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Gait Patterns and Muscle Activity in the Lower Extremities of Elderly Women during Underwater Treadmill Walking against Water Flow

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Abstract This study sought to determine the characteristics of gait patterns and muscle activity in the lower extremities of elderly women during underwater treadmill walking against water flow. Eight female subjects (61.4±3.9 y) performed underwater and land treadmill walking at varying exercise intensities and velocities. During underwater walking (water level at the xiphoid process) using the Flowmill, which has a treadmill at the base of a water flume, the simultaneous belt and water flow velocities were set to 20, 30 and $4\,m \cdot min^{-1}$. Land walking velocities were set to 40, 60 and $80\,m \cdot min^{-1}$. Oxygen uptake and heart rate were measured during both walking exercises. Maximum and minimum knee joint angles, and mean angular velocities of knee extension and knee flexion in the swing phase were calculated using two-dimensional motion analysis. Electromyograms were recorded using bipolar surface electrodes for five muscles: the tibialis anterior (TA), medial gastrocnemius (MG), vastus medialis (VM), rectus femoris (RF) and biceps femoris (BF). At the same exercise intensity level, cadence was almost half that on land. Step length did not differ significantly because velocity was halved. Compared to land walking, the maximum and minimum knee joint angles were significantly smaller and the mean angular velocity of knee extension was significantly lower. Knee extension in the swing phase was limited by water resistance. While the muscle activity levels of TA, VM and BF were almost the same as during land walking, those of MG and RF were lower. At the same velocity, exercise intensity was significantly higher than during land walking, cadence was significantly lower, and step length significantly larger. The knee joint showed significantly smaller maximum and minimum angles, and the mean angular velocity of knee flexion was significantly larger. The muscle activity levels of TA, VM, and BF increased significantly in comparison with land walking, although those of MG and RF did not significantly differ. Given our findings, it appears that buoyancy, lower cadence, and a moving floor influenced the muscle activity level of MG and RF at the same exercise intensity level and at the same velocity. These results show promise of becoming the basic data of choice for underwater walking exercise prescription. *J Physiol Anthropol 26(6): 579–586, 2007* http://www.jstage.jst.go.jp/browse/jpa2
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Keywords: gait pattern, muscle activity in the lower extremities, elderly women, underwater treadmill walking against water flow

Introduction

In the water, resistance and buoyancy make it possible to expend high levels of energy while simultaneously reducing strain and impact force on the lower extremity joints. For this reason, underwater exercise is effective for individuals suffering from hip, leg, or back problems as well as for the middle-aged and elderly whose physical fitness has decreased through aging and physical inactivity. Underwater walking is one such form of exercise and can be practiced by individuals without swimming skill. It is also an easy aerobic activity for middle-aged and elderly people who wish to start underwater exercise.

Numerous studies have reported metabolic and cardiorespiratory responses during underwater walking (Evans et al., 1978; Gleim and Nicholas, 1989; Migita et al., 1994, 1996; Hotta et al., 1993ab, 1994, 1995; Hall et al., 1998; Shimizu et al., 1998; Shono et al., 2000, 2001ab). However, of the few reports that have investigated muscle activity (Nishizono et al., 1994; Takaishi et al., 1994; Watanabe et al., 1995; Yamamoto et al., 2001; Kato et al., 2002ab) and kinematic analyses (Miyakawa and Onodera, 1999; Miyoshi et al., 2001; Kato et al., 2001, 2002ab; Shono et al., 2004) during such exercise, the majority have compared underwater walking with land walking at the same velocity. During underwater walking in a swimming pool, it is difficult to exceed a velocity of $0.8\,\mathrm{m \cdot sec^{-1}}$ ($48\,\mathrm{m \cdot min^{-1}}$) (Evans et al., 1978; Kato et al., 2002a), and this velocity is very low when compared to the typical range of walking velocity on land. Since walking exercise for health at such a low velocity is rarely recommended, comparison at the same exercise intensity level is necessary in order to obtain data to facilitate exercise prescription. From the viewpoint of exercise intensity, underwater walking is considered suitable for maintaining and improving the health of the middle-aged and elderly. Gait patterns during land walking, however, change with aging. To date, there are few reports comparing underwater walking and land walking at the same exercise intensity level among middle-aged and elderly populations (Shono et al., 2004).

