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Research Article

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# Effect of Gaze Stabilization Exercise with Balance Exercise on Static and Dynamic Balance Function of Healthy Young Adults: A Randomized Controlled Trial

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| Abstract |

**PURPOSE:** This study examined the effects of four weeks of gaze stabilization exercises and balance training on the static and dynamic balance functions.

**METHODS:** The study was an assessor-blinded randomized controlled trial conducted at Daegu University in South Korea. Thirty subjects who fulfilled the inclusion criteria were selected and divided randomly into three groups containing ten each. The first group received balance exercises with gaze stabilizing exercises (BGG). The second group received a balance exercise (BEG), and the third group received gaze-stabilizing exercise (GEG). Each group exercised for 40 minutes, three times a week for four weeks. The subjects were asked to complete the following static balance test: 1) one-leg standing test, 2) sharpened Romberg test, dynamic balance test, 3) Y-balance test, and 4) single-leg stand-squat-stand test. The static and dynamic balance were measured before and after four weeks to determine the effect of exercise on balance.

**RESULTS:** The static (OLS and SRT) and dynamic (YBT and SST) balance tests showed significant differences in the surface and length of the three groups ($p < .05$), and the y-balance score effect size, 11.477 ($p < .05$), was improved significantly. On the other hand, the change in BGG value was larger than those of BEG and GEG, and the improvements in balance control were the most significant.

**CONCLUSION:** After four weeks of exercise, BGG showed the best improvement in static and dynamic balance, suggesting that this specific type of gaze stabilization exercise with balance exercise may benefit healthy young adults.

**Key Words:** Balance exercise, Dynamic balance, Gaze stabilization exercise, Static balance

## Ⅰ. Introduction

During human walking, the stability of the human gait is controlled by the anteroposterior (AP) placement of the foot of the swing leg relative to the body. Therefore, humans must maintain a constant balance[1]. Balance involves coordinating the transfer of the center of mass and the

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center of pressure (COP)[2]. For different postures and movements, the central nervous system uses inputs from vision, vestibular sense, and proprioception to maintain balance[3]. Balance is classified into static and dynamic balance. Static balance is defined as the maintenance of a stable base of support[4]. Dynamic balance is the ability to perform tasks while maintaining balance and posture within an unstable basal plane[3]. Static and dynamic balance in the sitting or standing positions are essential for performing physical functions, and balance and function are closely related[5].

Decreases in the balance performance potentially impair the activities of daily living. Virtually all neuromusculoskeletal disorders result in some degeneration of the balance control system[6]. Gait and balance disorders are the most common causes of falls in older adults, often leading to injury, disability, loss of independence, and limitations in the quality of life[7]. The early identification of balance disorders and appropriate intervention may prevent dysfunctions and a loss of independence[8]. Several studies have recently shown that balance can be improved using balance exercises in combination with other types of exercises by augmenting musculoskeletal strength, executive cognitive function, and motor control, thus helping reduce the fall risk[9].

During movement, the ability to fix one's gaze on objects and use optic flow for the heading is essential[10]. The vestibulo-ocular reflex (VOR) plays a major role in gaze stabilization, mainly the optomotor and cervico-ocular reflexes[11]. The vestibulo-ocular reflex is the first mechanism of the gaze stability. The vestibulo-ocular reflex stabilizes gaze (eye position in space) during head movements, producing eye movements of equal speed and opposite direction to the movement of the head to allow an adequate visual acuity[12]. Gaze stability is the ability of the eyes to fix on a stable point in the environment while the head is moving relative to space. Adjusting the balance ability is a complicated process requiring the integration of sensory information and appropriate postural response practice. Visual, articular, and muscular sensory information is integrated through the central nervous system via the non-sequitur visual, somatic senses, and the vestibular system to maintain an erect position[13].

Gaze stabilization exercises are often used to promote compensatory saccades[14]. Studies have shown that the ocular-motor activity activates areas of the brain that have a positive effect on the ability to maintain balance[15]. Afferent impulses from proprioceptors cooperate with labyrinthine impulses to support oculomotor muscle activity through the VOR[16]. The VOR starts to work during head movement. The eye muscles are immediately triggered to induce eye movement to oppose the head movement at the same speed to adjust the visual cue, which in turn stabilizes the image of the retina. It keeps the eye in space and focused on the target despite the head movement [17]. This primary eye movement system stabilizes visual gaze during rapid head rotation[14]. These gaze stabilization exercises improve the aVOR gain during active head rotations[18,19]. The connection between the organ of vision and the muscles of the masticatory organ occurs through the deep fascia of the orbit (Tenon's fascia) connecting with the deep fascia of the skull (cranial fascia) and through the temporal fascia[20]. The fascial network enables the correct distribution of tension information generated by various tissues covered or supported by the fascia, allowing the entire body system to interact in real time[20,21]. Clinical observations have revealed changes in the resting activity of the masticatory muscles caused by the changes in visual stimulus[22]. Recent advances in vestibular exercise programs suggest that increasing VOR gain adaptation can increase gaze stabilization directly[18,23].

