THE FOLLOWING IS A CORRECTION FOR A PREVIOUSLY PUBLISHED PAPER. THE ORIGINAL PAPER IMMEDIATELY FOLLOWS THE CORRECTED MANUSCRIPT.

QUANTITATIVE ANALYSIS ON THE MUSCULAR ACTIVITY OF LOWER EXTREMITY DURING WATER WALKING

Koichi KANEDA[1], Daisuke SATO[2], Hitoshi WAKABAYASHI[3], Yuji OHGI[1] and Takeo NOMURA[4]

Graduate School of Media and Governance, Keio University, Fujisawa, JAPAN[1]
Niigata University of Health and Welfare, Niigata, JAPAN[2]
Kyushu University, Fukuoka, JAPAN[3]
NPO Tsukuba Aqua Life Research Institute, Tsukuba, JAPAN[4]

Authors conducted comparative studies both the water walking (WW) and the land walking (LW), in order to evaluate the muscular activities of the lower extremity. Nine young healthy subjects performed WW at voluntary slow, normal and fast speeds for 8 seconds with two repetitions. As for the LW, they walked at the normal speed condition. Surface electromyography electrodes were placed on the tibialis anterior (TA), medial gastrocnemius (GAS), rectus femoris (RF) and biceps femoris (BF). As for WW, some shank muscular activity patterns at different speed had moderate or high correlation with LW in cross correlation function (r = 0.62-0.80). The mean muscular activities of GAS at slow speed condition during WW were lower than that of LW. At the fast speed condition, TA, RF and BF activities in WW were higher than that of LW. It was considered that WW was able to simulate LW highly regardless of speed of WW especially in the shank muscles and stimulate thigh muscles and TA sufficiently even in slow speed WW.

KEY WORDS: water, walking, electromyography, similarity.

INTRODUCTION:

Water exercise has become more popular for both the fitness enhancement and the rehabilitation training. In water, buoyancy acts our body to reduce the gravitational stress at the joints, while water viscosity requires the subject to exert greater force than when moving on land (Miyoshi et al., 2005). Though many studies about muscular activity of water walking (WW) had been conducted and often compared with land walking (LW), almost all the studies were mainly focused on the difference between LW and WW (Kato et al., 2002; Barela et al., 2006). From the viewpoint of rehabilitation training, the similarity of LW and WW should be important. It might be able to suggest the utility of WW as a walking practice. The purpose of this study was to analyze quantitatively muscular activities of the lower extremity during WW compared with LW.

METHOD:

Subject: Nine healthy young males participated in this experiment. Their mean age, height, weight and %fat were 24.9 ± 2.2 yr, 172.0 ± 3.8 cm, 69.3 ± 3.7 kg, and 19.4 ± 4.1%, respectively. Ethics Committee of the Institute of Health and Sports Sciences at the University of Tsukuba approved this study.
Experimental design: Subjects performed LW at voluntary normal paced speed. On the other hand, for the WW, they walked voluntary slow, normal and fast speed for 8 seconds with two repetitions. In advance to the WW trials, subjects performed LW at their comfortable speed (normal). As for the WW, subjects carried out their trial at their comfortable speed (normal; WWN), faster and slower speed (WWF or WWS). The water temperature was kept 27 ± 2°C; its depth was 1.1 m which correspond to approximately the level of the navel.

Electromyogram recordings: The left lower extremity muscular activity of the tibialis anterior (TA), medial gastrocnemius (GAS), rectus femoris (RF) and long head of the biceps femoris (BF) were measured using a surface electromyography (EMG) electrodes (Mini Ag/AgCl Skin Electrode, NT-511G; Nihon Kohden Corp., Japan) at 1.5 cm intervals of two electrodes. A reference electrode was placed on the clavicle. The skin cuticle was removed carefully using a blood lancet (Blood Lancet; Asahi Polyslider Co. Ltd., Japan) and cleaned with alcohol wipes so that the inter-electrode impedance was less than 20 kΩ. The electrodes were covered with transparent film and putty for waterproofing. Subjects were instructed to perform isometric maximal voluntary contraction (MVC) for 5 seconds for each muscle on land in advance. The raw EMG signals were measured by using the eight-channel multi-telemeter system (WEB-5500 multi-telemeter system; Nihon Kohden Corp., Japan) at a time constant of 0.03 seconds and with 2 kHz sampling rate.
Data analysis: A digital video camera which was synchronized with the EMG was placed on the left side of the subject; it allowed coverage of one cycle from the latter part of the trials at 30 Hz frame rate. Ball-marker with 3cm diameter was attached to the top of the head, inorder to analyze the walking speed. One single cycle EMG data which was defined by the interval between two sequential heel contacts were recorded. The raw EMG data were filtered using 4th-order band-pass filters with cut-off frequencies of 500 Hz and 10 Hz, and subsequently full-wave rectified and low-pass filtered with moving average at 5 Hz to obtain the linear envelope. The muscular activity level was presented at percentages of peak 1-second values of the maximum voluntary contraction (%MVC) for each muscle.
Statistics: Every one cycle was normalized into 0% to 100% with a step of 1%, and its magnitude was presented as mean ± standard deviation (SD). A cross correlation function without time lag was adapted to compare the muscular activity patterns during one cycle. An one-way repeated measures analysis of variance (ANOVA) with the Dunnet post hoc test was used to compare the mean values of the data. All comparison was conducted between the LW and each speed of the WW. Statistical significance was inferred at $p < 0.05$.