Underwater walking in a swimming pool can also involve the use of certain underwater walking devices, such as the underwater treadmill. However, since their use changes the characteristics of the underwater walking exercises, it is necessary to analyze these characteristics separately in order to clarify how underwater walking can be of the most practical use. Using the Flowmill, which has a treadmill at the base of a water flume, underwater treadmill walking is performed against water flow of the same velocity as walking velocity. Thus, users show a cardiorespiratory response similar to that for swimming pool walking, because water resistance equal to that of swimming pool walking is included in the exercise (Migita et al., 1994; Shono et al., 2002). In addition, as the highest walking velocity is around $50\,\mathrm{m \cdot min^{-1}}$ using the Flowmill (Shono et al., 2000), underwater walking utilizing this device should be very similar to underwater walking in a swimming pool.

The present study sought to determine the characteristics of gait patterns and muscle activity in the lower extremities of the elderly during underwater treadmill walking against water flow and to compare the data to land treadmill walking.

Methods

Subjects

Eight healthy female volunteers were recruited as subjects. All belonged to the same sports club and regularly swam and exercised in the water. Mean age, height, weight and body-fat level were 61.4 ± 3.9 y, 155.0 ± 2.5 cm, 58.4 ± 6.0 kg, and $25.3 \pm 6.0\%$, respectively. Body-fat level was determined from the triceps and subscapula fat folds. The mean$\pm$SD result for the 10 m maximum walking test was 4.9 ± 0.25 seconds. That for the 10 m obstacle walking test, in which subjects step over six obstacles (height: 20 cm, length: 10 cm, width: 50 cm) at 2 m intervals, including the start line and goal, was 6.0 ± 0.49 seconds.

This study was approved by the Ethics Committee of the Institute of Health Science, Kyushu University. Before testing, each subject was informed of the purpose of the study and the testing procedures. All subjects gave written informed consent to participate.

Protocol

Underwater walking was performed using the Flowmill (FM1200D, Japan Aqua Tech Co., Ltd., Japan), which has a treadmill at the base of a water flume. All subjects had previously walked in the water with the Flowmill and appeared to be familiar with its use. Each subject completed three consecutive rounds of walking for 4 minutes per round, each round at progressively increasing belt and water-flow velocities (20, 30, and $40\,\mathrm{m \cdot min^{-1}}$), with a 1-minute rest interval after the first and second rounds. Since blood lactate concentration when walking at $50\,\mathrm{m \cdot min^{-1}}$ was found to be significantly higher than at rest and at lower velocities used in a previous study (Shono et al., 2000), the maximum walking velocity in the water was set at $40\,\mathrm{m \cdot min^{-1}}$. Subjects were instructed to swing both arms in order to maintain balance while walking. The water level was at the xiphoid process for each subject. The water temperature was 30.7 ± 0.1°C.

Land walking was performed on a treadmill (WOODWAY ELG-2, Sakai Co., Ltd., Japan). The subjects had used the machine before and appeared familiar with its use. To obtain the same level of physiological effort as during Flowmill walking, approximately double the velocity is required when walking on a land treadmill (Migita et al., 1994). Thus, the maximum walking velocity of the treadmill was set to $80\,\mathrm{m \cdot min^{-1}}$. The grade of the treadmill was 0%. Each subject completed three consecutive 4-minute walks in air at a progressively increasing velocity (40, 60, and $80\,\mathrm{m \cdot min^{-1}}$), with a 1-minute rest interval after both the first and second walks. During the interval the subject rested in a chair for at least 10 minutes until heart rate (HR) recovered to the pre-exercise value. The room temperature and relative humidity were 24.6 ± 0.7°C and $56.4 \pm 7.5\%$, respectively.

Subjects completed land walking before starting the underwater walking.

Measurements

Oxygen uptake ($\dot{V}O_2$) was determined every 30 seconds during the experiment by a mass spectrometer (WSMR-1400, WESTRON CORP., Japan) and an automatic breath-by-breath gas-exchange measurement system (RM-300i, Minato Medical Science Co., Ltd., Japan). HR was monitored using telemetry (ST-30, DS-501, Fukuda Denshi Co., Ltd., Japan) and recorded every 30 seconds. The HR reserve method was used to estimate individual exercise intensity. Relative HR reserve (%HRR) was calculated using the following equations: %HRR$=$[(HR exercise$-$HR rest)/(HR max$-$HR rest)]$\times$100. HR max$=$220$-$age (years). We defined HR rest as the minimal HR during pre-exercise rest.

Walking motion was recorded on videotape (DCR-TRV20, SONY, Japan) from the right side of the subject, where 3 points were marked (hip joint, knee joint and ankle joint) (Fig. 1).

