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The Influence of Short-term Aquatic Training on Obstacle Crossing in Gait by the Elderly

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Abstract. [Purpose] The purpose of this study was to examine the fall-prevention effect of 12 weeks of aquatic training for the elderly using variables representative of the relationship between the trailing foot and an obstacle. [Subjects] Ten healthy elderly participants, who lived in C city, (age: 77.15±5.21 yrs, height: 149.87±3.54 cm, body mass: 57.44 ±6.74, and BMI: 25.58±2.98 kg/m^2), participated in this study. [Methods] To determine the effect of 12 weeks' aquatic training, 3-D motion analysis with 7 infrared cameras and one force plate, was performed. [Results] TC, HC, MVHC, and CV significantly increased after intervention. For the all gait stability parameters, statistically significant training effects were found. [Conclusion] In conclusion, 12 weeks' aquatic exercise can help the elderly become more stable when crossing a height obstacle, which is the most frequent cause of falls by the elderly.

Key words: Obstacle-crossing in gait, The elderly fall, Elderly gait stability

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INTRODUCTION

In daily life, walking is an essential movement and it is the most frequently performed action by human being. Therefore, stable walking is a very important element in people's lives. As people age, the muscles related to walking weaken and, as a result, the elderly are more exposed to injuries in comparison to young people in fall. The proportion of the elderly, defined as adults aged 65 or older, is increasing worldwide because of extended lifespan due to the development of medical facilities and improved diet. Particularly, in South Korea, the baby boom generation is entering the old age and old population is becoming a larger share of the entire population than ever before. Various injuries of the elderly, as a result of the increasing older population, can cause serious economic and social problems, unlike those of younger people, and are thought to be a social priority in many developed countries. Fall is one of the most common accidents experienced by the elderly, and it can cause serious injury which may even lead to death[1)].

Falls by the elderly are closely related to declining muscle strength of the lower limbs and deteriorating balance[2–5)], and it has been reported that fall risk factors of the elderly can be reduced by strengthening the muscles of the lower limbs[6–8)]. Many researchers have designed various ways for improving the muscle strength of the lower limbs in order to reduce the risk factors of falls for the elderly. O'Neil et al.[9)] and Schlicht et al.[10)] reported that the elderly showed significant increases of muscle power and had a positive effect on the lower limb muscle strength after 8 weeks of lower body muscle strength training, respectively. In addition, Tsouslou et al.[11)] and Kim and Shin[12)] revealed that aquatic exercise for 24 weeks and 12 weeks decreased fall risk factors for the elderly.

Considering the findings of many previous studies, continuous exercise for lower limb muscle strength and aquatic exercise have a positive effect on preventing falls by the elderly. However, from the perspective of the elderly who have weaker physical strength, muscle strength training may cause excessive stress or pain on the musculoskeletal system, while an aquatic exercise reduces the burden on the joints because of reduction of bodyweight as a result of buoyancy. It is, therefore, thought that an aquatic exercise is more beneficial for the elderly than muscle strength training.

There are, however, two potential limitations to studies investigating training for preventing falls by the elderly. First, the elderly mostly experience falls when balance is lost, such as when ascending stairs or crossing an obstacle. Compared to level walking, obstacle crossing walking increases the joint range of motion and translation, and raises the body, which significantly reduces gait stability[13)]. However, most previous studies have been conducted using level walking without an obstacle to examine the effects of training. These findings, therefore, cannot properly reflect the psychological withdrawal of fall due to an obstacle and function of the lower limb muscle in crossing an obstacle. Second, in selecting variables to evaluate the effect of training, many previous researches attempted to prove

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*Corresponding author. Sukhoon Yoon (E-mail: sxy134@knsu.ac.kr) the effect of training using general gait variables such as gait speed and stride. To be sure, gait speed may be a valid variable in general gait analysis, but perhaps more detailed variables are needed for analysis of the training effects. In other words, variables that can represent the relationship between trailing foot (swing foot) and an obstacle in crossing an obstacle must be defined in order to prove the effect of training.

