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The Effect of Biofeedback-based Balance Training while Performing Cognitive Tasks on Temporal and Spatial Parameters and Gait Stability of the Elderly

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Abstract. [Purpose] The purpose of this study was to investigate the effect of biofeedback-based balance training while performing cognitive tasks on gait of the elderly. [Subjects] Forty-one participants were selected from a fall prevention class and were randomly allocated to two groups: 20 to the experimental group (81.12 ± 7.24 years), and 21 to the control group (81.29 ± 6.19 years). [Methods] The experimental group received biofeedback-based balance training while performing cognitive tasks for 50 minutes a day, 3 days a week, for 8 weeks. Temporal and spatial parameters and stability were measured pre- and post-training. [Results] The experimental group showed significant improvements in all measures. [Conclusion] This study confirms that biofeedback-based balance training while performing cognitive tasks effectively improves the mobility of elderly people at risk of falling.
Key words: Elderly, Falling, Cognition

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INTRODUCTION

Human gait is a pattern of forward movement that is achieved by use of the lower limbs. For normal gait, people stand upright, and while maintaining balance, move their bodies smoothly and rhythmically[1)]. Normal gait also requires the right amount of muscle strength and joint motion, which is delivered with the assistance of the visual, auditory, and vestibular senses[2)].

The gait of senior citizens exhibits several variations during the process of aging[3)]. Aging leads to a decline in regulation of the central nervous system, and the visual, vestibular, and somatic senses[4)], and also adversely affects cognition and the musculoskeletal system[5, 6)]. In particular, these physical changes cause a deterioration in balance and changes in gait[7)].

Gait of the elderly tends to have shorter cadence and stride length and increased step length in order to maintain balance and stability[8)], and these characteristics lead to secondary changes, such as, a reduced stance phase, extended double support, a widened base of support (BOS), increased step width, and reduced speed[3, 8)]. Furthermore, these changes limit the independence of the elderly and are the main risk factors of falls[9)].

More than 45% of falls by the elderly are reported to occur while walking[10)]. Reduced standing balance and mobility have been reported as possible causes of falls[9)]. In fact, 10 to 25% of falls at all ages are related to decreased balance and an abnormal gait[11)]. Furthermore, reduced cognitive abilities of older people are correlated with reductions in balance[5)], and as tasks become more complex, postural stability decreases[12)]. As Shumway-Cook et al.[13)] have reported, a reduction in balance occurs when performing more than two cognitive tasks, and reduced cognition is a major factor in falls by the elderly.

Falling is the most common source of injury for senior citizens[7)]. Injury and fractures from such incidents limit mobility, lower quality of life, and even threaten life via secondary side effects[14)]. These findings emphasize the importance of fall prevention for the elderly[15)].

There are various ways of reducing falls by the elderly. Common interventions include aerobic exercises[16)], muscle strengthening exercises[17)] and complex gait training[18)]. As Sherrington et al.[12)] reported, balance affects the risk of falling more than muscle strength, and interventions such as balance training, can reduce the risk of falling by 17% or more. Moreover, research has shown that improving dynamic balance and mobility can reduce the incidence of falls among senior citizens[12)].

Biofeedback-based balance training with cognitive tasks has recently been introduced as a stability-improving intervention[19)]. An exercise that uses visual biofeedback on a simulation screen to maintain balance during the performance of a cognitive task, is also effective at improving spatial cognition, judgment, memory, and coordination[20)]. In addition, fast feedback after tasks increases the motivation to exercise[21)]. Visual biofeedback-based balance training has also been reported to be an effective intervention for older adults and for the rehabilitation of people with stroke[22, 23)]. In one report, biofeedback-based balance training with cognitive tasks was found to be effective at improving the stability of senior citizens with attention deficit[23]. However, few studies have investigated balance training for elderly people at risk of falling, and thus, the benefits of such training programs are unclear[19]. Therefore, the objective of this study was to examine the effectiveness of biofeedback-based balance training while performing cognitive tasks on the gait of elderly people at risk of falling.

SUBJECTS AND METHODS

The study subjects were 52 community-dwelling elderly (aged 65 years or older) who attended a fall prevention program provided by a physical therapist at a Senior Welfare Center in Seoul.

Subjects were included in this study if they: had experienced a fall more than once within the previous year; had not participated in a regular balance improving program (involving ≥ 3 times a week) during the past 6 months; had a Mini-Mental State Examination (MMSE) score of over 24; could stand for 2 minutes without any aid; and could walk 100 m with or without an aid.

