



Original Article

## Gaze stabilization exercises derive sensory reweighting of vestibular for postural control

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**Abstract.** [Purpose] The aim of this study was to investigate whether gaze stabilization exercise derives sensory reweighting of vestibular for upright postural control. [Subjects and Methods] Twenty-three healthy volunteers participated in this study. The center of pressure of the total trajectory length was measured before (pre), immediately after (post), and 10 min after (post10) gaze stabilization exercise, in the static standing position, with the eyes open or closed, on the floor or on foam rubber. The sensory contribution values of the visual, somatosensory, and vestibular systems were calculated using center of pressure of the total trajectory length value in these measuring conditions. [Results] The center of pressure of the total trajectory length on foam rubber in post and post10 were significantly lower than that in the pre. The sensory contribution values of vestibular in post10 stages were significantly higher than that in pre-stage. [Conclusion] Gaze stabilization exercise can improve the static body balance in a condition that particularly requires vestibular function. The possible mechanism involves increasing sensory contribution of the vestibular system for postural control by the gaze stabilization exercise, which may be useful to derive sensory reweighting of the vestibular system for rehabilitation.

**Key words:** Gaze stabilization exercise, Sensory reweighting, Vestibular

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### INTRODUCTION

The visual, vestibular, and proprioceptive sensory systems contribute to maintain the upright posture<sup>1)</sup>. The relative contribution of each sensory system can be changed depending on environmental conditions<sup>2, 3)</sup> and modulated by motor task<sup>4)</sup>. Therefore, the balance training method based on these sensory reweighting dynamics can be useful and improve the effect on rehabilitation.

One of the methods that can possibly induce sensory reweighting is the gaze stabilization exercise (GSE), which is often applied for vestibular rehabilitation. The GSE is effective to improve not only gaze stability during head movement in patients with vestibular hypofunction<sup>5)</sup> and in healthy young adults<sup>6)</sup>, but also balance function in static and dynamic movements of healthy elderly people<sup>7)</sup>. Furthermore, GSE recently improved the balance in a condition that required vestibular function<sup>8)</sup>, and one of the mechanisms of this improvement is plastic change of vestibulospinal reflex for upright standing<sup>8)</sup>. Therefore, GSE is a pos-

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sible method to induce sensory contribution of the vestibular sensory system for upright static postural control, but it is unclear.

The sensory contribution<sup>9)</sup> can be estimated using the sensory contribution value (SCV) calculated from the center of pressure (CoP) of the total trajectory length (CoP-L) measured with force plate and foam rubber<sup>10)</sup>. Therefore, based on these findings, we investigated whether GSE increases the sensory contribution of the vestibular sensory system for upright static postural control, and other sensory contributions are modulated by GSE.

## SUBJECTS AND METHODS

We recruited 23 healthy volunteers (16 men and 7 women; mean age,  $24.1 \pm 1.6$  years) with no history of neurological diseases. After explaining the experimental protocol, all subjects provided written informed consent to participate in this experiment. The ethics committee of Shijonawate Gakuen University approved this study. This study was conducted according to the principles and guidelines of the Declaration of Helsinki.

With regard to GSE, the upright standing subjects were instructed to repetitively rotate their heads to the right and left in accordance with a 2-Hz beeping sound for 1 min while gazing at a visual target placed in front, with the stipulation that the target remains in focus during the head movements<sup>8)</sup>. The left and right rotation angles of the head were the largest when the subjects were able to gaze at the target. Five GSE trials were conducted at 1-min intervals.

The CoP was measured from the ground reaction force, recorded using the force plate (Gravicorder G5500; Anima, Japan) with the eyes open (EO) or closed (EC). To assess the CoP-L during the maintenance of the upright standing position in somatosensory input from ankle unreliable condition, the subjects were instructed to stand barefoot as still as possible on foam rubber (Anima; thickness, 3.5 cm; tension strength, 2.1 kg/cm<sup>2</sup>) placed on the force plate with the eyes open (EO+R) or closed (EC+R). In four measuring conditions, the subjects were instructed to look straight ahead with their head erect and their arms hanging by their sides for 30 s. The CoP in four conditions was measured before GSE (pre), immediately after GSE (post), and 10 min after GSE (post10). The CoP-L values in four measuring conditions were calculated. These parameters, which are CoP-L in the EO (A), EC (B), EO+R (C), and EC+R (D), were used to calculate the sensory contribution in the upright standing position in the formula by Lord et al<sup>9)</sup>. The parameter (x) was calculated by  $(A-B)/B$ , (y) by  $(C-A)/C$ , and (z) by  $A/D$ . Finally, these parameters were converted to the sensory contribution value (SCV) of vision, which was  $x/(x+y+z) \times 100$ , that of somatosensory was  $y/(x+y+z) \times 100$ , and vestibular was  $z/(x+y+z) \times 100$ , which was similar to a previous study<sup>9)</sup>.