Moreover, most gaze stabilization exercises focus on vestibular dysfunction problems. The effects of gaze stability exercises in patients with vestibular dysfunction are well-established and include improved postural stability and dynamic visual acuity[23]. On the other hand, there are no reports that gaze stability and balance exercises are beneficial for healthy people. It was hypothesized that gaze stability and balance exercises would influence the static and dynamic balance of healthy subjects. Therefore, this study examined the effects of gaze stability and balance exercises on the static and dynamic balance in healthy young adults.

## Ⅱ. Methods

### 1. Experimental Subjects

The sample size for this study was calculated using the G* Power program 3.1.0 (G power program Version 3.1, Heinrich-Heine University Dusseldorf, Germany). Based on the data from a pilot study, the estimated sample to obtain a power of 90% at the 95% significance level was 24 subjects.

The desired sample size was calculated to be at least eight subjects per group. A dropout percentage of 20% was expected, so 10 healthy adults were included in each group.

Before participating, all subjects read and signed university-approved human subject consent forms. This study complied with the ethical standards of the Declaration of Helsinki. The study was approved by the Institutional Review Board of Daegu University (IRB No. 1040621-202301-HR-019).

During the subject selection process, the subjects were tested for the vestibular function, including the Head Impulse Test[24] and dynamic visual acuity. The dynamic visual acuity test was validated and demonstrated good test–retest repeatability[25]. The target used was a single-letter "Tumbling E" chart, which was presented in black on a white background at four orientations (right, left, up, or down). The DVA was measured for horizontal (the target moved across the screen from left to right only once) and random motion paths[26]. The subjects had to say the correct orientation of the letter E branches to pass the test. Defective performance was excluded from the study. The subjects had a history of impaired vestibular function[27], visual impairment, severe hearing loss, history of vertigo attacks or medication for vertigo, refractive error, mental disorder that could restrain the ability to concentrate during exercise, and subjects with recent musculoskeletal injuries and lower limb injury were excluded.

### 2. Experimental Design

The study was an assessor-blinded randomized controlled trial conducted at Daegu University in South Korea. Thirty healthy adults were assigned a number in advance, and a table of random numbers was generated based on these numbers. Simple randomization was performed using an Excel-generated random number table. The first number was assigned to the balance exercise with the gaze stabilization exercise group (BGG); the second number was assigned to the balance exercise group (BEG); the third number was assigned to the gaze stabilization exercise group (GEG). The same pattern was followed for the other subjects of this study, 10 in each group. Each group exercised for the same time, three times a week for four weeks. Two-minute rest intervals were given in one set of exercises if required. The subjects underwent a static balance test (one-leg standing test and Sharpened Romberg test) and dynamic balance test (Single-leg stand-squat-stand test and Y-balance Test) before and after four weeks of exercise(Fig. 1).

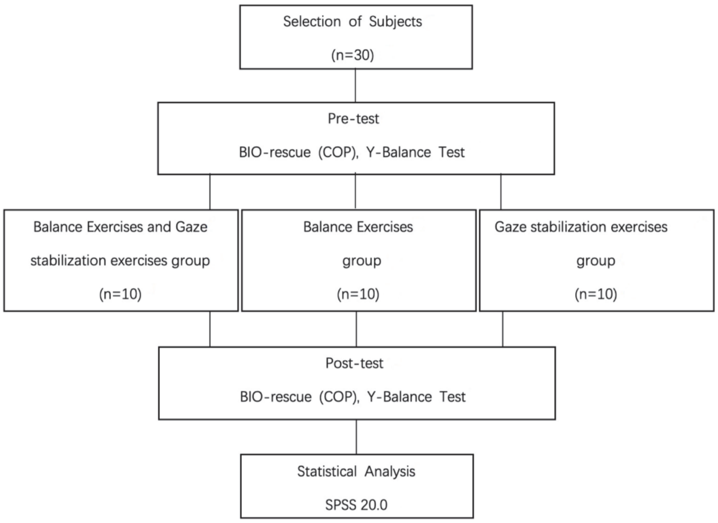


Fig. 1. Study flow chart.

### 3. Balance Exercise with Gaze Stabilization Exercise

Balance exercises with gaze stabilization exercises (BGG) were adopted from previous studies[19, 28-30]. The subjects stood on a hard surface, foam pad, and BOSU (BOSU PRO, USA) to perform one-leg and two-leg standing exercises. With a one-inch target "X" in the center of a plain or busy background, subjects were also asked to perform rapid, active head rotations, moving from one end (i.e., right or up) to the other (i.e., left or down) while observing visual objects during balance exercise. The subjects were also instructed to maintain attention during head movements three times a week for 40 minutes for four weeks.

In week 1, one meter away from the plain background, the subject stood on the bladder side of the BOSU ball with their arms crossed and on one leg. They kept an eye on the "X" and moved their head from left to right in a rhythmic motion for 30 seconds. Next, they stood on the hard ground with their arms crossed and one leg one meter away from the plain background. The patient watched the "X" and moved their head from up to down for 45 seconds. Finally, the subjects stood on the hard ground with crossed arms and legs two meters from the plain background. The subject stared at the "X" and moved their head rhythmically from left to right and up to down for 60 seconds.