People were excluded from this study if they had: an orthopedic condition, such as, a fracture, a deformity, or severe osteoarthritis; visual-perceptual impairment, neurological damage (CNS, vestibular system), postural hypotension, or a mental or psychiatric deficiency.

When a participant expressed willingness to take part in the study, we obtained their informed consent in accordance with the requirements of the Institutional Review Board of Sahmyook University (Seoul, Korea).

Forty-four subjects who met the inclusion criteria were randomly assigned to an experimental group (n=22) or a control group (n=22) using Random Allocation Software (version 1.0)[24]. However, 2 in the experimental group were excluded because their program participation rate was less than 80%, and one in the control group was excluded because of a fracture which required hospitalization. Accordingly, the study cohort comprised 41 subjects: 20 in the experimental group, and 21 in the control group. The baseline characteristics of the study subjects are shown in Table 1.

Table 1. Subject characteristics

	Experimental	Control
Gender (male/female)	20 (6/14)	21 (8/13)
Age (years)	81.12 ± 7.24	81.29 ± 6.19
Height (cm)	155.21 ± 10.62	156.10 ± 10.93
Weight (kg)	56.74 ± 7.53	59.99 ± 8.08
Experience of falls (n)	1.07 ± 0.88	1.14 ± 0.95
MMSE-K (score)	26.35 ± 2.62	25.14 ± 2.88

Note. Values are expressed as mean ± standard deviation (SD)

Participants exercised for 8 weeks. Evaluations were performed twice, a week before the program started and a week after its completion. Mobility was measured by an assessor who was blind to the study details. The experimental group received biofeedback-based balance training with cognitive tasks for 50 minutes a day, 3 times a week, for a total of 8 weeks. Sessions were conducted on an individual basis in a private room under the supervision of a researcher. Members of the control group did not receive any form of training.

Biofeedback-based balance training with cognitive tasks involves performing different cognitive tasks and stability exercises simultaneously. The BioRescue program (RM INGENIERIE, Rodez, France) was used in this study. This is a game-like program that presents tasks on a screen, and recognizes motion through sensors connected to a platform. This program was originally developed for people with orthopedic or neurological conditions, and senior citizens, and has also been used for athlete's rehabilitation. Sensory feedback regarding range of motion, accuracy, and balance can help patients maintain good posture and perform tasks well. Moreover, the program can be individualized, that is, game time, task intensity, and the durations of breaks between sessions can be varied, which enables organized training.

Participants stood on a platform located 1–1.5 m away from a monitor, and had to move their bodies to perform each task. Sessions were started after 5 minutes of stretching, warm-up exercise. Three different 10-minute exercises were presented, with a 5-minute break between exercises and a final 5-minute cool-down, stretching exercise (a total of 50 minutes per session). The three main activities addressed were weight-shifting, involving trunk flexion and extension, balance control, and ROM exercise of the upper and lower extremities. Each exercise included simultaneous cognitive tasks. The first situation was a grocery shopping simulation. Subjects had to shift their body weight while choosing goods and putting them in a basket. The second activity involved matching cards among 6 pairs of cards presented face down. Participants had to match cards by shifting their weight to make choices. The last task was more complex and was designed to improve balance control. The participants were asked to walk through groups of people without touching anyone. Exercise intensities were set individually and gradually increased. Due to concerns about falling, a safety handrail was installed in front and on both sides of subjects. A private room was used so that participants could focus on their tasks without interruption.

The GAITRite system (CIR system Inc, USA, 2008) was used to analyze improvements in temporal and spatial parameters and gait stability. This system has a floor mounted electronic board (500 × 61 × 0.6 cm) with multiple sensor pads placed at 1.27-cm intervals that collect information on spatiotemporal parameters. Data was processed using GAITRite GOLD Version 3.2 software. Several studies have reported on the reliability and validity of the GAITRite system for different populations, including healthy young and elderly individuals[25–27].

