

An 8-week Aquatic Exercise Program is Effective at Improving Gait Stability of the Elderly

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Abstract. [Purpose] The purpose of this study was to investigate the effect of 8 weeks aquatic exercise on the gait stability of the elderly using dynamic factors: center of mass (COM), velocity of center of mass (COMV), and center of pressure (COP). [Subjects] Eleven elderly participants (age: 77.18 ± 4.96 yrs, height: 149.48 ± 3.61 cm, body mass: 56.94 ± 6.62 kg, and leg length: 82.36 ± 2.98 cm), participated in this study. [Methods] To identify the 8-week aquatic training effect, 3-D motion analysis with 7 infrared cameras and one force plate, was performed. [Results] For the COM-COP inclination angles, significantly decreased medial inclination angles were shown in both the posterior and anterior swing phases. For the COMV-COP inclination angles, decreased medial inclination angles were shown in both the posterior and anterior swing phases, but significant difference was found only in the posterior phase. [Conclusion] The results suggest that 8 weeks aquatic exercise is effective at improving the gait stability of the elderly. Further studies should extend the training period to gain statistically significant results for the effect of aquatic exercise in the anterior-posterior direction.

Key words: Obstacle gait, Inclination angles, Elderly gait stability

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INTRODUCTION

The elderly, defined as individuals aged 65 years and older, are rapidly increased due to the advances in medical facilities and the improved diet of modern society. Falls by the elderly frequently occur and often result in injuries requiring hospitalization. It has been estimated that one third of the elderly population experiences at least one fall per year in the United States, and 50% and 65% of the elderly population have been reported to experience falls and injury in Australia and South Korea, respectively^{1, 2)}. Injuries from falls by the elderly are a cause of rapidly increasing medical expenses. In United States, the total direct cost of fall-related injuries for the elderly reached \$20 billion, and it is expected to climb to \$44 billion by the year 2020³⁾.

Falls by the elderly are more serious because they happen not only during some special movement, but also during activities of daily living, due to age-related declines in balance control. Even though the injury resulting from a fall may be small, the elderly may suffer more seriously than young people, and sometimes falls by the elderly may result in severe injury or even death, depending upon their

physical status^{4, 5)}. Moreover, if an elderly person falls and experiences difficulty in walking, he or she may easily tend to lose confidence, become lethargic, face a deteriorated living quality, and disengage from the society⁶⁾. Therefore, the fall injuries of the elderly should be taken seriously and receive an immediate social response.

The fall risk factors of the elderly include gender, race, past fall experience, illness history, sensory organ damage, weak leg muscles and poor sense of balance⁷⁾. Among the risk factors, weakening leg muscles and sense of balance have received a lot of research attention since it is thought possible to improve them through regular exercise^{8–11)}. To prevent falls by the elderly, diverse training methods have been tried by many researchers. The most frequent ones are exercises on the ground such as aerobic and leg muscle strength workouts. Many researchers have reported that such regular ground exercises help to improve elderly people's leg muscular strength, bodily function and postural stability, upgrading their walking safety and preventing falls^{9, 11–13)}.

Although these ground exercises have plenty of strong points, aerobics or muscular workouts may cause excessive stress or pain to physically feeble elderly, and such concerns have been reported to reduce the amount of exercise by the elderly¹⁴⁾.

Unlike ground exercise, aquatic exercise lowers joint stress, thanks to underwater buoyancy that lightens body weight, while offering higher density to cut the risk of fall injuries. Underwater exercise also causes body resistance, helps isokinetic muscle contraction and balanced develop-

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ment between agonist and antagonist muscles¹⁵). Therefore, compared to ground exercise, aquatic exercise is deemed more appropriate for physically weak elderly people, and regular aquatic exercise would also be appropriate for them.

Most researches, however, seem to have more fundamental problems than choosing a type of exercise (ground vs. aquatic). The majority of studies have measured gait stability gained as a result of training only in a static status (i.e., duration of standing on one leg, sit-to-stand time, Berg balance scale). Such an approach may not fully explain walking stability since walking is a dynamic situations³).

Diverse efforts have been expended by many researchers to address this issue and measure walking stability in dynamic situations where actual walking stability is compromised^{16–18}). They have reported that the center of pressure (COP), which represents the biomechanical trend of the supporting foot in the stance phase, and the center of mass (COM) or the velocity of center of mass (COMV), which represents human body movement, are closely related to body stability in walking. Especially, the inclination angle between the vertical axis and the vector connecting the position of COP to the position or velocity of COM has been found to be very accurate and useful for evaluating walking stability. These studies also reported that for walking stability evaluation, the frontal Medial-Lateral (M-L) inclination angle was more sensitive than that of the sagittal plane. Since previous studies have examined either only young people, or groups of healthy elderly and the elderly with diseases, it is hard to find a study which has examined the effect of exercise in this regard.