In week 2, the subjects stood one meter away from the busy background: one leg and arms crossed on the bladder side of the BOSU ball. The subjects watched the "X" and moved their head from left to right for 30 seconds. Next, one meter from the busy background, the subject stood on the bladder side of the BOSU ball with their arms crossed and one leg while lifting the non-support leg forward and backward. The subject stared at the "X" and moved their head from up to down for 45 seconds. Finally, the subjects stood on a foam pad with their arms across two meters away from the busy background, staring at the "X." They moved their head rhythmically from left to right and up to down for 30 seconds.

In week 3, the subjects stood one meter away from the busy background with one leg and arms crossed on the hard side of the BOSU ball. They stared at an "X" and moved their head from left to right and up to down for 60 seconds. Next, they stood on the hard ground with arms crossed two meters away from the busy background.

They stared at the “X” and moved their head from left to right and up to down for 45 seconds. Finally, in the VOR X2 exercise, the subject stood on one leg on a foam pad and held a card (plain background) at arm's length. They stared at the “X” and moved their head and card left and right in opposite directions for 60 seconds.

In week 4, the subjects stood with one leg and their arms crossed on the hard side of the BOSU ball one meter away from the busy background while lifting their non-supporting leg forward and backward. The subjects stared at the “X” and moved their head from left to right and up to down for 60 seconds. Next, they stood one meter away from the busy background, with one leg and arms crossed on the bladder side of the BOSU ball. They stared at the “X” and moved their head from left to right for 45 seconds. Finally, in the VOR X2 exercise, the subjects stood on a foam pad with one leg and held a card (busy background) at arm's length. They stared at the “X” and moved their head and card left and right in the opposite directions of the card for 90 seconds.

1) Balance Exercise

The balance exercises (BEG) were adopted from previous studies [28-30]. They were trained for four weeks with a single-limb standing exercise and two-limb standing exercise on a hard surface, foam pad, and BOSU ball. The exercise was performed three times a week for 40 minutes for four weeks.

In week 1, the subjects stood on a hard surface with their arms crossed on one leg for 30 seconds. Next, they stood barefoot with one leg on the bladder side of the BOSU ball and their arms crossed for 45 seconds. Finally, the subjects stood barefoot on the bladder side of the BOSU ball with their arms crossed for 60 seconds.

In week 2, the subjects stood on one leg on the bladder side of the BOSU ball with their arms crossed for 30 seconds. Next, they stood with one leg and arms crossed on the bladder side of the BOSU ball while lifting the non-support leg forward and backward for 45 seconds. Finally, they stood on a foam pad with their arms crossed for 30 seconds.

In week 3, the subjects stood on one leg on a hard surface with their arms crossed for 60 seconds. Next, they stood on one leg on the hard side of the BOSU ball with their arms crossed for 45 seconds. Finally, they stood on a foam pad with their arms crossed for 60 seconds.

In week 4, the subjects stood one leg on the bladder side of the BOSU ball with their arms crossed for 60 seconds. Next, they stood with one leg and their arms crossed on the hard side of the BOSU ball while lifting the non-support leg forward and backward for 45 seconds. Finally, the subjects stood on a foam pad with their arms crossed for 90 seconds.

2) Gaze Stabilization Exercise

The gaze stabilization exercise (GEG) was varied based on three factors: (1) the direction of the head movement, i.e., yaw (horizontal) or pitch (vertical); (2) the background was plain or busy; (3) a one-inch target “X”[31] was fixed at the center of the background one meter away, and fixed at the center of the background two meters away[19]. These exercises required the individuals to perform rapid, aggressive head rotations while observing a visual target and required the target to remain focused during head movement[32,33]. The subjects were asked to move their heads continuously (i.e., side to side or up and down) at the highest speed possible without the target being blurred. Three times a week for 40 minutes for four weeks.

In week 1 (VOR X1), the subject stood one meter away from a plain background at eye level. They stared at the target “X” and turned from left to right and back again. They moved upward and downward again, staring at the target “X.” Finally (VOR X1), the subjects stood two meters away from a plain background at eye level. The previous motion was repeated.

In week 2 (VOR X1), the subjects stood one meter away from a busy background at eye level. They stared at the target “X” and turned from left to right and back again. They then moved upward and downward again, staring at the target “X.” Finally (VOR X1), the subjects stood two meters away from a busy background at eye level. The previous motion was repeated.

In week 3 (VOR X1), the subjects stood one meter from a busy background at eye level. They stared at the target “X” and turned from left to right and back again. They moved upward and downward again. Next (VOR X1), the subjects stood two meters away from a busy background at eye level and repeated the (1) exercise. Finally (VOR X2), while standing, they held a card with an “X” on a plain background and held the card at arm's length. They stared at the “X” and moved their head and card from left (upward) to right (downward) in opposite directions.

In week 4 (VOR X1), the subjects stood one meter from a busy background at eye level. They stared at the target “X” and turned from left to right and back again. They then moved upward and downward again. Next (VOR X1), they stood two meters away from a busy background at eye level. They repeated the previous motion. Finally (VOR X2), while standing, the subjects held a card with an X on a busy background and held the card at arm's length. They stared at the “X” and moved their head and card from left (upward) to right (downward) in opposite directions.