RESULTS:

Muscular activity pattern: Figure 1 shows each muscular activity pattern during one single cycle for LW and WW. The cross correlation coefficient between LW and each speed of the WW were moderate negatively in the RF (r = -0.57 - -0.61), and were high positively in the TA with slow WW and GAS (r = 0.62 - 0.80).
Magnitude of muscular activity: Table 1 represents mean %MVC during one single cycle for each trial. Significantly lower muscular activities of the GAS were found in WWS and WWN than that of LW. The muscular activities of the TA and RF in the WWN and WWF were significantly higher than that of the LW. The BF activity in the WWF was significantly higher than that of the LW.
Walking speed: The walking speeds were 1.26 ± 0.14 m/s at the LW, 0.44 ± 0.08 m/s at the WWS, 0.57 ± 0.07 m/s at the WWN, 0.72 ± 0.06 m/s at the WWF. All speeds of the WW were significantly slower than that of the LW.

Table 1. The mean muscular activity during one cycle.

	LW	WWS	WWN	WWF
TA (%)	9.9 ± 2.1	8.1 ± 3.5	12.7 ± 5.0 *	17.5 ± 3.8 *
GAS (%)	15.6 ± 5.4	8.6 ± 3.9 *	11.7 ± 5.1 *	13.8 ± 5.6
RF (%)	1.8 ± 0.8	2.4 ± 1.2	3.5 ± 1.4 *	5.5 ± 2.2 *
BF (%)	4.0 ± 2.2	4.5 ± 2.8	5.5 ± 2.3	9.3 ± 4.2 *

Mean ± SD.
* ; significant difference between LW and each WW at $p < 0.05$.
LW: land walking, WWS: water walking at slow speed, WWN: water walking at normal speed, WWF: water walking at fast speed. TA: the tibialis anterior, GAS: medial gastrocnemius, RF: rectus femoris, BF: long head of the biceps femoris.

