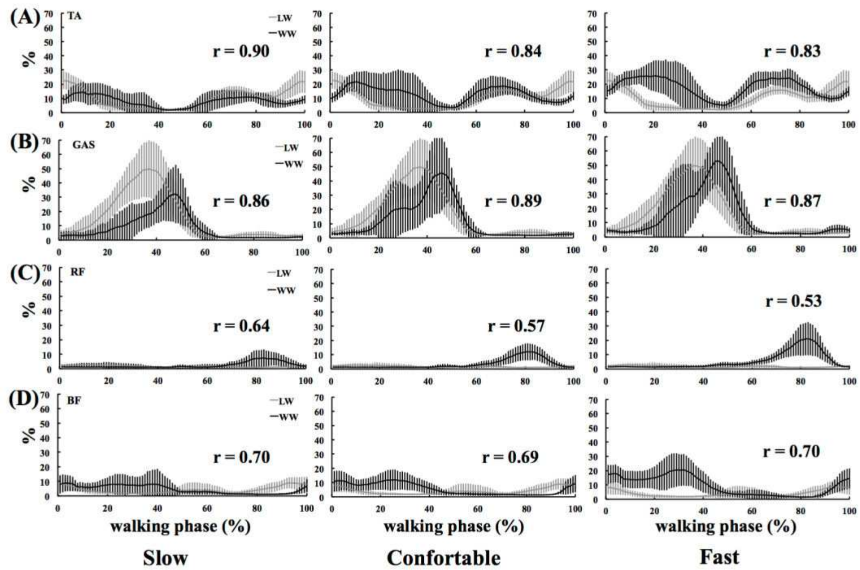
A: shank muscles, B: thigh muscles, C: hip muscles, D: trunk muscles

F: forward walking, B: backward walking, D: DWR, R: normal running, S: side walking, L: walking with long-step, T: walking with trunk-twisting, K: walking with kicking, U: walking with knee-up, P: walking with elbow-knee alternative touching

Figure 21. The mean %MVC value of the lower limb, hip and trunk muscle during exercise in water. [Unpublished data]

6. Rehabilitation training in water for regaining normal walking, is it truly effective?

The EMG characteristics introduced in this chapter are used in the comparison of the EMG data such as mean value or quantity. However, it is important to evaluate the quality of EMG signal to identify where the stimulus happened as the mean value is nothing more than the representative mean of the data for the targeted period. The quality analysis for EMG signal of exercise in water is a comparison of the wave forms that accompany exercise movement. Normalization from 0 to 100% of one cycle was applied so as to compare the muscle activity time course pattern [26, 34]. However, there was no statistical comparison made to the time course pattern. Instead the authors compared the time course pattern of walking exercise in water and on land by applying a cross correlation function. This correlation was then used in discussing the similarity of muscle activity patterns between water- and land-walking, as well as the usability of walking in water as a form of rehabilitation training. The hypothesis being that a water environment may have the benefit of less gravity stress and greater safety in preventing falling accidents. In addition, training of the targeted movement may be more effective and movement function specific [35] in water than on land. Thus, further investigation of the similarity of muscle activity between water- and land-walking would provide increased understanding regarding the use of water activity and exercise prescription for rehabilitation.



Values are mean ± SD of the subjects
A: TA, B: GAS, C: RF, D: BF
LW: land-walking, WW: water-walking
r: cross correlation coefficient

Figure 22. The normalized time course pattern of %MVC during walking in water and on land. [Modified from reference [36]

In the study by the authors [36], nine male subjects walked in water and on land condition at self-selected slow, comfortable, and fast speed in water as well as comfortable speed on land.

During each effort, the muscle activity of TA, GAS, RF and BF were collected at 2000Hz with a time constant of 0.03sec equal to 5.3Hz high-pass filter. After the collection, the data was filtered with low and high pass filter of 500Hz and 10Hz, respectively. Then, the data was full-wave rectified and low-pass filtered with moving average at 5 Hz to obtain the linear envelope. Following this, the data was normalized from heel contact (0%) to next heel contact (100%), and expressed as %MVC. The comparison was then made between each water-walking speed and confortable speed of the land-walking.

A normalized time course pattern and results of the cross correlation analysis are shown in Figure 22. The cross correlation coefficients were moderate in the RF and BF (r = 0.53 - 0.70), and were high in the TA and GAS (r = 0.83 - 0.90). This showed the muscle activity pattern of the water-walking were similar to that of the land-walking even in the slow and fast speed. Moreover, as seen in the figure 22, the muscle activation was higher during the water-walking than land-walking during most part of one full stride for all muscles except the GAS. This suggests the water-walking would be able to simulate the land-walking very closely regardless of the speed of the water-walking, and stimulate the thigh muscles and TA sufficiently even in the slow speed. The authors also suggest that even during slow speed, water-waking is an effective exercise modality for muscle training in a similar way to normal walking on land.

A possible limitation can be seen when applying normalization method to time course pattern in that the normalization process resulted in apparent cancelations in time length changes which may alter the sequencing and timing of events especially in exercise in water due to the buoyancy and water resistance affect on the movement duration. In addition, changing the time length may also distort the time course pattern, where the exact timing may not be comparable between the same timing of two wave forms (i.e. does the 50% of land-walking truly match to the 50% of water-walking in normalized data?). This should be considered in studying outputs from EMG modality of water-walking.

7. Conclusion

This chapter focused on muscle activity during exercises in water especially variations of gait (walking and running) and other activities of daily living. Descriptions on how to waterproof electrodes, placing the electrodes on the muscle of interest, and the verification of EMG collection in the water environment was then discussed. The authors also suggest that when the electrodes are waterproofed appropriately, EMG recording is not affected by water immersion. Namely, we can measure muscle activity correctly even in underwater condition without any artifact.

In summary of the reported characteristics of muscles activity during walking in water, TA and thigh muscles and ES tended to show higher activity than land-walking with self-selected pace. There was a lower activity than land-walking with Triceps Surae muscle, VL and abdominal muscle. Further, most muscles tended to decrease their activity when walking on treadmill apparatus, compared to land treadmill walking. During DWR the characteristics of muscle activity for the thigh, hip and trunk muscles show higher activity than walking in water and/or on land, whilst the muscle activity of Triceps Surae muscle decrease dramatically. From these results the authors concluded that muscle activity would probably decrease in DWR, when compared to land treadmill running. In addition, the muscle activity modality can be changed significantly by using different flotation devices. In the results of the comparison between water exercise and land exercise, the muscle activity modality was affected by the physical qualities of water (buoyancy and water resistance). For example, horizontal movement in water tended to increase agonist muscle activity, hence vertical movement and horizontal- and vertical-included-movement decreased agonist muscle activity. The water physical qualities would affect the posture during exercise and result in changes to muscle activity modality. The muscle activity characteristics in fundamental variations of water-walking vary its pattern resulting in unique movements, and the characteristics basically conform with exercise direction. Running in water, with feet touching the bottom of the swimming pool, generated the highest muscle activity. Walking in water with knee up has the lowest intensity among variations of water exercise when exercising in self-selected moderate pace.

This chapter introduced research comparing the EMG of water-walking to land-walking. The results concluded that the shank and thigh muscle activity during water-walking was similar to that of land-walking. Identifying the water environment can simulate land-walking in respect to muscle activity even at slow speed. This reinforces the concept in water environment as a legitimate and effective exercise. In addition, the water environment provides increased safety with respect to falls. In summary, the water environment would be very beneficial especially not only for the physically fit but also for people wishing to regain the normal motion which may be difficult to achieve on normal land environment.

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