Therefore, the purpose of this study was to investigate the effect of 8 weeks aquatic exercise on the gait stability of the elderly using dynamic factors (COP, COM, and COMV).

SUBJECTS AND METHODS

Eleven elderly participants, who stayed at the Seoul K welfare center, were recruited for this study. All participants had no history of orthopedic abnormality within the past 1 year and completed the aquatic exercise program which lasted for 8 weeks. Their average age, height, body mass, and leg length were 77.18 ± 4.96 yrs, 149.48 ± 3.61 cm, 56.94 ± 6.62 kg, and 82.36 ± 2.98 cm, respectively. Before the training, each participant was asked to kick a soccer ball three times to check their dominant leg, and the foot they used to kick the ball was determined as their dominant leg. In this study, the right foot was the dominant leg of all the participants.

Prior to participation, informed consent was received from each participant. This study was approved by the Institutional Review Board of the Korea National Sport University.

The aquatic exercise for the study was conducted by 1 qualified trainer and lasted for 8 weeks. The exercise took place 3 times a week and each class lasted about 60 minutes for class. The class started with 10 minutes' warm-up exercise and finished with 10 minutes' stretching, and the main exercise was performed for 40 minutes. The main exercise included side walking, forward walking, jogging, backward

walking, cross stepping, and joint rotation movement. The program intensity was gradually elevated every 3 weeks with RPE being adjusted to 12–16. Before the program began, we offered the subjects pre-notice, safety education and information, and received their written consent to participate in the exercise program and the experiment. We offered 2 identical programs (A: Mon, Wed, Fri., B: Tue, Thu, Sat) to choose from for subjects' convenience. The training was performed in a swimming pool heated to 27 °C, with a depth of water of 130–150 cm.

To identify the 8-week aquatic training effect, we conducted walking tests with obstacles for the subjects twice: one week before, and one week after the aquatic exercise. The obstacle used in the study had an adjustable height. To control effects related to subjects' height, the obstacle height was adjusted to 30% of each subject's leg length.

The gait test was performed on a 15-m walking path in a laboratory. An obstacle was placed about 10 m away from the starting point and one force plate was put right before the obstacle. After sufficient warm-up, each participant was asked to start walking 10 m away from the obstacle, and to continue walking for an additional 5 m after overcoming the obstacle. Subjects were asked to overcome the obstacle with their dominant leg as the leading (supporting) foot and the non-dominant leg as the trailing (swing) foot. Participants' self-selected walking speed was used during the experiment to minimize potential discomfort to their body, which could have possibly been caused if the speed has been pre-set^{19, 20}).

One force plate (9286AA, Kistler) was used to measure the COP position of the leading foot while crossing over the obstacle; a sampling frequency of 1,000 Hz was used. For the calculation of center of body weight (COM), a 14-segment (both hands, forearms, upper arms, feet, lower legs, thighs, torso and head) body model was used. A total of 26 reflection markers were attached to the body, and each subject's obstacle crossing was recorded by 7 infrared cameras (Proreflex MCU 240, Qualysis) at a recording speed of 100 Hz. To reduce experimental random errors, acquired data were filtered with a fourth order Butterworth low-pass filter with a cutoff frequency of 6 Hz. The recorded videos and COP data were synchronized using QTM (Qualysis Tracking Manager, Qualysis) software.

To evaluate dynamic stability during obstacle crossing, this research employed the formulas of Lee and Chou¹⁸) and Chang and Yoon¹⁷) for the inclination angles of the sagittal and frontal planes, respectively. Calculations in this study were performed using Matlab 7.0 Software.

The paired t-test was conducted to test the differences in elderly obstacle-crossing stability after 8 weeks aquatic exercise. An alpha level of 0.05 was used as the criterion for significance.