Therefore, the purpose of this study was to examine the fall-prevention effect of 12 weeks' aquatic training for the elderly using variables that are representative of the relationship between the trailing foot and an obstacle.

SUBJECTS AND METHODS

Ten healthy elderly participants, who lived in C city, were recruited for this study. They had no history of orthopedic abnormalities in the past one year. All participants finished the 12 weeks of aquatic training, and their average age, height, body mass, and BMI were 77.15±5.21 years, 149.87±3.54 cm, 57.44 ±6.74 kg, and 25.58±2.98 kg/m^2 respectively. Before starting the study, the dominant leg of each subject was determined by kicking a soccer ball. Three of them are left foot dominant people and the others are left foot dominant ones. This study was approved by the Institutional Review Board of Korea National Sport University, and prior to their participation, informed consent was received from each participant.

The aquatic exercise program used in this study was conducted by a qualified trainer and it was performed three times a week, 60 minutes per session for 12 weeks. The exercise was composed of 10 minutes warm-up, 10 minutes cool-down, and 40 minutes main exercise. The warm-up was mostly stretching and light walking, and the main exercise consisted of side walking and running, forward walking and running, cross-stepping, and lunge. The cool-down consisted of stretching and balance exercise, and for exercise intensity the RPE was adjusted to between 12 and 13.

To determine the effect of the 12 weeks' aquatic training, the subjects performed two obstacle-crossing tests, one week before the beginning of the exercise program and one week after the program had finished. Before each test, the subjects were explained about the procedure of the test and performed enough warm-up exercise in order to allow natural movements during the test. The obstacle used in this study was adjustable in height and was adjusted to 30% of each subject's leg length in order to exclude the influence of the subject's height. After sufficient warm-up, the subjects were asked to start walking at 5 m from the obstacle, cross the obstacle, and then walk three more meters. A force plate was installed before the obstacle, and the subjects were not given an explanation about the force place so that they would naturally step on it when crossing the obstacle. When crossing the obstacle, the subjects used their dominant foot as the supporting foot (leading foot) and non-leading foot as the swing foot (trailing foot). In order to minimize potential physical discomfort caused by a fixed walking speed, the subjects used a self-selected speed when walking[14, 15]. The obstacle-crossing of each subject was recorded using seven infrared cameras (Oqus, Qualysis) at a recording speed of 100 Hz. The recorded data were processed using a fourth-order Butterworth low-pass filter, to reduce experimental random error, and a cutoff frequency of 6 Hz.

For the outcome variables, we calculated MaxCOP and MeanCOP. MaxCOP was defined as the maximum distance from average COP of the stance phase to COP of at any instant of the stance phase. MeanCOP was defined the mean distance between average COP and COP of each instance during the stance phase.

$$MaxCOP = \max\sum_{i=1}^{n}\left(\frac{\sum_{i=1}^{n} cop_i}{n}\right) - cop_i \quad \text{MeanCOP} = \frac{\sum_{i=1}^{n}\left(\frac{\sum_{i=1}^{n} cop_i}{n}\right) - cop_i}{\text{n}}$$

Toe clearance (TC), heel clearance (HC), and maximum vertical heel clearance (MVHC) were measured in this study. They are variables that indicate the relationship between the trailing foot and an obstacle when crossing an obstacle. TC was measured as the horizontal distance between the toe and obstacle before crossing the obstacle when the vertical positions of both were the same. Also, HC was measured as the horizontal distance between the obstacle and the heel after crossing the obstacle at the point where the vertical position of the heel was the same as the height of the obstacle. MVHC was defined as the vertical distance between the heel and obstacle when the heel was directly above the obstacle. Crossing velocity (CV) was calculated by measuring the horizontal distance between the point where the lead foot touched the ground before crossing the obstacle and the one where it landed on the ground after crossing it, and dividing it by the time it took.

To examine the effect of the 12 weeks' aquatic training on the safety of obstacle-crossing in gait by the elderly, the paired t-test was used. In this study, an alpha level of 0.05 was used as the criterion for significance.