Subjects practiced walking without paying attention to the board, to keep their eyes straight ahead, and to swing their arms naturally. Then, the participants were instructed to "walk at a comfortable pace, as if you were walking down the street". Subjects began walking at a starting position 3 m before the beginning of the mat and continued walking

Table 2. Comparison of temporal gait parameters within groups and between groups

		Experimental (n=20)	Control (n=21)
Velocity (cm/s)	Pre	84.57 ± 17.76	85.59 ± 24.45
	Post	95.76 ± 15.62	82.54 ± 14.50
	Pre-Post	11.19 ± 10.48*	–3.04 ± 21.15
Cadence (step/m)	Pre	110.65 ± 11.07	109.27 ± 13.40
	Post	115.90 ± 11.26	106.51 ± 15.95
	Pre-Post	5.25 ± 8.65*	–2.76 ± 11.85
Step time (second)	Pre	0.54 ± 0.06	0.55 ± 0.07
	Post	0.52 ± 0.06	0.57 ± 0.09
	Pre-Post	–0.03 ± 0.04*	0.03 ± 0.06
Stride time (second)	Pre	1.09 ± 0.11	1.12 ± 0.16
	Post	1.05 ± 0.11	1.15 ± 0.18
	Pre-Post	–0.05 ± 0.08*	0.03 ± 0.10

Note. Values are expressed as mean ± standard deviation (SD). * Significant changes between pre- and post- intervention.

–3 m beyond the end of the mat. This enabled us to record steady-state gait without the effects of gait initiation and termination. Values obtained during 3 trials were averaged for analysis.

The temporal parameters measured were velocity, cadence, step time, and stride time. Spatial parameters included step length and stride length. Stability was calculated as single support, double support and H-H base of support (HHBS). HHBS is the vertical distance from the heel center of one footprint to the line of progression formed by two footprints of the opposite foot. The results for each parameter were measured on subjects' dominant sides.

Statistical analyses were performed using SPSS version 19.0 software. The Shapiro-Wilks test was used to test the normal distribution of all parameters. Differences in continuous variables between groups were tested using Student's two-sample t-test, and within group differences were tested by Student's paired t-test. Differences in categorical variables were analyzed using the χ^2 test. P values less than 0.05 were considered statistically significant.

RESULTS

Table 2 shows differences in temporal gait parameters after training. There was no difference between the control group and experimental group in terms of velocity, cadence, step time, or stride time before training. Balance improved significantly in the experimental group based on improvements in velocity, cadence, step time, and stride time ($p<0.05$). No significant differences were observed in the control group over the study period.

Table 3 shows the differences in spatial parameters after training. Neither group showed differences in step length or stride length before training. Balance significantly improved in terms of step length and stride length ($p<0.05$) in the experimental group. However, no significant difference was observed in the control group over the study period.

Table 4 shows differences in walking stability after training. The two groups showed no differences before training in terms of single support, double support, or HHBS. Balance significantly improved in terms of single and double support ($p<0.05$) in the experimental group, but the control group showed no significant differences over the study period.

DISCUSSION

Mobility is an integral part of independent living. Since decreased mobility lowers quality of life and increases the risk of falling, the ability to walk independently is of considerable importance for the elderly. As people get older, the rate of falls increases[10]. Incidents peak between 80 and 84 years of age, after which the frequency falls due due to survival rate decreases and as more limitations are experienced in daily life[28].

Gillespie et al.[15] reported that one in two people in their 80's falls more than once a year and that those who fall are twice as likely as those who do not fall to fall again.

Hence, this study was undertaken to identify the effects of biofeedback-based balance training with cognitive tasks on gait of elderly people at risk of falling. The tool used for the gait assessment was GAITRite, which provides a highly reliable and valid means of analyzing spatiotemporal parameters. The temporal parameters checked were velocity, cadence, step time, and stride time. Step length and stride length were used to measure spatial parameters. Walking stability was measured through single support, double support and HHBS.

A reduction in step length due to aging decreases velocity[8]. This reduction in velocity is a compensatory way of improving balance and safety while walking with more frequent double support[8, 29]. However, changes in gait pattern increase the risk of a fall[9]. Some participants in the present study had short step and stride lengths which is considered a way of keeping balance.

Temporal parameters are now used to evaluate the abilities of the lower extremities and to quantitatively present changes in gait pattern after intervention[30]. Velocity

Table 3 . Comparison of spatial gait parameters within groups and between groups

		Experimental (n=20)	Control (n=21)
Step length (cm)	Pre	46.78 ± 8.97	46.25 ± 9.28
	Post	50.23 ± 7.88	45.30 ± 5.21
	Pre-Post	3.45 ± 4.78*	–0.95 ± 5.11
Stride length (cm)	Pre	92.74 ± 18.71	92.83 ± 19.90
	Post	100.06 ± 15.37	92.84 ± 16.27
	Pre-Post	7.32 ± 10.63*	0.01 ± 6.39

Note. Values are expressed as mean ± standard deviation (SD). * Significant changes between pre- and post- intervention.