Maximum and minimum knee joint angles, and mean angular velocities of knee extension and knee flexion in the swing phase were calculated using two-dimensional motion analysis software (2DMADT Ver 3.0, Neuroscience Co., Ltd., Japan). The swing phase was defined from the right toe-off to the next right foot contact. Stable walking in the final minute of each phase was used for analysis. Step frequency was measured for 60 seconds in the third minute of each exercise round and was defined as cadence. The velocity of each exercise was divided by each cadence and defined as step length.

An electromyogram (EMG) was recorded using bipolar surface electrodes (8 mm in diameter) placed 20 mm apart on the right lower extremity for five muscles: the tibialis anterior (TA), medial gastrocnemius (MG), vastus medialis (VM), rectus femoris (RF), and biceps femoris (BF). The EMG signals were telemetered via a multi-channel biotelemeter system (Multi Telemeter, Nihon-Koden, Japan), and transformed into digital data at a sampling rate of 1 kHz using an AD converter (MacLab, AD Instruments, USA). For the quantitative measurement of muscle activity, the signal was full-wave rectified and the integrated EMG (iEMG) was obtained. Stable walking for the final minute of each phase was used for analysis. The iEMG values of one walking cycle for each muscle were calculated five times. The mean values were divided by the time needed for one walking cycle and then the integral value of quantity of discharge per second was calculated. To standardize the iEMG data, maximum voluntary contraction (MVC) was used for the five muscles of each subject and referred to as %MVC. MVC for each muscle was measured on land before the walking trials.

Statistical analyses

All values are expressed as means±SD. The relationship between HR and $\dot{V}O_2$ was analyzed by linear regression. All data were analyzed by repeated-measures ANOVA. The post-hoc Scheffe test was used to determine statistical difference. Differences at $p<0.05$ were considered significant for all statistical analyses.

Results

Heart rate and oxygen uptake

Relationships between HR and $\dot{V}O_2$ during underwater and land treadmill walking are shown in Fig. 2. A highly significant linear relationship was found between HR and $\dot{V}O_2$ during both walks (land: $R^2=0.994$, $p<0.05$; underwater: $R^2=0.997$, $p<0.05$). The relationship between HR and $\dot{V}O_2$ in both exercise modes was similar. We therefore used the HR reserve method to estimate individual exercise intensity. There were no significant differences between %HRR during underwater walking at 40 m·min^{-1} (42.5±8.3%) and land walking at 80 m·min^{-1} (37.0±7.0%), or between %HRR during underwater walking at 30 m·min^{-1} (23.0±3.0%) and land walking at 60 m·min^{-1} (26.2±4.3%). %HRR during underwater walking at 20 m·min^{-1} (12.3±4.5%), however, was significantly lower than during land walking at 40 m·min^{-1} (22.5±3.5%, $p<0.01$). In addition, %HRR during underwater walking at 30 m·min^{-1} and land walking at 40 m·min^{-1} did not significantly differ and showed almost the same mean values. At the same velocity (40 m·min^{-1}), %HRR during underwater walking was significantly higher than during land walking ($p<0.0001$).

Cadence and step length

Relationships between %HRR and cadence, and %HRR and step length for each walking exercise are shown Fig. 3. Cadence during underwater walking at 40 m·min^{-1} (66.1±10.1 steps·min^{-1}) was significantly lower than during land walking at 80 m·min^{-1} (123.1±8.0 steps·min^{-1}, $p<0.0001$). Cadence during underwater walking at 30 m·min^{-1} (56.0±10.3 steps·min^{-1}) was significantly lower

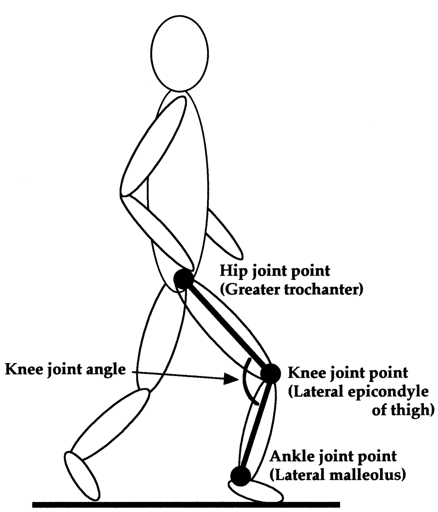

Fig. 1 Diagram of the analyzed points and the measured knee joint angle.