In CoP-L, which is a parametric value, repeated-measures one-way analysis of variance (ANOVA) was performed to test the difference in the means among the pre, post, and post10 GSE conditions. The Holm test as post hoc multiple comparison test was conducted if the ANOVA revealed a significant difference. In SCV, which is a non-parametric value, Friedman test was used to test the difference in the median among the pre, post, and post10 GSE conditions. Scheffe's multiple comparison test as post hoc test was conducted if the Friedman test revealed a significant difference. The alpha level was set at 0.05. Data of CoP-L are expressed as mean and standard error, and data of SCV are expressed first quartile-median-third quartile.

## RESULTS

The CoP-L in EO of the pre, post, and post10 GSE conditions were  $32.8 \pm 9$ ,  $31.1 \pm 7.8$ , and  $31.9 \pm 6.6$  cm, respectively. The CoP-L in EC of the pre, post, and post10 GSE conditions were  $46.2 \pm 14.2$ ,  $46.2 \pm 13.5$ ,  $43.2 \pm 10$  cm, respectively. The CoP-L in EO+R of the pre, post, and post10 GSE conditions was  $64.6 \pm 15.9$ ,  $59.1 \pm 9.9$ , and  $55.6 \pm 10.8$  cm, respectively. The CoP-L in EC+R of the pre, post, and post10 GSE conditions was  $133 \pm 37.1$ ,  $121.5 \pm 33.6$ , and  $116.7 \pm 25.4$  cm, respectively. One-way ANOVA revealed that no significant difference was found in EO ( $F=0.92$ , d.f.=2,  $p=0.4$ ) and EC ( $F=1.83$ , d.f.=2,  $p=0.17$ ). In contrast, a significant difference was found in EO+R ( $F=9$ , d.f.=2,  $p=0.0005$ ) and EC+R ( $F=6.5$ , d.f.=2,  $p=0.003$ ). The post-hoc test revealed that the value of post and post10 GSE conditions were significantly lower than that of pre GSE condition in EO+R and EC+R.

The SCV of visual in pre, post and post10 GSE conditions were 20–26.4–31%, 28.7–32–35.8%, and 17.9–27.4–33.4%, respectively. The SCV of somatosensory in pre, post and post10 GSE conditions were 41.8–45.5–51%, 42–44.2–49.9%, and 42.6–44.9–47.5%, respectively. The SCV of vestibular in pre, post and post10 GSE conditions were 18.5–24.5–31.6%, 19.9–24.2–29%, and 24.5–29–37%, respectively. No significant difference was found in visual ( $\chi^2=3.4$ , d.f.=2,  $p=0.18$ ) and somatosensory ( $\chi^2=2.7$ , d.f.=2,  $p=0.26$ ), but a significant difference was found in vestibular ( $\chi^2=8.1$ , d.f.=2,  $p=0.018$ ). The post-hoc test revealed a significant difference was found only in the pre and post10 GSE conditions ( $p=0.03$ ).

## DISCUSSION

The CoP-L of post and post10 GSE conditions were significantly lower than that of pre GSE condition in the EO+R and EC+R, wherein the measuring condition particularly requires vestibular function<sup>1)</sup>. The SCV of vestibular significantly increased after GSE, but the SCV of the other sensory systems did not change. These findings indicate that GSE induces sensory reweighting of vestibular for postural control and improves standing balance in upright standing condition particularly when requiring vestibular function.

In this study, the CoP-L values on foam rubber with EO and EC were significantly decreased after GSE. This finding is consistent with a previous study wherein GSE improved the balance function during upright standing on foam rubber<sup>8)</sup>. The

foam rubber can make the somatosensory input from peripheral of lower limb unreliable<sup>1)</sup>, thus the usable sensory is visual and vestibular during standing on foam rubber. Thus, in this study, the decrease of CoP-L value indicates that the stability in standing depending on vestibular function may be increased after GSE.

The SCV of vestibular was significantly increased after GSE, indicating that the sensory contribution of the vestibular system for upright standing is increased by GSE. A previous study reported that GSE improves vestibulospinal reflex for upright standing, therefore the sensory contribution of vestibular is possibly increased because of the plastic change of the vestibulospinal reflex.

The canals and otoliths are stimulated by head rotation, and the vestibular nerve and nucleus are activated, resulting in the transmission of some impulses to the rectus and oblique muscles to drive eye movement to decrease retinal slips<sup>11)</sup>. This vestibule-ocular reflex is induced during GSE repeatedly, and dynamic visual activity, which requires the vestibule-ocular reflex, was increased by GSE<sup>6)</sup>. Therefore, GSE can induce a plastic change of the vestibule-ocular reflex activity. Furthermore, GSE modulates the vestibulospinal reflex<sup>8)</sup>. In contrast, the vestibulospinal reflex and vestibule-ocular reflex have a common pathway and center, which are vestibular, vestibular nerves, and vestibular nuclei. These findings lead one idea that the modulation of excitability of vestibular nerve and nuclei associated with the vestibule-ocular reflex by GSE can increase the vestibulospinal reflex and contribution of vestibular for postural control.