Table 4. Comparison of gait stability within groups and between groups

		Experimental (n=20) M ± SD	Control (n=21) M ± SD
Single support (%)	Pre	35.69 ± 1.90	36.50 ± 1.57
	Post	36.79 ± 2.35	35.97 ± 1.21
	Pre–Post	1.11 ± 1.53*	–0.53 ± 2.04
Double support (%)	Pre	29.25 ± 4.71	26.50 ± 1.86
	Post	26.33 ± 3.11	26.30 ± 1.49
	Pre–Post	–2.93 ± 3.17*	–0.20 ± 1.88
H–H base of support (cm)	Pre	10.05 ± 2.40	10.47 ± 4.20
	Post	8.79 ± 2.19	10.46 ± 3.22
	Pre–Post	–1.26 ± 1.13*	–0.01 ± 1.90

Note. Values are expressed as mean ± standard deviation (SD). * Significant changes between pre- and post- intervention.

of gait is an additional indicator of walking ability, because walking is an important requirement for an independent social life[31]. In the present study, mobility was improved in several ways by training: velocity by 13.23%, cadence by 4.25%, a decrease in step time of 4.93%, and stride time of 4.15%. The normal range of velocity and cadence of people aged between 80 and 84 is 95–129 cm/s and 95–111 steps/min, respectively, for males, and 86–116 cm/s and 101–119 steps/min, respectively, for females[30]. Although 43% of the subjects in the experimental group were in the normal velocity range before training, this increased to 68% after training. In terms of cadence, 87% of subjects in the experimental group were in the normal range pre-training, but all were within the normal range post-treatment. Since Verghese et al.[8] reported that a 10 cm/s decrease in velocity is equivalent to a 10% loss of mobility in daily life for the elderly, the 15% improvement observed in velocity in the experimental group shows that training enhanced subject's independence.

Previous studies have shown velocity increases in senior citizens as a result of balance training. Allet et al.[32] reported that task-oriented balance exercises for 12 weeks resulted in an 11.6% improvement in velocity, and Hill et al.[33] reported that 6 months of multi-factorial interventions with tasks increased velocity by 11.5% in elderly people. Although the present study included people of different ages, and has limitations on directly comparing gait changes, balance training with cognitive tasks is considered to enhance mobility.

In a previous study, it was reported that dual-task training is more effective at improving balance than single-task training[34]. The results of the present study showed better enhancement of gait than other interventions because of the self-correction of feedback on the screen during the performance of the cognitive tasks.

Zijlstra et al.[19] reported that balance training with biofeedback is more effective at improving reaction times for posture adjustment and at improving movement, balance, and mobility. Trombetti et al.[21] showed an apparent enhancement of stride length after multi-task training based on an auditory feedback paradigm. The effects of their treatment lasted 6 months and resulted in a 54% decrease in incidences of falls. In the present study, a 7.38% improvement in step length and a 7.89% improvement in stride length were achieved through training. Furthermore, training strengthened the leg muscles and the ability to balance. In addition, single support was easier, and we consider this the main factor responsible for the observed step and stride length increases. Walking speed is inversely proportional to double support time[3]. During double support, balance control while shifting weight and stable movements of the upper limbs is important[8]. Single support requires more balance control due to a narrower BOS[35]. Since walking conditions are variable, it is necessary to sustain a stable gait while changing direction or speed without falling[36]. Regarding walking stability, the results of the present study showed an improvements of 3.1% in single support and 10.0% in double support.

Research related to gait stability of the elderly shows that strengthening of the leg muscles through resistance exercises leads to better balance during walking, and reduced step width with narrowed BOS[17]. The distance between the two heels was also reduced by 12.56% in the present study. This demonstrates that balance training with cognitive tasks changes gait stability for the better. In this study, we performed balance keeping training while carrying out cognitive activities under virtual reality. Subjects tried to maintain stable posture by biofeedback while carrying out the cognitive tasks. Also, accurate movement and quick weight shifting was needed as the difficulty of the cognitive task increased. We considered that these movements improved balance control ability as well as enhancing stability of gait and mobility.

The biofeedback-based balance training with cognitive tasks, examined in the present study, was found to effectively improve the mobility of the elderly. However, actual changes in fall rates were not investigated. Further studies are required to investigate the effect of training on fall rates and to identify specific interventions that enhance balance and mobility and improve the quality of life of senior citizens at risk of falling.

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