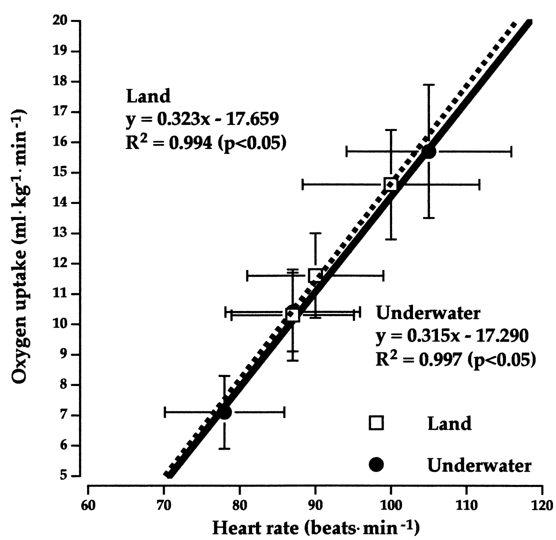

Fig. 2 Relationships between heart rate and oxygen uptake during underwater and land treadmill walking.

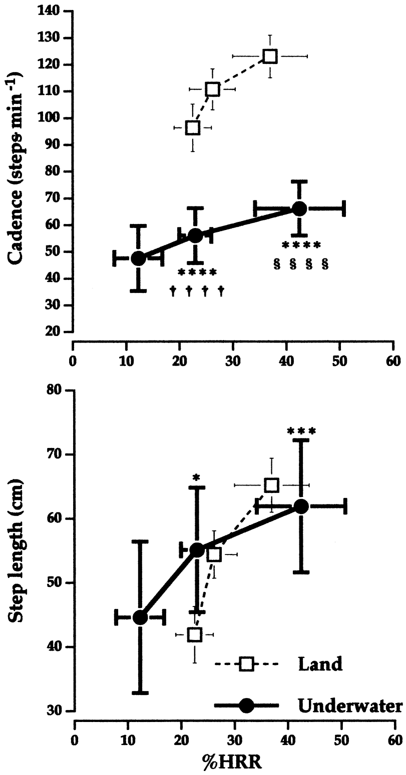

Fig. 3 Relationships between exercise intensity (%HRR) and cadence, and exercise intensity (%HRR) and step length during underwater and land treadmill walking. $^{*}p<0.05$, $^{***}p<0.001$, $^{****}p<0.0001$ vs land treadmill walking at 40 m·min^{-1}, $^{\dagger\dagger\dagger\dagger}p<0.0001$ vs land treadmill walking at 60 m·min^{-1}, $^{\S\S\S\S}p<0.0001$ vs land treadmill walking at 80 m·min^{-1}.

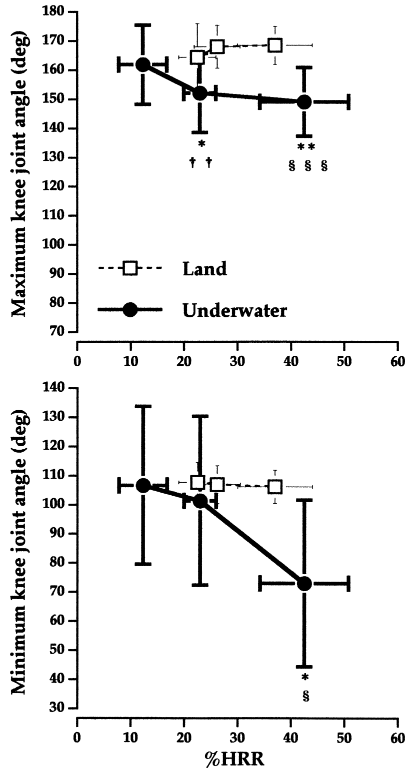

Fig. 4 Relationships between exercise intensity (%HRR) and maximum knee joint angle in the swing phase, and exercise intensity (%HRR) and minimum knee joint angle in the swing phase during underwater and land treadmill walking. $^{*}p<0.05$, $^{**}p<0.01$ vs land treadmill walking at 40 m·min^{-1}, $^{\dagger\dagger}p<0.01$ vs land treadmill walking at 60 m·min^{-1}, $^{\S}p<0.05$, $^{\S\S\S}p<0.001$ vs land treadmill walking at 80 m·min^{-1}.

than during land walking at 40 m·min^{-1} (96.4±8.9 steps·min^{-1}, $p<0.0001$) and at 60 m·min^{-1} (110.8±7.7 steps·min^{-1}, $p<0.0001$). Compared to land walking at 40 m·min^{-1} (41.9±4.4 cm), step length during underwater walking at 30 m·min^{-1} (55.1±9.7 cm) was significantly higher ($p<0.05$). At the same velocity (40 m·min^{-1}), cadence during underwater walking was significantly lower ($p<0.0001$) and step length during underwater walking (61.9±10.3 cm) was significantly higher ($p<0.001$).