The sensory reweighting dynamics is consisted with fast and slow dynamics<sup>12)</sup>. The change of external condition of the body is the trigger of the reweighting to reliable sensory input<sup>1)</sup>, and the weighting of sensory for postural control remains after sensory reweighting training with change of the sensory input<sup>4)</sup>. These plastic changes of sensory weighting is affected by the central nervous system<sup>12)</sup>, but the mechanism is unclear. Based on these findings, in this study, the effect of sensory reweighting of vestibular by GSE can be learned by involving the central nervous system.

Abnormal sensory weighting occurs in elderly people<sup>13)</sup> and stroke patients<sup>14)</sup>. Therefore, GSE can be a useful exercise for not only patients with vestibular dysfunction, but also elderly people and stroke patients. Further studies are needed to investigate whether GSE derives the sensory reweighting in elderly people and stroke patients.

In conclusion, our results indicate that GSE improves the static body balance in conditions particularly requiring vestibular function. The possible mechanisms are not only the modulation of vestibulospinal reflex, but also increase of sensory contribution of vestibular for postural control by GSE. The GSE may be a useful exercise that induces sensory reweighting of vestibular.

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## REFERENCES

- 1) Horak FB, Nashner LM, Diener HC: Postural strategies associated with somatosensory and vestibular loss. *Exp Brain Res*, 1990, 82: 167–177. [[Medline](#)] [[CrossRef](#)]
- 2) Nashner L, Berthoz A: Visual contribution to rapid motor responses during postural control. *Brain Res*, 1978, 150: 403–407. [[Medline](#)] [[CrossRef](#)]
- 3) Assländer L, Peterka RJ: Sensory reweighting dynamics in human postural control. *J Neurophysiol*, 2014, 111: 1852–1864. [[Medline](#)] [[CrossRef](#)]
- 4) Haran FJ, Keshner EA: Sensory reweighting as a method of balance training for labyrinthine loss. *J Neurol Phys Ther*, 2008, 32: 186–191. [[Medline](#)] [[CrossRef](#)]
- 5) Clendaniel RA: The effects of habituation and gaze stability exercises in the treatment of unilateral vestibular hypofunction: a preliminary results. *J Neurol Phys Ther*, 2010, 34: 111–116. [[Medline](#)] [[CrossRef](#)]
- 6) Morimoto H, Asai Y, Johnson EG, et al.: Effect of oculo-motor and gaze stability exercises on postural stability and dynamic visual acuity in healthy young adults. *Gait Posture*, 2011, 33: 600–603. [[Medline](#)] [[CrossRef](#)]
- 7) Bhardwaj VM: Effectiveness of gaze stability exercise on balance in healthy elderly population. *Int J Physiother Res*, 2014, 2: 642–647.
- 8) Matsugi A, Ueta Y, Oku K, et al.: Effect of gaze-stabilization exercises on vestibular function during postural control. *Neuroreport*, 2017, 28: 439–443. [[Medline](#)] [[CrossRef](#)]
- 9) Mergner T, Maurer C, Peterka RJ: Sensory contributions to the control of stance: a posture control model. *Adv Exp Med Biol*, 2002, 508: 147–152. [[Medline](#)] [[CrossRef](#)]
- 10) Lord SR, Ward JA: Age-associated differences in sensori-motor function and balance in community dwelling women. *Age Ageing*, 1994, 23: 452–460. [[Medline](#)] [[CrossRef](#)]
- 11) Shelhamer M, Roberts DC, Zee DS: Dynamics of the human linear vestibulo-ocular reflex at medium frequency and modification by short-term training. *J Vestib Res*, 2000, 10: 271–282. [[Medline](#)]
- 12) Chiba R, Takakusaki K, Ota J, et al.: Human upright posture control models based on multisensory inputs; in fast and slow dynamics. *Neurosci Res*, 2016, 104: 96–104. [[Medline](#)] [[CrossRef](#)]
- 13) Eikema DJ, Hatzitaki V, Tzovaras D, et al.: Application of intermittent galvanic vestibular stimulation reveals age-related constraints in the multisensory reweighting of posture. *Neurosci Lett*, 2014, 561: 112–117. [[Medline](#)] [[CrossRef](#)]
- 14) Bonan IV, Marquer A, Eskizmiriler S, et al.: Sensory reweighting in controls and stroke patients. *Clin Neurophysiol*, 2013, 124: 713–722. [[Medline](#)] [[CrossRef](#)]