## 4. Measurements

### 1) Static balance

The one-leg standing (OLS) test and Sharpened Romberg test (SRT) were used to assess the postural stability in the static positions.

BIO-Rescue (RM Ingenierie, France) balance measuring equipment was used to measure the pressure of the feet and postural balance before and after exercise. The Bio-Rescue system is composed of a platform, software, and monitor. The platform (610 mm × 580 mm × 10 mm) is very thin and is equipped with approximately 1,600 pressure sensors. Using this equipment, the moving surface (mm), moving distance ($mm^2$), and average speed (cm/s) of the center of pressure (COP) of the study subjects were measured. The COP tracks the measured area ($mm^2$), length (cm), and speed (cm/s) while the subject maintains postural balance. Geronimo et al. reported good to high intraclass correlation coefficients (ICC = .83–.95)[34,35].

The inter-rater reliability analysis of the one-leg standing test was conducted using the ICC and 95% confidence intervals[36]. The subject stood on one leg with the dominant leg and the second toe aligned with the BIO-rescue angle line, approximately 30°. The subject was measured for 15 seconds with the non-dominant leg lifted and a natural arm droop[37]. The examiner closely supervised the subject during the test to prevent falls. Data were collected for ten seconds, and five successful trials were recorded with a thirty-second rest between trials. The mean of three successful trials was used for data processing (Fig. 2).

The SRT measures a person's sense of balance. The interrater reliability was excellent for the Sharpened Romberg eyes open test with an ICC of 1.0. The intrarater reliability between successive trials within a session for the Sharpened Romberg eyes open test was excellent, with an ICC of .786[38]. The subject stood on the BIO-rescue, requiring one foot to be in front of the other. The heel of the front foot should touch the tip of the back foot. The heel should be aligned with the tip of the foot. The arms should be in front of the chest. The eyes should be forward, and the body weight should be balanced between the feet for 30 seconds[39]. The examiner closely supervised the subject during the test to prevent falls. The data were captured for 30 seconds, and five successful trials were recorded with a thirty-second rest between trials. The mean of three successful trials was used for data processing (Fig. 3).

Fig. 2. Measurement position of the OLS.

Fig. 3. Measurement position of the SRT.

2) Dynamic Balance

A single-leg stand-squat-stand test (SST) and Y-balance test were used to assess the postural stability in dynamic positions. BIO-Rescue (RM Ingenierie, France) balance measuring equipment was used to measure the single-leg stand-squat-stand test (SST). The subjects stood on the dominant leg, with the second toe aligned with the BIO-rescue angle line, approximately 30°. The subject stood on the dominant leg, lifted the non-dominant leg off the ground, flexed the hip approximately 45°, flexed the non-standing knee approximately 90°, dropped their arms naturally, maintained balance for three seconds, squatted until the knee was bent approximately 60°, keep the back straight for five seconds, and returned to the starting position for five seconds[40,41]. The examiner closely supervised the subject during the test to prevent falls. Data were captured for 15 seconds, and five successful trials were recorded with a thirty-second rest between trials. The mean of three successful trials was used for data processing. The kinematic evaluation was reliable (ICC = .83-1.00)[35](Fig. 4).

The Y-balance test was performed on the preferred leg as the standing leg. The internal reliability ICC ranged from .85-.91[42,43]. The leg length (cm) was initially measured in the supine position from the anterior superior

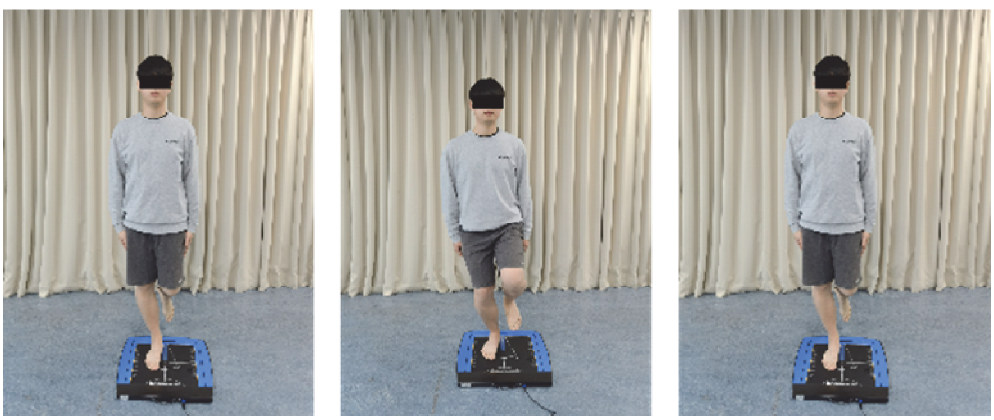

Fig. 4. Measurement position of the SST.