Maximum and minimum knee joint angles in the swing phase

Relationships between %HRR and maximum knee joint angle in the swing phase, and %HRR and minimum knee joint angle in the swing phase for each walking exercise are shown in Fig. 4. Though neither parameter changed much during land walking, there was a tendency to decrease with an increase in exercise intensity during underwater walking. Maximum knee joint angle during underwater walking at 40 m·min^{-1} (149.0±11.8 degrees) was significantly smaller than during land walking at 80 m·min^{-1} (168.4±6.5 degrees, $p<0.001$). Maximum knee joint angle during underwater walking at 30 m·min^{-1} (152.1±13.6 degrees) was significantly smaller than during land walking at 40 m·min^{-1} (164.4±11.5 degrees, $p<0.05$) and at 60 m·min^{-1} (168.0±7.4 degrees, $p<0.01$). Compared to land walking at 80 m·min^{-1} (106.1±5.7 degrees), minimum knee joint angle during underwater walking at 40 m·min^{-1} (72.9±28.6 degrees) was significantly smaller ($p<0.05$). At the same velocity (40 m·min^{-1}), maximum knee joint angle during underwater walking was significantly smaller ($p<0.01$), as was minimum knee joint angle (land: 107.6±6.9 degrees, $p<0.05$).

Mean angular velocities of knee extension and knee flexion in the swing phase

Relationships between %HRR and mean angular velocity of knee extension in the swing phase, and %HRR and mean angular velocity of knee flexion in the swing phase for each walking exercise are shown Fig. 5. Mean angular velocity during knee extension for underwater walking was significantly lower at 40 m·min^{-1} (166.0±64.6 deg·sec^{-1}) than during land walking at 80 m·min^{-1} (275.8±26.3 deg·sec^{-1}, $p<0.001$), as well as at 30 m·min^{-1} (88.9±43.4 deg·sec^{-1}) compared to land walking at 40 m·min^{-1} (189.6±33.8 deg·sec^{-1}, $p<0.001$) and at 60 m·min^{-1} (233.5±25.6 deg·sec^{-1}, $p<0.0001$). There was no significant

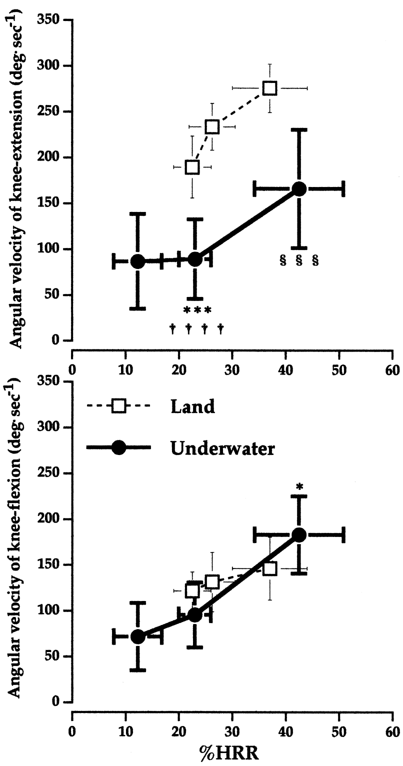

Fig. 5 Relationships between exercise intensity (%HRR) and mean angular velocity of knee-extension in the swing phase, and exercise intensity (%HRR) and mean angular velocity of knee-flexion in the swing phase during underwater and land treadmill walking. $^{*}p<0.05$, $^{***}p<0.001$ vs land treadmill walking at $40\,m\cdot min^{-1}$, $^{\dagger\dagger\dagger\dagger}p<0.0001$ vs land treadmill walking at $60\,m\cdot min^{-1}$, $^{\S\S\S}p<0.001$ vs land treadmill walking at $80\,m\cdot min^{-1}$.

difference in mean angular velocity of knee flexion at the same exercise intensity levels. At the same velocity ($40\,m\cdot min^{-1}$), mean angular velocity of knee flexion for underwater walking ($182.9\pm42.1\,deg\cdot sec^{-1}$) was significantly higher than for land walking ($121.9\pm20.4\,deg\cdot sec^{-1}$, $p<0.05$).

