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Original Article

Postural Stability Changes during Large Vertical Diplopia Induced by Prism Wear in Normal Subjects

Toshihiko Matsuo[a]*, **Hanako Yamasaki**[b], **Hirotaka Yasuhara**[b], and **Kayoko Hasebe**[c]

[a]*Department of Ophthalmology, Okayama University Medical School and Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences,* [b]*Undergraduate Course for Medicine, Okayama University Medical School and* [c]*Department of Medical Technology, Okayama University Hospital, Okayama 700-8558, Japan*

To test the effect of double vision on postural stability, we measured postural stability by electric stabilometry before prism-wearing and immediately, 15, 30, and 60 min after continuous prism-wearing with 6 prism diopters in total (a 3-prism-diopter prism placed with the base up in front of one eye and with the base down in front of the other eye) in 20 normal adult individuals with their eyes open or closed. Changes in stabilometric parameters in the time course of 60 min were analyzed statistically by repeated-measure analysis of variance. When subjects' eyes were closed, the total linear length (cm) and the unit-time length (cm/sec) of the sway path were significantly shortened during the 60-minute prism-wearing ($p < 0.05$). No significant change was noted in any stabilometric parameters obtained with the eyes open during the time course. In conclusion, postural stability did not change with the eyes open in the condition of large vertical diplopia, induced by prism-wearing for 60 min, while the stability became better when measured with the eyes closed. A postural control mechanism other than that derived from visual input might be reinforced under abnormal visual input such as non-fusionable diplopia.

Key words: body sway, postural stability (postural control), stabilometry, prism, vertical diplopia

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Postural stability is mandatory for human behavior and is controlled by sensory inputs such as visual perception and muscle proprioception. In the field of vision, postural stability in the elderly was shown to deteriorate under the influence of refractive blur [1], blurred vision [2], and cataract simulation [3]. Indeed, postural control has been shown to become better after cataract surgery [4]. Postural instability was also demonstrated to be associated with impaired contrast sensitivity in older patients with age-related maculopathy [5]. The positive effect of visual acuity on postural control has also been observed in young normal individuals [6-8].

Equilibrium function, including postural control, is assessed clinically in routine vestibular and neurological examinations [9]. Body sway or postural instability is a clinical manifestation of the equilibrium function, and, at present, can be measured in a quantitative manner with computerized static stabilometry, which provides a reliable and non-invasive technique [10]. In this study, we measured postural stability during double vision induced by continuous prism-wearing, to test how the visual input would influence postural control.

Methods

Subjects. Stabilometric measurements were

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*Corresponding author. Phone:+81-86-235-7297; Fax:+81-86-222-5059
E-mail:matsuot@cc.okayama-u.ac.jp (T. Matsuo)

done in 20 normal individuals, 7 men and 13 women, age 19 to 28 (mean, 21.3) years. All were medical students at this University, who understood the aim of the study and voluntarily participated in the study. The study adhered to the tenets of the Declaration of Helsinki.

No individuals had any systemic or eye disease or a past history of trauma or neurological disease. Subjects were tested to confirm the absence of strabismus, visual acuity at 5 m of 1.0 or better without correction or with correction by contact lenses as measured with the standard Landolt-C decimal acuity chart, binocular single vision on the Bagolini striated glasses test, and stereoacuity of 60 sec of arc or better at 0.3 m as measured by the TNO Test for Stereoscopic Vision (Clement Clarke International, Ltd., Harlow, UK). Each individual wore continuously a 3-prism-diopter prism with the base up in front of one eye and with the base down in front of the other eye to achieve 6 prism diopters in total in the vertical direction, and underwent stabilometric measurements at 5 time points during a time course of 60 min before the prism-wearing, immediately after, and 15, 30, and 60 min after the prism-wearing. In the intervals among the stabilometric measurements, all individuals were instructed to sit on a chair with natural viewing. Each individual decided arbitrarily which eye to place the prisms in front of with the base up or down.

Stabilometric measurement. The center of pressure between each subject's feet was measured by stabilometry with a computerized vertical force platform (Gravicorder GS-31; Anima Co., Tokyo, Japan). Individuals were instructed to stand naturally and barefoot on a hard platform in the upright position, with both ankles touching. Changes in vertical forces, applied to the platform, were recorded as changes in electric signals with the sampling frequency of 20 Hertz, 20 times/sec, while maintaining an upright stance for 60 sec [11, 12]. Body sway was assessed by instantaneous fluctuations in the center of pressure, namely, the sway path of the center of pressure, designated as a statokinesigram (Fig. 1). The stabilometric measurements consisted of a standard test battery, and real-time calculations were carried out by the built-in software program of the Gravicorder GS-31.

The main parameters were the length, defined as the linear length (cm) of the sway path in 60 sec; the enveloped area, defined as the area (cm^2) surrounded by the outermost reach of the sway path; the rectangular area, defined as the area (cm^2) of a rectangle that fit into the outermost dimensions of the sway path; the root mean square area (cm^2) of the sway path; the length in a unit of time (cm/sec), calculated by division of the length by the time; and the length in a unit of the area (1/cm), calculated by division of the length by the enveloped area. The center of pressure (Fig. 1) was calculated as the mean of the fluctuations observed in 60 sec and was expressed as deviations along the X axis and Y axis (positive to negative values in cm) from the theoretical center of both feet, to obtain the mean of X and the mean of Y, respectively.