RESULTS

The peak COM-COP and COMV-COP inclination angles between pre-training and post-training are presented in Tables 1 and 2. During the swing phase of the foot while walking, whole body COM moves forward and passes through the horizontal COP location. In this study, we de-

Table 1. Peak COM-COP inclination angles before and after the training period

	Posterior Swing Phase		Anterior Swing Phase	
	Medial inclination angles (deg)	Posterior inclination angles (deg)	Medial inclination angles (deg)	Anterior inclination angles (deg)
Before	11.71 ± 1.66*	16.27 ± 2.99	8.08 ± 1.17*	14.26 ± 0.65
After	6.62 ± 1.00	24.57 ± 2.97	4.86 ± 1.09	15.10 ± 0.53

Values are group mean ± SE. COM-COP is the vector connecting COP position to COM position.

*: a significant difference between pre- and post-aquatic training ($p < 0.05$).

Table 2. Peak COMV-COP inclination angles before and after the training period

	Posterior Swing Phase		Anterior Swing Phase	
	Medial inclination angles (deg)	Posterior inclination angles (deg)	Medial inclination angles (deg)	Anterior inclination angles (deg)
Before	12.25 ± 1.82*	14.43 ± 1.69	6.62 ± 1.15	24.74 ± 1.11
After	7.02 ± 0.86	16.64 ± 1.08	5.40 ± 1.06	26.60 ± 0.74

Values are group mean ± SE. COMV-COP is the vector connecting COP position to COM velocity.

*: a significant difference between pre- and post-aquatic training ($p < 0.05$).

defined the posterior swing phase as the period from the start of the swing in crossing the obstacle until the horizontal position of the whole body COM coincided with the COP horizontal position, and the anterior swing phase as the period from the end of the posterior swing phase to the time when the trailing foot touched the ground.

For the COM-COP inclination angles, significantly decreased medial inclination angles were shown in both the posterior and anterior phases (Table 1, $p < 0.05$). For the COMV-COP inclination angles, decreased medial inclination angles were shown in both the posterior and anterior swing phases, but a significance was found only in the posterior phase (Table 2, $p < 0.05$).

DISCUSSION

In this study, we calculated the inclination angles of the sagittal and frontal planes during obstacle crossing to identify changes in the walking stability of the elderly induced by aquatic exercise. We found statistically a significantly decreased medial inclination angle in the anterior swing phase after the aquatic exercise (Table 1). The starting point of the posterior swing phase shows the lowest stability in walking, since the support moves from two feet to one foot. Also, at this moment, since base of support (BOS) is narrowed, and the whole body COM becomes easier to move out of the BOS, the ground reaction torque can work most adversely on the human body¹²⁾. That is, when the whole body COM is within the BOS, the ground reaction torque functions in the same direction to support the body, further stabilizing the move, but if the COM moves out of the BOS, the torque starts to drag the body down toward the ground. Therefore, people need to overcome the torque using their lower extremity muscles at this moment, or change their posture so that the COM does not move out of the BOS, in order to prevent falls. Our findings for the obstacle crossing are consistent with those of previous studies^{17, 18, 21)} which have reported that the frontal plane's COM-COP inclination

angle is a very accurate guide to understanding the fall risk of elderly subjects. Previous studies have also reported that as the angle becomes larger the stability of gait declines. Chang and Yoon¹⁷⁾ also reported the frontal plane's XCOM-COP inclination angle (XCOM includes COM speed factors) is a good measure of unstable conditions of gait. Thus, the reduced medial inclination angle observed after the intervention can be interpreted as proving the beneficial effect of aquatic exercise on the gait stability of the elderly.

In this study, we found that the average anterior-posterior (A-P) inclination angle was not significantly changed in both the posterior and anterior swing phases after the exercise. However, unlike previous training studies^{12, 14)}, we found no statistically significant training effects. One possible explanation for this could be the difference in research design (i.e. training period). Yoon et al.¹²⁾ conducted walking training for the elderly for 6 months and found significant changes in the 6th month. The intervention they used was a ground walking exercise, and the A-P inclination angle was tested every 3 months (0, 3, 6 months). In their study, the A-P angle increased as the training period progressed but significant differences were only found after 6 months. Kim and Shin¹⁴⁾ reported that the elderly showed improved gait parameters after 3 months of their training periods. Accordingly, we would expect to find significant changes in gait parameters, if the training period of the aquatic exercise were extended. The increased A-P inclination angle, reported in previous studies, seems to be the result of older people trying to put the whole body COM closer to the COP while crossing the obstacle, by straightening the upper body, using their training-strengthened lower extremity muscles, to overcome the physically unstable conditions (COM movement in a smaller basal area) and prevent falls. So, we think subsequent studies need to extend the training period to gain statistically significant results for the effect of aquatic exercise.

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