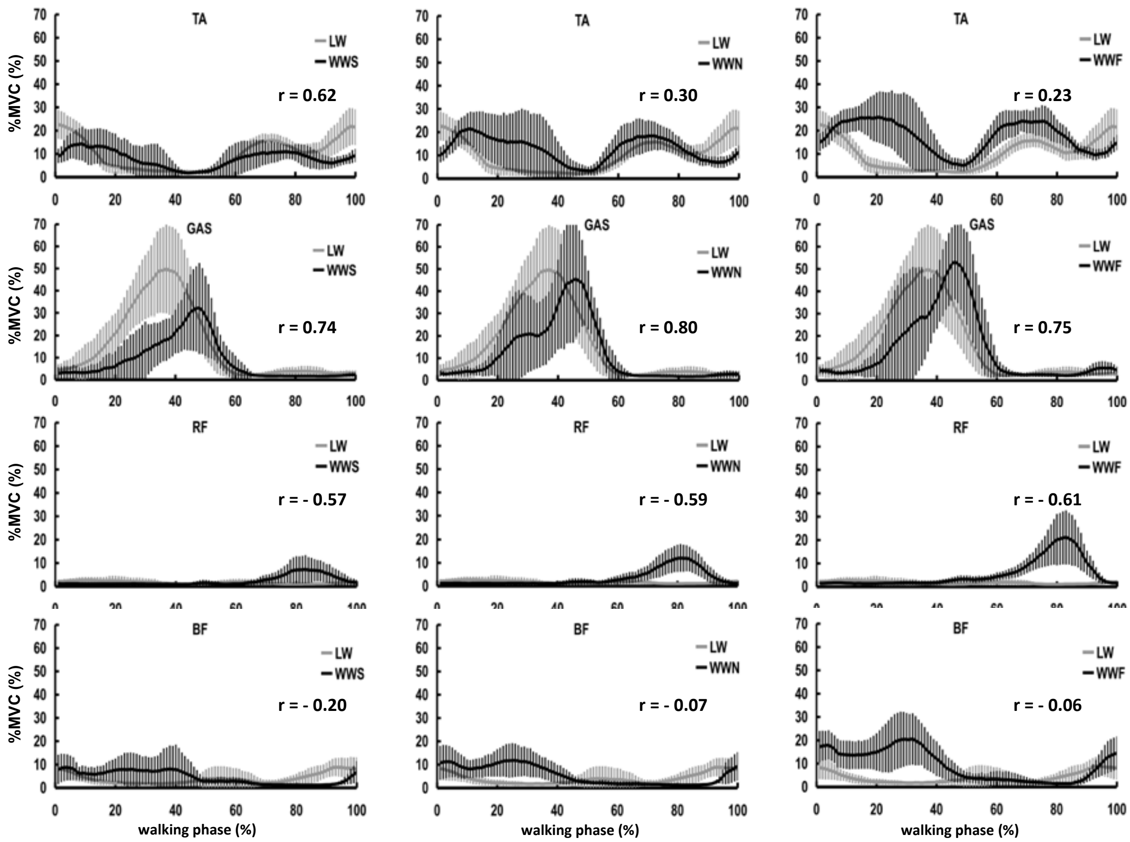

Figure 1. Each muscular activity pattern during one single cycle on LW and WW trials.
Magnitude are mean ± SD.
r: cross correlation coefficient values.
LW: land walking, WWS: water walking at slow speed, WWN: water walking at normal speed, WWF: water walking at fast speed. TA: the tibialis anterior, GAS: medial gastrocnemius, RF: rectus femoris, BF: long head of the biceps femoris.

DISCUSSION:

Muscular activity pattern: The significantly moderate to high cross correlation coefficient were obtained in comparison with the muscular activity pattern between the LW and the each speed of the WW. The moderate to high positive cross correlation coefficient would mean that the muscle activity pattern of the WW were similar to that of the LW even in the slow speed WW and fast speed WW. Especially, the correlation coefficient of the RF and BF were moderate negatively, whereas those of the TA with slower WW and GAS at the every speed were high on the WW. The reason of that in the RF was due to the higher muscular activity in the WW than the LW during the latter part of one cycle to overcome water resistance for forward swing of lower extremity (Kato et al., 2002). As for the BF, the higher muscular activity in the WW than the LW during the former part of one cycle, which was due to the generation of high propulsive force to overcome water resistance (Barela et a., 2006), would affect to the cross correlation values. In the other characteristic of the muscle activity pattern, the higher muscle activity of the TA in the WW than the LW was observed. It would be due to the function to control stable posture during the WW (Kato et al., 2002).
Magnitude of muscular activity: The magnitudes of the muscular activity of the TA and RF were significantly higher in the normal and fast speed WW than the LW, and of the BF at the fast speed WW. The reason of that was described above. The magnitude of the muscular activity of the GAS was significantly lower in the slow and normal speed WW than the LW. It

was considered that the extremely slower speed in the WW than the LW was affected to the GAS activity for generating propulsive force by ankle plantar flexion (Miyoshi et al., 2006). All walking speeds of the WW were significantly slower than the LW. However, there was no significant difference between the slow speed WW and LW in the TA, RF and BF, and between the fast speed WW and LW in the GAS. Because of that, it was considered that the thigh muscles and TA was able to stimulate sufficiently even in slow speed WW, but the GAS could not stimulate sufficiently if it was not a fast speed WW.

Availability of the water walking: Water exercise has become widely used for rehabilitation training for people with lower extremity arthritis, frail elderly people, because of the effect of the buoyancy (Suomi et al., 2000; Sato et al., 2007). From the viewpoint of the rehabilitation training, it must be important to clarify the similarity and difference between WW and LW. On one hand, many previous studies have focused on the difference between LW and WW, our present study focuses on the similarity of the muscular activity. As a result, the WW was able to simulate the LW highly regardless of the speed of the WW in the GAS, and stimulate the TA sufficiently even in the slow speed WW. It was suggested that slow speed WW also effective as a walking practice on muscle training.