Muscle activity in the lower extremities

Figure 6 shows the relationships between %HRR and %MVC for each muscle during both walking exercises. For TA, VM, and BF, %HRR and %MVC showed a similar tendency to increase in both walking exercises. However, the activity levels of MG and RF during underwater walking showed a tendency to decrease compared to land walking at the same exercise intensity level. %MVC of MG during underwater walking at $40\,m\cdot min^{-1}$ ($19.7\pm11.0\%$) was significantly lower than during land walking at $80\,m\cdot min^{-1}$ ($49.2\pm11.7\%$, $p<0.0001$). %MVC of MG during underwater walking at $30\,m\cdot min^{-1}$ ($12.9\pm6.3\%$) was significantly lower than during land walking at $60\,m\cdot min^{-1}$ ($32.6\pm9.1\%$, $p<0.01$). %MVC of RF during underwater walking at $40\,m\cdot min^{-1}$ ($17.4\pm9.6\%$) was significantly lower than during land walking at $80\,m\cdot min^{-1}$ ($38.6\pm17.1\%$, $p<0.001$), as well as at $30\,m\cdot min^{-1}$ ($14.1\pm10.7\%$) compared to land walking at $60\,m\cdot min^{-1}$ ($28.8\pm13.2\%$, $p<0.05$). At the same velocity ($40\,m\cdot min^{-1}$), %MVC of TA, VM, and BF during underwater walking ($37.7\pm14.9\%$, $32.6\pm16.5\%$, and $31.9\pm4.2\%$, respectively) was significantly higher than during land walking ($19.8\pm6.6\%$, $p<0.05$; $13.6\pm7.5\%$, $p<0.05$; and $19.3\pm4.7\%$, $p<0.01$, respectively).

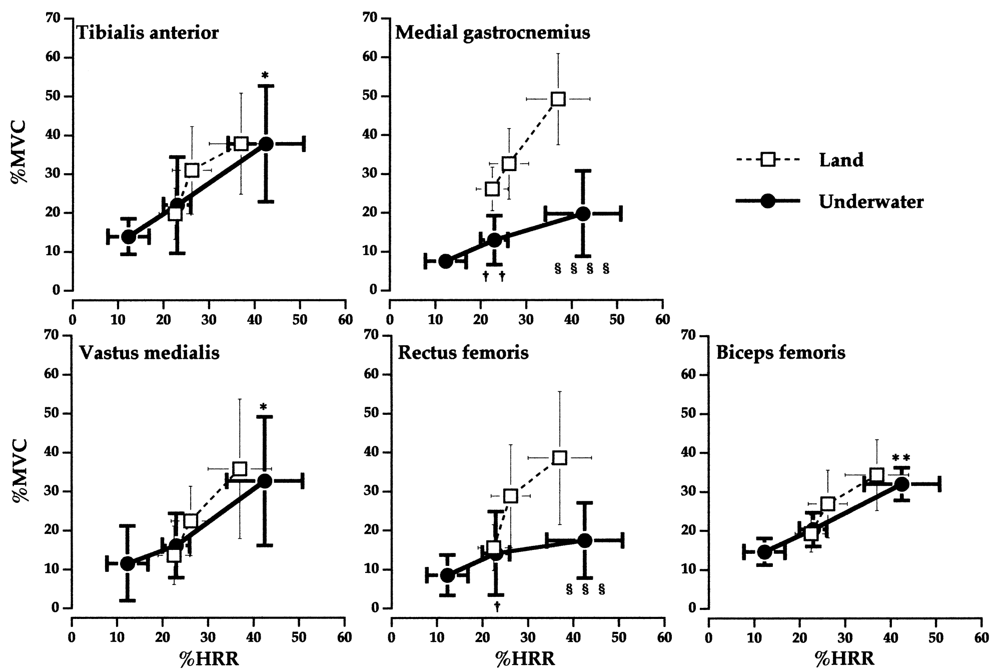

Fig. 6 Relationships between exercise intensity (%HRR) and relative iEMG (%MVC) for five muscles in the lower extremities during underwater and land treadmill walking. $^{*}p<0.05$, $^{**}p<0.01$ vs land treadmill walking at $40\,m\cdot min^{-1}$, $^{\dagger}p<0.05$, $^{\dagger\dagger}p<0.01$ vs land treadmill walking at $60\,m\cdot min^{-1}$, $^{\S\S\S}p<0.001$, $^{\S\S\S\S}p<0.0001$ vs land treadmill walking at $80\,m\cdot min^{-1}$.