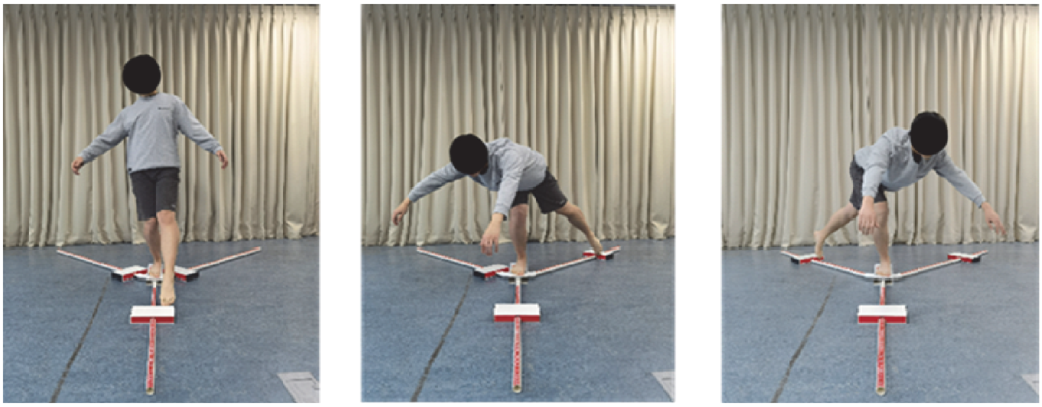

Fig. 5. Measurement position of the Y-balance.

iliac spine to the distal medial malleolus. The subject stood on the middle pedal with the big toe at the starting line. The subject stood on one leg and pushed the stretch indicator on AN, PM, and PL as far as possible with the other leg. At the end of each trial, the participants returned to the starting position under control[44].

The trial was unsuccessful if any of the following occurred: (1) the subjects failed to keep one leg (for example, the free body touch the ground or stand feet down from the center plate); (2) subjects failed to keep in touch when motion anchor was in contact with the red target area (for example, playing touchdown indicator) after making contact with the indicator; (3) the subjects used the touchdown indicator for support; (4) the subjects kept jump and returned to the position after one second, canceled the test, and repeated[47]. The optimal reach distance in each direction was used for further analysis(Fig. 5).

This test uses a Y-shaped plastic device. The Y-Balance Test (YBT) is a precise quantitative test of the comprehensive ability of core stability. The YBT assesses an individual's dynamic balance in a single-legged stance while reaching in three directions (anterior, posteromedial, and posterolateral) with the contralateral limb. The composite YBT score was also calculated for each subject using the following formula[45]:

$$\text{YBT-CS (\%)} = [(AN + PM + PL)/(LL \times 3)] \times 100,$$

YBT-CS (%) is the YBT composite reach score; AN is the anterior reach; PM is the posteromedial reach; PL is the posterolateral reach; LL is the relative length of the extremity. High reliability was also reported for the YBT (ICC = .85– .93, SEM: 2.0–3.5 cm)[46].

### 5. Statistical Analysis

The data were analyzed using SPSS (statistical package for the social sciences) version 20.0 for Windows software (version 20.0, SPSS Inc., Chicago, IL, USA). The differences between the three groups before and after the intervention were compared using a paired t-test, and the differences between the three groups were assessed using a one-way ANOVA test. The least-square difference (LSD) was determined as a post-test explaining the differences between the groups after the test, and the significance level was $p < .05$. The effect size of the interventions was calculated using Cohen's d.

## Ⅲ. Results

### 1. General Characteristics of the Subjects

Table 1 lists the general characteristics of the subjects. No significant differences in height, weight, and age were observed between the three groups ($p > .05$).

Table 1. General characteristics of the subjects

| | BGG (n = 10) | BEG (n = 10) | GEG (n = 10) | F | P |
|---|---|---|---|---|---|
| Age(year) | 24.90 ± 2.42 | 23.6 ± 3.75 | 22.7 ± 2.80 | 1.624 | .216 |
| Gender(male/female) | 5/5 | 5/5 | 5/5 | .000 | 1.000 |
| Height(cm) | 173.60 ± 9.07 | 167.90 ± 9.19 | 167.20 ± 6.36 | 1.784 | .187 |
| Weight(kg) | 69.80 ± 15.65 | 61.40 ± 7.37 | 57.60 ± 9.73 | 2.464 | .104 |
| BMI($kg/m^2$ ) | 23.02 ± 3.32 | 21.77 ± 1.85 | 20.63 ± 2.67 | 1.349 | .277 |

BGG: balance exercise with gaze stabilization exercise group
BEG: balance exercise group
GEG: gaze stabilization exercise group
BMI: body mass index
Mean (± standard deviation)

## 2. Changes in Static and Dynamic Balance

The results of static and dynamic balance tests showed significant differences in the COP surface, length, and YBT scores (p < .05) between the BGG, BEG, and GEG, and the speed change was also reduced. On the other hand, the change range of BGG was larger than those of BEG and GEG, and the improvement of balance control was most significant.

The OSL test result showed that the surface and length of the BGG, BEG, and GEG were significantly different before and after exercise (p < .05); there was no significant difference in speed, but it was reduced (p > .05). The BGG showed greater improvement in the surface [effect value: 6.401,(p < .05)], speed [effect value: 2.213,(p < .05)], and length[effect value: 4.076,(p < .05)](Table 2).

The SRT result showed that the surface of the BGG, BEG, and GEG was significantly different before and after exercise (p < .05); there was no significant difference in speed (p > .05). The SST result showed that the lengths of the BGG, BEG, and GEG were significantly different before and after exercise(p < .05); there was no significant difference in speed (p > .05). On the other hand, the BGG showed greater improvement in the surface [effect value: 2.834,(p < .05)] and speed [effect value: 1.184, (p > .05)](Table 3).