CONCLUSION:

This study investigated muscular activity during LW and WW. Compared with the LW and the WW for these patterns and magnitude of the muscular activity. As a result, it was considered that the WW was able to simulate the LW highly regardless of the speed of the WW with GAS and stimulate the TA sufficiently even in the slow speed WW. And it was suggested that the slow speed WW also effective as a walking practice on muscle training.

REFERENCES:

Barela, A. Stolf, S. & Duarte, M. (2006). Biomechanical characteristics of adults walking in shallow water and on land. *Journal of Electromyography and Kinesiology.* 16(3), 250-9.

Kato, T. Sugagima, Y. Koeda, M. Fukuzawa, S. & Kitagawa, K. (2002). Electromyogram activity of leg muscles during different types underwater walking. *Advances in Exercise and Sports Physiology.* 8(2), 39-44.

Miyoshi, T. Shirota,T. Yamamoto, S. Nakazawa, K. & Akai, M. (2005). Functional roles of lower-limb joint moments while walking in water. *Clinical Biomechanics*, 20, 194-201.

Miyoshi, T. Nakazawa, K. Tanizaki, M. Sato, T. & Akai, M. (2006). Altered activation pattern in synergistic ankle plantarflexor muscles in a reduced-gravity environment. *Gait and Posture.* 24(1), 94-9.

Sato, D. Kaneda, K. Wakabayashi, H. & Nomura, T. (2007). The water exercise improves health-related quality of life of frail elderly people at day service facility. *Quality of Life Research*. 16, 1577-85.

Suomi, R. Koceja, D.M. (2000). Postural sway characteristics in women with lower extremity arthritis before and after an aquatic exercise intervention. *Archives of Physical Medicine and Rehabilitation*. 81(6), 780-785.

QUANTITATIVE ANALYSIS ON THE MUSCULAR ACTIVITY OF LOWER EXTREMITY DURING WATER WALKING

Koichi KANEDA[1], Daisuke SATO[2], Hitoshi WAKABAYASHI[3], Yuji OHGI[1] and Takeo NOMURA[4]

Graduate School of Media and Governance, Keio University, Fujisawa, JAPAN[1]
Niigata University of Health and Welfare, Niigata, JAPAN[2]
Kyushu University, Fukuoka, JAPAN[3]
NPO Tsukuba Aqua Life Research Institute, Tsukuba, JAPAN[4]

This study compared water walking (WW) with land walking (LW) in order to evaluate the muscular activities of the lower extremity. Nine young healthy subjects performed WW at voluntary slow, normal and fast speeds for 8 seconds with two repetitions. On the LW condition, subjects performed two trials at normal pace. Surface electromyography electrodes were placed on the tibialis anterior (TA), medial gastrocnemius (GAS), rectus femoris (RF) and biceps femoris (BF). As for WW, each muscular activity patterns at different speeds had moderate or high correlation with LW in cross correlation function (r = 0.53-0.90). The mean value of the muscular activity of GAS at slow speed condition during WW were lower than that of LW. At the fast speed condition, TA, RF and BF activities in WW were higher than that of LW. It was considered that WW was able to simulate LW at any levels of speeds and stimulate thigh muscles and TA sufficiently even in slow speed WW.

KEY WORDS: water, walking, electromyography, similarity.

INTRODUCTION:

Water exercise has become more popular for both the fitness enhancement and the rehabilitation training. In water, buoyancy acts on the body to reduce the gravitational stress at the joints, while water viscosity requires the subject to exert greater force than when moving on land (Miyoshi et al., 2005). Though many studies about muscular activity of water walking (WW) have been conducted and often compared with land walking (LW), almost all the studies were mainly focused on the difference between LW and WW (Kato et al., 2002; Barela et al., 2006). From the viewpoint of rehabilitation training, the similarity of LW and WW should be important. It might be able to suggest the utility of WW as a walking practice. The purpose of this study was to analyze quantitatively muscular activities of the lower extremity during WW compared with LW.

METHODS:

Subject: Nine healthy young males participated in this experiment. Their mean age, height, weight and %fat were 24.9 ± 2.2 yr, 172.0 ± 3.8 cm, 69.3 ± 3.7 kg, and 19.4 ± 4.1%, respectively. Ethics Committee of the Institute of Health and Sports Sciences in the University of Tsukuba approved this study.