Discussion

Cadence and step length

Compared to land walking at the same velocity, lower cadence or stride frequency has been reported in the water (Kato et al., 2001, 2002b; Shono et al., 2004). During underwater walking in the present study, cadence was significantly lower and step length was significantly longer than during land walking at the same velocity.

Comparing underwater walking and land walking at the same exercise intensity level ($40\,\mathrm{m \cdot min^{-1}}$ versus $80\,\mathrm{m \cdot min^{-1}}$, and $30\,\mathrm{m \cdot min^{-1}}$ versus $60\,\mathrm{m \cdot min^{-1}}$, respectively), we found that cadence during underwater walking was significantly lower, at almost half that observed on land. However, there was no significant difference in step length because velocity was halved. Although underwater walking at $30\,\mathrm{m \cdot min^{-1}}$ and land walking at $40\,\mathrm{m \cdot min^{-1}}$ showed the same exercise intensity level, cadence was significantly lower and step length was significantly higher during underwater walking. Furthermore, even though the exercise intensity level was significantly higher during land walking at $40\,\mathrm{m \cdot min^{-1}}$ than during underwater walking at $20\,\mathrm{m \cdot min^{-1}}$, cadence during underwater walking was almost half that on land and step length did not significantly differ. These findings suggest that water resistance and buoyancy exert a complicated influence on exercise performed in water.

Maximum and minimum knee joint angles in the swing phase

At the same exercise intensity levels when maximum knee joint angle in the swing phase during underwater walking was significantly smaller than during land walking, knee extension in the swing phase was found to be limited by water resistance. When the minimum knee joint angle in the swing phase during underwater walking at $40\,\mathrm{m \cdot min^{-1}}$ was significantly smaller than during land walking at $80\,\mathrm{m \cdot min^{-1}}$, knee flexion in the swing phase markedly increased to compensate for the influence of water resistance. At the same velocity, the maximum and minimum knee joint angles in the swing phase during underwater walking were significantly smaller than during land walking, indicating clearly the influence of water resistance. Underwater walking has a significantly shorter double-support phase than land walking (Shono et al., 2004). It is considered one of the reasons why peak value corresponding to braking force during the stance phase on land does not appear in the water; instead the driving force propelling the body forward in the water appears throughout the stance phase (Miyoshi et al., 2001). Thus, it is considered that transfer to the forward leg begins early. In other words, the braking phase is omitted for the forward leg due to water resistance, and could therefore produce the driving force required to propel the body forward immediately after heel contact. The limit of knee extension in the swing phase appears to be one factor demonstrating the omission of the braking phase due to water resistance.

Mean angular velocities of knee extension and knee flexion in the swing phase

Mean angular velocity of knee extension during underwater treadmill walking in still water at $40\,\mathrm{m \cdot min^{-1}}$ was significantly lower than during land treadmill walking at the same velocity (Miyakawa and Onodera, 1999). In the present study, although the mean angular velocity of knee extension during underwater walking was significantly lower at the same exercise intensity level, there was no significant difference at the same velocity. The maximum knee joint angle during land walking was also observed frequently before heel contact, whereas during underwater walking, it was observed frequently in the midstance phase. This appears to be due to the influence of water resistance and buoyancy. Therefore, the swing phase was investigated in the present study. Different results from the present study may be found in one walking cycle using a different method of analysis.

Miyakawa and Onodera (1999) reported that no significant difference was observed in the mean angular velocity of knee flexion between land treadmill walking and underwater treadmill walking in still water at the same velocity ($40\,\mathrm{m \cdot min^{-1}}$), but a significantly higher value was observed during underwater treadmill walking in viscous water. In the present study, it was considered that the mean angular velocity of knee flexion at the same velocity showed a higher value during underwater walking because water resistance was increased due to the influence of water flow.

Muscle activity in the lower extremities

From the findings of the relationship between %HRR and %MVC, the activity levels of TA, VM, and BF during underwater walking at the same exercise intensity levels was almost the same as that during land walking. Conversely, %MVC of MG and RF during underwater walking tended to decrease markedly and thus the activity levels of MG and RF during underwater walking can be considered lower than during land walking.