The SST result showed that the lengths of BGG, BEG, and GEG were significantly different before and after exercise (p < .05); no significant difference in speed was noted (p > .05). The BGG showed greater improvement in the length [effect value: 4.281,(p < .05)]( (Table 4).

The YBT results showed statistically significant differences between the three groups before and after exercise (p < .05). According to the results, BGG showed the greatest improvement in balance compared to BEG and GEG. On the other hand, the BGG showed greater improvement in the score [effect value: 11.477,(p < .05)] (Table 5).

In the LSD post hoc test of the OSL, there was a significant difference between the BGG and GEG and between the BGG and GEG in surface(p < .05). A significant difference in the length results was observed between the BGG and BEG and between the BEG and GEG(p < .05)(Fig. 6). A significant difference in the post-test LSD of SRT was noted between the BGG and BEG and between the BEG and GEG in surface(p < .05)(Fig. 7). A significant difference in the length according to the post-test LSD of SST was observed between the BGG and BEG and between the BEG and GEG (p < .05)(Fig. 8). Significant differences in the post-test LSD of YBT was noted between the BGG and BEG, between the BGG and GEG, and between the BGG and GEG(p < .05)(Fig. 9).

Table 2. Pre-post changes in OLS test

| Variables | Group | Pre | Post | Change | t | p | Effect size |
|---|---|---|---|---|---|---|---|
| Surface | BCG | 131.93 ± 42.33 | 51.93 ± 22.59 | 80.00 ± 25.00 | 10.121* | .000* | 6.401 |
| | BEG | 118.80 ± 51.70 | 83.27 ± 45.52 | 35.53 ± 24.00 | 4.682 | .001* | 2.961 |
| | GEG | 106.13 ± 48.89 | 86.03 ± 43.87 | 20.10 ± 9.31 | 6.831 | .000* | 4.320 |
| | F | | | 22.540* | | | |
| | P | | | .000* | | | |
| | effect size | | | 2.147 | | | |
| Speed | BCG | 1.43 ± .33 | 1.10 ± .22 | .33 ± .30 | 3.500 | .007* | 2.213 |
| | BEG | 1.43 ± .50 | 1.19 ± .43 | .24 ± .25 | 3.008 | .015* | 1.902 |
| | GEG | 1.50 ± .43 | 1.33 ± .37 | .16 ± .27 | 1.864 | .095 | 1.179 |
| | F | | | .979 | | | |
| | P | | | .389 | | | |
| | effect size | | | .331 | | | |
| Length | BCG | 9.77 ± 3.32 | 3.55 ± .70 | 6.23 ± .3.01 | 6.445 | .000* | 4.076 |
| | BEG | 9.23 ± 4.60 | 5.14 ± 2.06 | 4.08 ± 2.84 | 4.546 | .001* | 2.875 |
| | GEG | 8.74 ± 3.43 | 7.81 ± 2.87 | .93 ± .78 | 3.753 | .005* | 2.374 |
| | F | | | 11.819 | | | |
| | P | | | .000* | | | |
| | effect size | | | .877 | | | |

BGG: balance exercise and gaze stabilization exercise group
BEG: balance exercise group
GEG: gaze stabilization exercise group
Mean (± standard deviation)
*p < .05

Table 3. Pre-post changes in SRT

| Variables | Group | Pre | Post | Change | t | p | Effect size |
|---|---|---|---|---|---|---|---|
| Surface | BCG | 193.00 ± 108.08 | 61.83 ± 32.78 | 131.17 ± 92.56 | 4.481 | .002* | 2.834 |
| | BEG | 149.03 ± 89.97 | 79.43 ± 49.31 | 69.60 ± 52.74 | 4.173 | .002* | 2.640 |
| | GEG | 176.47 ± 105.60 | 159.90 ± 93.32 | 16.57 ± 13.00 | 4.029 | .003* | 2.548 |
| | F | | | 8.567 | | | |
| | P | | | .001* | | | |
| | effect size | | | .993 | | | |
| Speed | BCG | 4.92 ± 6.78 | 3.41 ± 4.25 | 1.51 ± 2.56 | 1.872 | .094 | 1.184 |
| | BEG | 3.94 ± 4.87 | 2.61 ± 2.68 | 1.33 ± 2.27 | 1.857 | .096 | 1.175 |
| | GEG | 1.70 ± .43 | 1.51 ± .38 | .19 ± .38 | 1.613 | .141 | 1.020 |
| | F | | | 1.299 | | | |
| | P | | | .289 | | | |
| | effect size | | | .091 | | | |

BGG: balance exercise and gaze stabilization exercise group
BEG: balance exercise group
GEG: gaze stabilization exercise group
Mean (± standard deviation)
*p < .05