Experimental design: Subjects performed LW at normal (comfortable) speed. On the other hand, for the WW, they walked voluntary slow, normal and fast speed for 8 seconds with two repetitions. The water temperature was kept 27 ± 2°C. Depth of the pool was 1.1 m which corresponds to approximately the level of the navel.

Electromyogram recordings: The left lower extremity muscular activity of the tibialis anterior (TA), medial gastrocnemius (GAS), rectus femoris (RF) and long head of the biceps femoris (BF) were measured using a surface electromyography (EMG) electrodes (Mini Ag/AgCl Skin Electrode, NT-511G; Nihon Kohden Corp., Japan) at 1.5 cm intervals of two electrodes. A reference electrode was placed on the clavicle. The skin cuticle was removed carefully using a blood lancet (Blood Lancet; Asahi Polyslider Co. Ltd., Japan) and cleaned with alcohol wipes so that the inter-electrode impedance was less than 20 kΩ. The electrodes were covered with transparent film and putty for waterproofing. Subjects were instructed to perform isometric maximal voluntary contraction (MVC) for 5 seconds for each muscle on land in advance. The raw EMG signals were collected by using the eight-channel multi-telemeter system (WEB-5500 multi-telemeter system; Nihon Kohden Corp., Japan) at a time constant of 0.03 seconds and with 2 kHz sampling rate.

Data analysis: A digital video camera which was synchronized with the EMG was placed on the left side of the subject; it allowed coverage of one cycle from the latter part of the trials at 30 Hz frame rate. Ball-marker with 3cm diameter was attached to the top of the head, inorder to analyze the walking speed. One single cycle EMG data which was defined by the interval between two sequential heel contacts were recorded. The raw EMG data were filtered using 4th-order band-pass filters with cut-off frequencies of 500 Hz and 10 Hz, and subsequently full-wave rectified and low-pass filtered with moving average at 5 Hz to obtain the linear envelope. The muscular activity level was presented at percentages of peak 1-second values of the maximum voluntary contraction (%MVC) for each muscle.

Statistics: Every single cycle duration was normalized into 0% to 100% with a step of 1%, and its data was presented as mean ± standard deviation (SD). A cross correlation function was adapted to compare the muscular activity patterns during one cycle. An one-way repeated measures analysis of variance (ANOVA) with the Dunnet post hoc test was used to compare the mean values of the data. All comparison was conducted between the LW and each speed of the WW. Statistical significance was inferred at $p < 0.05$.

RESULTS:

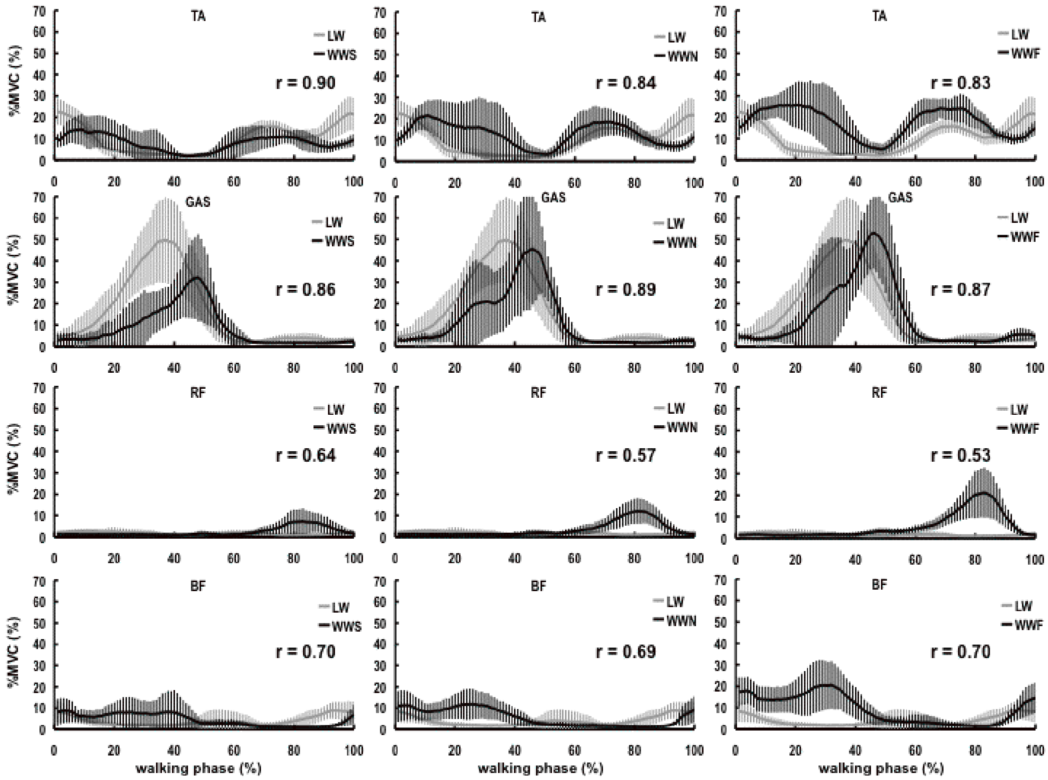

Figure 1. Each muscular activity pattern during one single cycle on LW and WW trials.
Values are mean ± SD.
r: cross correlation coefficient values.
LW: land walking, WWS: water walking at slow speed, WWN: water walking at normal speed, WWF: water walking at fast speed. TA: the tibialis anterior, GAS: medial gastrocnemius, RF: rectus femoris, BF: long head of the biceps femoris.

Muscular activity pattern: Figure 1 shows each muscular activity pattern during one single cycle for LW and WW. The cross correlation coefficients between LW and each speed of the WW were moderate in the RF and BF ($r = 0.53 - 0.70$), and were high in the TA and GAS ($r = 0.83 - 0.90$). All coefficient values were significant ($p < 0.05$).
Mean values of muscular activity: Table 1 represents the mean values of the %MVC during one single cycle for each trial. Significant lower muscular activities of the GAS were found in slow and normal speed WW than that of LW ($p < 0.05$). The muscular activities of the TA in the normal and fast speed WW were significantly higher than that of the LW ($p < 0.05$). The muscular activities of the RF were also significantly higher in the normal and fast speed WW than the LW ($p < 0.05$). The BF activity in the fast speed WW was significantly higher than that of the LW ($p < 0.05$).
Walking speed: The walking speeds were 1.26 ± 0.14 m/s at the LW, 0.44 ± 0.08 m/s at the slow speed WW, 0.57 ± 0.07 m/s at the normal speed of the WW, 0.72 ± 0.06 m/s at the fast speed WW. All speeds of the WW were significantly slower than that of the LW ($p < 0.05$).

Table 1. The mean values of the muscular activity during one cycle.

	LW	WWS	WWN	WWF
TA (%)	**9.9 ± 2.1**	**8.1 ± 3.5**	**12.7 ± 5.0 ***	**17.5 ± 3.8 ***
GAS (%)	**15.6 ± 5.4**	**8.6 ± 3.9 ***	**11.7 ± 5.1 ***	**13.8 ± 5.6**
RF (%)	**1.8 ± 0.8**	**2.4 ± 1.2**	**3.5 ± 1.4 ***	**5.5 ± 2.2 ***
BF (%)	**4.0 ± 2.2**	**4.5 ± 2.8**	**5.5 ± 2.3**	**9.3 ± 4.2 ***

Mean ± SD.
* ; significant difference between LW and each WW at $p < 0.05$.
LW: land walking, WWS: water walking at slow speed, WWN: water walking at normal speed, WWF: water walking at fast speed. TA: the tibialis anterior, GAS: medial gastrocnemius, RF: rectus femoris, BF: long head of the biceps femoris.

DISCUSSION:

Muscular activity pattern: The muscular activity patterns of the LW and each speed of the WW in the present study were very similar to the previous study which investigated the activitys of TA, GAS, BF, vastus lateralis, erector spine and rectus abdominis during normal speed of WW (Barela et al., 2006). The peak activities of the GAS in WW were relatively 10% later than that of in LW. On the other hand, the TA was activated mainly during the swing phase, and BF was activated during the support phase. Statistical analysis revealed that the significantly moderate to high cross correlation coefficients were obtained in comparison between the LW and the each speed of the WW. The moderate to high cross correlation coefficient indicate that the muscle activity pattern of the WW were similar to that of the LW even in the slow speed WW and fast speed WW. Especially, the correlation coefficients of the RF and BF were moderate, whereas those of the TA and GAS were high at the every speed on the WW. The reason of that in the RF was due to the higher muscular activity in the WW than the LW during the latter phase of one cycle to overcome water resistance for forward swing of lower extremity (Kato et al., 2002). As for the BF, the higher muscular activity in the WW than the LW during the former part of one cycle, which was due to the generation of high propulsive force to overcome water resistance (Barela et al., 2006), would affect to the moderate cross correlation values. In addition, the authors found that the higher muscle activity of the TA in WW than that of on LW. It was considered that subjects should to walk with stable posture during WW (Kato et al., 2002).
Mean values of the muscular activity: The mean values of the muscular activity of the TA and RF were significantly higher in the normal and fast speed WW than that of the LW, and in the BF, the muscular activity was significantly higher in the fast speed WW than LW. The reason of that was to overcome water resistance during forward swing and to generate high propulsive force during stance phase (Kato et al., 2002; Barela et al., 2006) with stable posture (Kato et al., 2002). The mean values of the muscular activity of the GAS were

significantly lower in the slow and normal speed WW than the LW. Kato et al (2004) found that the GAS activity during WW was higher than LW in the same walking speed. However, the maximal walking speed of the present study during WW was slower than that of during LW. It was considered that the extremely slow speed in the WW was affected to the GAS activity for generating propulsive force by ankle plantar flexion (Miyoshi et al., 2006). However, there was no significant difference between the slow speed WW and LW among the TA, RF and BF, and between the fast speed WW and LW in the GAS. It was considered that the thigh muscles and TA was able to stimulate sufficiently even in slow speed WW, however GAS could stimulate insufficiently except at the fast speed WW.

Availability of the water walking: Water exercise has become widely used for rehabilitation training for people with lower extremity arthritis and frail elderly people, because of the effect of the buoyancy (Suomi et al., 2000; Sato et al., 2007). From the viewpoint of the rehabilitation training, it must be important to clarify both the similarity and the difference between WW and LW. On one hand, many previous studies have focused on the difference between LW and WW, our present study focuses on the similarity of the muscular activity. As a result, the WW was able to simulate the LW highly regardless of the speed of the WW, and stimulate the thigh muscles and TA sufficiently even in the slow speed WW. It was suggested that the slow speed WW also effective as a walking practice on muscle training especially in thigh muscles and TA with less risk of injury and increased overall safety (Devereux et al., 2005).

CONCLUSION:

This study investigated muscular activity during LW and WW, and compared with the LW and the WW for these patterns and mean values of the muscular activity. As a result, the walking patterns of the WW, even in the slow and fast speed conditions, were highly simulated to that of the LW. Additionally, the slow speed WW could stimulate thigh muscle and TA sufficiently, because there was no difference in the mean values of the muscular activities. Therefore, the WW has a possibility to adopt as a walking practice on muscle training for those who aims to re-acquire walking ability in daily life, such as, frail elderly receiving nursing care.

REFERENCES:

Barela, A. Stolf, S. & Duarte, M. (2006). Biomechanical characteristics of adults walking in shallow water and on land. *Journal of Electromyography and Kinesiology.* 16(3), 250-259.

Devereux, K. Robertson, D. & Bri�a, K. (2005). Effects of a water-based program on women 65 years and over: a randomized controlled trial. *Australian Journal of Physiotherapy.* 51(2), 102–108.

Kato, T. Sugagima, Y. Koeda, M. Fukuzawa, S. & Kitagawa, K. (2002). Electromyogram activity of leg muscles during different types underwater walking. *Advances in Exercise and Sports Physiology.* 8(2), 39-44.

Miyoshi, T. Shirota,T. Yamamoto, S. Nakazawa, K. & Akai, M. (2005). Functional roles of lower-limb joint moments while walking in water. *Clinical Biomechanics*, 20, 194-201.

Miyoshi, T. Nakazawa, K. Tanizaki, M. Sato, T. & Akai, M. (2006). Altered activation pattern in synergistic ankle plantarflexor muscles in a reduced-gravity environment. *Gait and Posture.* 24(1), 94-99.

Sato, D. Kaneda, K. Wakabayashi, H. & Nomura, T. (2007). The water exercise improves health-related quality of life of frail elderly people at day service facility. *Quality of Life Research*. 16, 1577-1585.

Suomi, R. Koceja, D.M. (2000). Postural sway characteristics in women with lower extremity arthritis before and after an aquatic exercise intervention. *Archives of Physical Medicine and Rehabilitation*. 81(6), 780-785.