At the same velocity, the activity levels of TA, VM, and BF during underwater walking were significantly higher than during land walking, and exercise intensity during underwater walking was significantly higher than during land walking. At the same velocity, it is common to perform underwater walking in a swimming pool (Nishizono et al., 1994; Takaishi et al., 1994; Kato et al., 2002b) or using an underwater treadmill in still water or a swimming flume (Kato et al., 2002ab) in order to increase the activity level of TA above that for land walking. The present study confirmed that the activity level of TA increased significantly in underwater treadmill walking against water flow.

The activity level of VM was higher in the swimming pool (water level at the waist) than during treadmill walking on land at $0.8\,\mathrm{m \cdot sec^{-1}}$ (Kato et al., 2002b). When the underwater treadmill (water level at the navel and diaphragm) has a belt that moves in still water, the activity level of VM does not differ significantly from land walking (Watanabe et al., 1995).

In the present study, however, the activity level of VM showed a significant increase when using the underwater treadmill with a belt that moves in a current. This finding suggests that the activity of VM is increased due to the influence of water flow. Therefore, one of the reasons why the activity level of VM increased in the present study appears to be due to a difference in the device used for water walking.

The activity level of BF was found to increase using an underwater treadmill in still water (Watanabe et al., 1995; Yamamoto et al., 2001) and when walking in the swimming pool (Kato et al., 2002b). It increased with a rise in water level from the knee to the diaphragm (Watanabe et al., 1995). BF is a bi articular muscle and is involved in the movement of the hip and knee joints. For body movement to overcome water resistance, the body must be pushed in a forward direction in order to walk underwater, which requires strong extension of the hip. In addition, it is necessary for the knee joint to remain bent and the crus to be raised (Yamamoto et al., 2001). In the present study, the mean angular velocity of knee flexion during underwater walking was significantly higher than during land walking at the same velocity. These findings are considered to result in the increased activity level of BF.

The activity levels of MG and RF did not show differences at the same velocity, but showed significantly lower values at the same exercise intensity levels. When walking in a swimming pool (water level at the waist), the activity level of MG increases (Nishizono et al., 1994; Takaishi et al., 1994; Kato et al., 2002b). Such walking requires strong body movement to counteract water resistance. A stronger push to a floor is needed in the late stance phase, and MG muscle activity is considered to increase during extension (Nishizono et al., 1994). In a previous study (Watanabe et al., 1995), the activity levels of MG did not change during underwater treadmill walking in still water (water level from the knee to diaphragm) when compared with land walking at the same velocity, although the activity level of RF increased significantly. The walking velocity employed in that study was $90\,\mathrm{m \cdot min^{-1}}$, which is about two times that of the present study. Thus, an increase in cadence with a rise of velocity appears to cause this increase in the activity level of RF. A possible cause of the decline seen in the activity level of MG in the present study is the effect of water immersion to the xiphoid process, which reduces weight load by 75% (Becker, 1997). Also because the floor moves, the body does not actually move forward during walking on an underwater treadmill. Therefore, a strong push to the floor is unlikely to be needed. As to why a significant difference was observed at the same exercise intensity level, the activity level of MG likely increased because of the faster walking velocity on land, and as to the cause of the decrease in the activity level of RF, it is likely that the load required to lift the lower extremities during underwater walking is reduced by buoyancy. In addition, the reason we observed a significant difference at the same exercise intensity level is that the activity level of RF was likely increased because walking velocity is higher on land.

Conclusion

Investigation of gait patterns and muscle activity in the lower extremities of elderly women during underwater treadmill walking against water flow, when compared with land treadmill walking, revealed the following results.

At the same exercise intensity level, cadence was almost half that on land. Step length did not differ significantly because velocity was halved. In the swing phase, maximum and minimum knee joint angles were significantly smaller and mean angular velocity of knee extension was significantly lower than during land walking. These findings indicate that the knee joint extends slowly after first bending considerably. Knee extension in the swing phase, however, was limited by water resistance. While the muscle activity levels of TA, VM, and BF were almost the same as during land walking, those of MG and RF were lower.

At the same velocity, exercise intensity was significantly higher than during land walking. There was a significant decrease in cadence, and step length significantly increased. The knee joint in the swing phase showed significantly smaller maximum and minimum angles, and mean angular velocity of knee flexion was significantly larger. These results clearly show the influence of water resistance and buoyancy. The muscle activity levels of TA, VM, and BF increased significantly compared to land walking, whereas those of MG and RF did not significantly differ. Given our findings, it appears that buoyancy, lower cadence, and a moving floor influenced the muscle activity level of MG and RF at the same exercise intensity level and at the same velocity. These results show promise of becoming the basic data of choice for underwater walking exercise prescription.

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