Table 4. Pre-post changes in SST

| Variables | Group | Pre | Post | Change | t | p | Effect size |
|---|---|---|---|---|---|---|---|
| Speed | BCG | 3.13 ± 1.91 | 2.47 ± 2.10 | .66 ± 1.02 | −2.051 | .070 | 1.297 |
| | BEG | 3.80 ± 3.87 | 3.17 ± 3.00 | .63 ± 1.47 | −1.355 | .209 | .857 |
| | GEG | 2.34 ± .47 | 1.80 ± .40 | .54 ± .38 | −4.467 | .002* | 2.825 |
| | F | | | .037 | | | |
| | P | | | .964 | | | |
| | effect size | | | .029 | | | |
| Length | BCG | 12.94 ± 2.68 | 7.99 ± 1.45 | 4.96 ± 2.32 | −6.769 | .000* | 4.281 |
| | BEG | 12.32 ± 5.28 | 6.20 ± 2.85 | 6.13 ± 3.72 | −5.207 | .001* | 3.293 |
| | GEG | 9.06 ± 4.46 | 7.41 ± 3.62 | 1.65 ± 1.89 | −2.756 | .022* | 1.743 |
| | F | | | 7.111 | | | |
| | P | | | .003* | | | |
| | effect size | | | .425 | | | |

BGG: balance exercise and gaze stabilization exercise group
BEG: balance exercise group
GEG: gaze stabilization exercise group
Mean (± standard deviation)
*p < .05

Table 5. Pre-post changes in the YBT

| Variables | Group | Pre | Post | Change | t | p | Effect size |
|---|---|---|---|---|---|---|---|
| Score(%) | BCG | .88 ± .72 | 1.02 ± .66 | .14 ± .02 | 18.146 | .000* | 11.477 |
| | BEG | .94 ± .79 | 1.01 ± .72 | .08 ± .40 | 5.999 | .000* | 3.794 |
| | GEG | .91 ± .78 | .93 ± .82 | .03 ± .03 | 2.910 | .017* | 1.840 |
| | F | | | 31.437 | | | |
| | P | | | .000* | | | |
| | effect size | | | 1.932 | | | |

BGG: balance exercise and gaze stabilization exercise group
BEG: balance exercise group
GEG: gaze stabilization exercise group
Mean (± standard deviation)
*p < .05

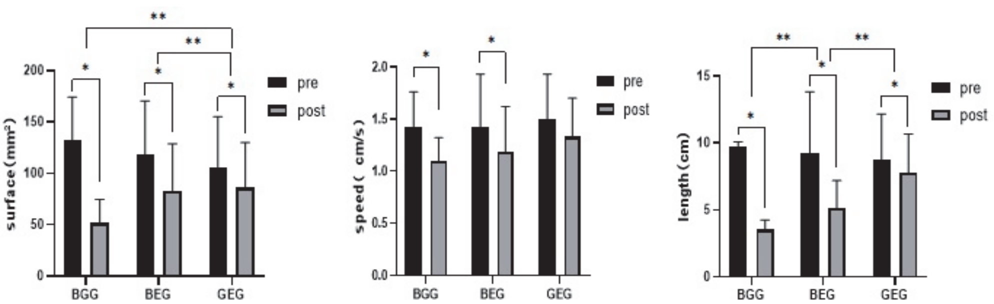


Fig. 6. Comparison of pre-post and post hoc tests of the OSL in each group.

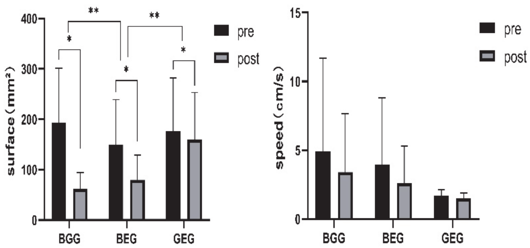


Fig. 7. Comparison of pre-post and post hoc tests of the SRT in each group.

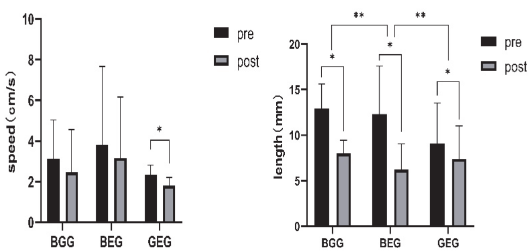


Fig. 8. Comparison of pre-post and post hoc tests of the SST in each group.

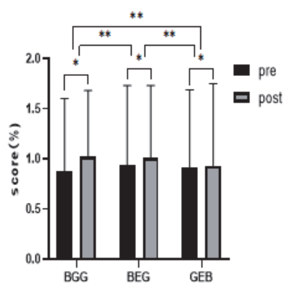


Fig. 9. Comparison of pre-post and post hoc tests of the YBT in each group.

## Ⅳ. Discussion

This study found that after four weeks of training, the static COP displacement (surface, speed, and length) and dynamic COP displacement (speed and length) Y-balance scores of the BGG, BEG, and GEG subjects were positively affected. On the other hand, the BGG showed the greatest change in the change value and the greatest improvement in static and dynamic balance.