RESULTS

The obstacle clearance parameters and gait stability parameters between pre-training and post-training are presented in Tables 1 and 2. For the obstacle clearance parameters, significantly increased patterns were found for all variables (Table 1, $p<0.05$). For the all gait stability parameters, statistically significant training effects were found (Table 2, $p<0.05$).

DISCUSSION

In this study, in order to assess the effect of 12 weeks of aquatic training for the elderly, variables that represent the safety and stability of obstacle-crossing were calculated. CV is reported to represent stable obstacle gait[16–18]. In this study, the elderly showed quicker CV after the 12 weeks of aquatic training (Table 1, $p<0.05$). CV is calculated by dividing step length (SL) with crossing time (CT), and to increase this value, either SL needs to increase or CT needs to decrease. In this study, the elderly used an increased step length (81.3 cm → 99.7 cm) and a decreased CT (1.4s → 1.2s) to increase their obstacle-crossing speeds. This in-

Table 1. Obstacle clearance parameters between training periods

	TC (cm)	HC (cm)	MVHC (cm)	CV (cm/s)
Pre-training	23.1 ± 1.8*	71.0 ± 12.0*	15.2 ± 4.4*	57.7 ± 3.2*
Post-training	31.7 ± 2.0	87.9 ± 14.5	20.4 ± 3.8	79.8 ± 5.9

Values are group mean ± standard error. *significant difference between pre- and post-aquatic training ($p<0.05$).

Table 2. Gait stability parameters between training periods

	MaxCOP (mm)	MeanCOP (mm)	SL (Step Length) (cm)	CT (Crossing Time) (s)
Pre-training	233.3 ± 22.9*	55.4 ± 4.6*	81.3 ± 3.7*	1.4 ± 0.1*
Post-training	118.6 ± 29.7	37.4 ± 5.8	99.7 ± 5.9	1.3 ± 0.1

Values are group mean ± standard error. *significant difference between pre- and post-aquatic training ($p<0.05$).

creased speed seems to be resulted from the increased lower limb muscle strength from a continuous aquatic exercise. This finding also agrees with the results of previous studies that concluded improved gait ability reduced the risks of fall for the elderly[16, 18)].

In the results of this study, the elderly showed statistically significant increases in TC, HC, and HMVC, which are representative of efficient obstacle-crossing, after the 12 weeks of aquatic exercise (Table 1, $p<0.05$). TC and HC represent safe distances before and after crossing the obstacle, and are reported to be closely related to safe obstacle-crossing[19–21)]. We think the increase in TC observed in this study (23.07 cm < 31.74 cm) resulted from effort by the elderly to secure a more safe distance in order to safely cross the obstacle. We also think the increase in HC after the exercise (71.65 cm < 84.74 cm) was the result of an effort to secure a wider base of support by landing the foot at a point further from the obstacle for safer obstacle-crossing. Also, the increase found in HMVC after the exercise (15.57 cm < 19.23 cm) agrees with the findings of Chen et al.[18)] and Yoon[16)], who reported that increased HMVC is necessary for safe obstacle landing of the elderly. We suggest that the improvements seen in all of the results related to the trailing foot (swing foot) were due to the aquatic exercise strengthening the lower limb muscles of the elderly and these findings indicate that continuous aquatic exercise can help to prevent falls by the elderly.

In this study, both MaxCOP and MeanCOP, which were calculated to evaluate the stability of obstacle-crossing by the elderly, showed statistically significant decreases (Table 2, $p<0.05$). Unlike the other variables, the COP parameters calculated in this study were representative of the movement of the lead foot (supporting foot) during crossing of the obstacle. That is, increases in COP would indicate that the lead foot was being supported less stably when crossing the obstacle, while decreases in COP would indicate more stable support with less shakiness. Therefore, the decreases of MaxCOP (232.26 mm to 118.58 mm) and MeanCOP (55.39 mm to 37.39 mm) seen in this study indicate that the supporting foot of the elderly became more stable when crossing the obstacle, and that the effect of the aquatic training can reduce the risk of fall for the elderly.

In conclusion, a 12 weeks of aquatic exercise can improve the stability of the elderly when crossing a height obstacle, which is the most frequent cause of falls by the elderly, and help to prevent falls by the elderly.

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