In the static balance measurement, the balance stability of the subjects was improved significantly. Among the change values of each group, the surface, speed, and length of the BGG, BEG, and GEG are all reduced. The decrease in swinging surface area indicates an improved ability to control posture. With improved balance, the lower extremity extensors accelerate the body vertically biomechanically, maintaining a standing position with a high center of gravity during motion[47]. The changes in the center of pressure can affect the symmetry of body coordination and static and dynamic balance[48]. Jakobsen[49] also reported that the reduction of the COP swing length and surface area can be considered an improvement of the attitude balance stability. This is consistent with the present experimental results. In particular, the change value of BGG was greater than that of BEG and GEG, indicating superior posture control and increased static balance stability. Gaze stabilization exercise is an adaptive exercise based on the ability of the vestibular system to adjust the intensity of the VOR in response to a given input (head movement). Integrating visual, vestibular, and somatosensory inputs is essential for planning and executing motor commands during the single-leg stance to maintain balance[50].

Vision plays a critical role in controlling locomotion because it provides input for anticipatory reactions of the body in response to constraints of the environment[51]. The eye muscles must be constantly active and perform movements to adjust the visual organs to the observed objects and produce three-dimensional vision[41]. During the head-eye coordination exercises in the intervention, centripetal impulses from the muscles of the neck proprioceptors cooperate with the labyrinth impulses to promote the oculomotor muscular activity through the cervical-vestibular-ocular reflex. Some important encephalic nuclei (trigeminal, oculomotor, vestibular, and accessorial nerve nuclei) were integrated into the medial longitudinal fasciculus. Moreover, the ocular proprioceptive receptors send afferents to the trigeminal and cuneate nuclei[16].

Proprioceptive messages from the neck muscles are integrated into the central nervous system. They help control the balance and body orientation in the space-time around it[16]. According to Schleip, active changes in fascial stiffness might contribute to the motoneuronal coordination aspect of low back stability and other musculoskeletal parameters when viewed in a time window of several minutes and longer[52]. Visual input had positive effects on the EMG activity of the temporal muscle, masseter muscle, sternocleidomastoid muscle, and anterior digastric muscle at rest[16]. Visual acuity decreases, usually by leaning forward or turning their head from side to side. These habits increase the tension of the thoracic muscles, descending fibers of the quadriceps, scapular lever, sternoclavicular and mastoid muscles, and suboccipital muscles[53]. Long-term shortening of the above-mentioned muscles may cause ischemia and the formation of musculofascial trigger points (MTrPs), resulting in pain[17]. One study reported that adults with dizziness and no vestibular deficits who added vestibular gaze stabilization exercises to standard balance rehabilitation reduced the risk of falls significantly and improved postural stability[54].

In dynamic balance measurements, the balance stability of the subjects was improved significantly in the SST and Y-balance tests. In the change values of each group in the SST, the speed and length of BGG, BEG, and GEG were all reduced. Among them, the change in BGG was greater than BEG and GEG, representing the best posture control and more stable dynamic balance. Improvements in the YBT score may result from improved neuromuscular control and dynamic balance and have less to do with lower limb strength, as suggested by Thorpe and Ebersole[55]. These results can be explained by the varied exercises in terms of coordination, leading to increased confidence in overall body movement control and the ability to choose correct, accurate movements faster and better[56]. The BGG exercise method uses balance training combined with gaze stabilization exercise to practice, which also affects movement control, resulting in greater postural stability. Therefore, the BGG-trained subjects showed better improvement in the dynamic balance test. This improvement should be related to an enhanced ability to use visual stimuli to gather the necessary information to keep the body in the desired position[16]. Body shaking and instability were the highest when balance and gaze stabilization exercises were performed simultaneously, which is more difficult for body stability and has higher requirements for balance. Buckley et al.[57] also reported that visual information affects interacting with each other with the position of the head and keeping the position and posture of the head stable.

After four weeks of training, the subject's torso tilt controls the body balance so that the COP is in a specific position and balancing ability. Thus, the BGG-trained subjects showed better improvement in the dynamic balance test. This improvement should be related to an enhanced ability to use visual stimuli to gather the necessary information to keep the body in the desired position to become more controlled and precise. Gaze stabilization exercises improved postural stability, and gaze stabilization subjects had a greater reduction in perception of motion sensitivity[58]. Morimoto et al. examined healthy non-athlete individuals. They reported that dynamic visual acuity and the limit of stability of healthy individuals produced significant progress after three weeks of ocular motor exercises[33]. Visual exercises can enhance the limit of stability and dynamic visual acuity in adults and other dynamic sports[59]. Good balance requires a complex integration of sensory information about the body's position in relation to its surroundings and the ability to generate appropriate motor responses to control body movements[60]. The reinforcement training of visual reflexes, combined with other training, has become an effective way of restoring balance and preventing falls[61].

This study had some limitations. First, the sample size was small, which may have influenced certain variables and the results. The study could not determine the long-term effects of self-control and mood after four weeks, and no follow-up tests were conducted. The retention status of participants is unclear. Therefore, future studies with larger sample sizes are recommended. High-definition eye trackers will be needed to ensure that subjects' eyes can aim and track objects horizontally during movement. Finally, the clinical trial protocol was not registered on any international clinical trial registry platform.

## Ⅴ. Conclusion

The preliminary results of this study indicate that gaze stabilization exercises with balance exercises are particularly effective for static and dynamic balance. Body stability and posture control were improved by exercising the interaction between eye and body movement. These results have implications for vestibular training, where active head rotation is prescribed to improve gaze stability.

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