The measurements took place in a room with white walls under the condition of uniform brightness with illumination. After each individual had stood on the platform for 10 sec, he or she underwent a round of tests, consisting of measurements of body sway with the eyes open for 60 sec, followed by a 10-sec interval, and then the measurements of body sway were repeated with the eyes closed for 60 sec. The round was repeated twice, and the second set of data was used for statistical analysis. A round blue visual target with a 15-mm diameter was placed 2 m away from individuals and was fixed on the wall at a height corresponding to the center of the neck of each individual. The individuals were instructed to look at the visual target in the measurements with their eyes open or to stand naturally with their eyes closed. An examiner stood outside the visual field of the patients, usually behind the individuals.

Data analysis. The Romberg quotient (open-eye/closed-eye ratio) was calculated for each stabilometric parameter by division of the parameter with the eyes open by that with the eyes closed. Changes of each parameter in the time course of 5 measurement points, before, immediately after, 15 min after, 30 min after, and 60 min after the start of prism-wearing, were analyzed statistically with repeated-measure analysis of variance (ANOVA) (StatView 5.0, SAS Institute, Inc., Cary, NC, USA), and then with the Bonferroni-Dunn test as a post-hoc test. The significance level was set at 0.05 for repeated-measure ANOVA and at 0.005 for the Bonferroni-Dunn test, as multiple comparisons were made 10 times between 2 time points.

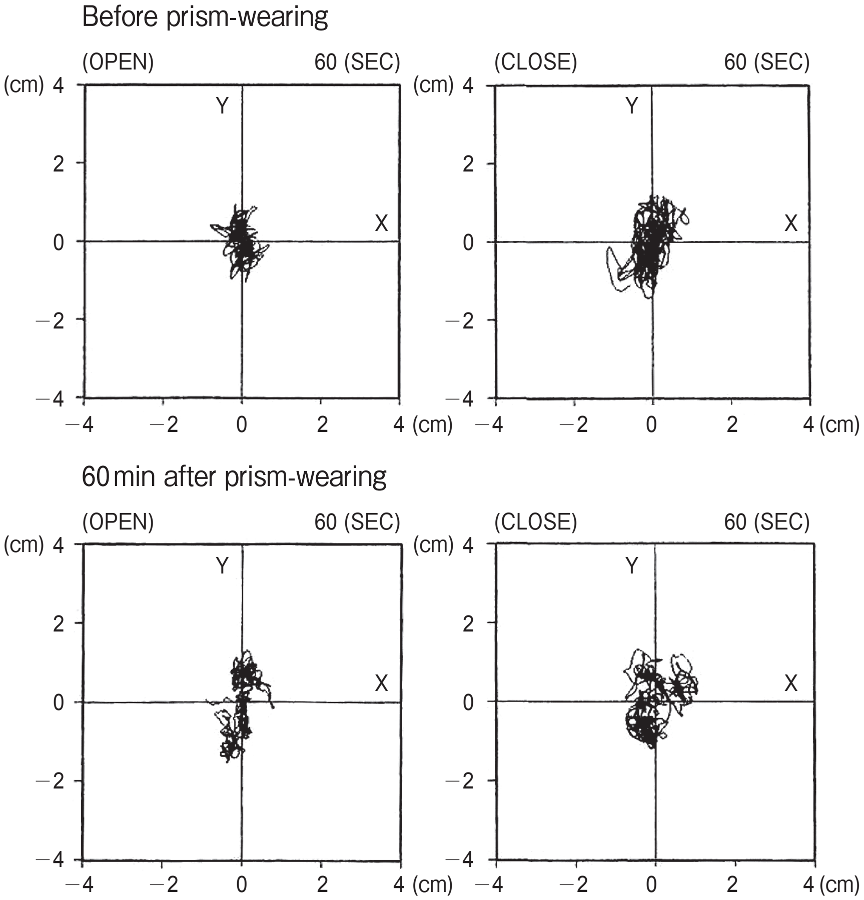

Fig. 1 The sway path of the center of pressure between the subject's feet while maintaining an upright stance for 60 sec with the eyes open (left column) or closed (right column) in a 20-year-old man before (top) and 60 min after (bottom) the start of continuous prism-wearing with 6 prism diopters in total in the vertical direction, obtained by placing a 3-prism-diopter prism with the base up in front of one eye and with the base down in front of the other eye.

Results

In the stabilometric measurements made with the eyes open, no parameters showed any significant change during the prism-wearing for 60 min (Table 1). In the condition of having the eyes closed, 2 stabilometric parameters, the linear length of the sway path and the linear length of the sway path in a unit of time, were significantly shortened during the prism-wearing for 60 min ($p=0.0355$ and $p=0.0359$, respectively, repeated-measure ANOVA, Fig. 2 and Fig. 3). In the statistical analysis by a post-hoc test with 10 multiple comparisons, the linear length of the sway path and the linear length of the sway path in a unit of time were significantly shortened both at 30 min and at 60 min after the prism-wearing, compared with those before the prism-wearing ($p=0.0043$ and $p=0.0047$ for the length, and $p=0.0044$ and $p=0.0046$ for the unit length, respectively). The Romberg quotient of each parameter did not show significant changes during the time course of prism-wearing (Table 1).

The center of pressure along the X axis and Y axis, the mean of X and the mean of Y, respectively, did not show significant changes during prism-wearing (Table 1).

Discussion

The goal of this study was to determine the effect of double vision on postural control. In our previous

Table 1 Stabilometric parameters (mean ± standard deviation) in 20 normal individuals with their eyes open or closed and Romberg quotients (eyes-open/eyes-closed ratios) in the time course of continuous prism wearing for 60 min

	Before Prism Wear	Immediately after Prism Wear	15 min after Prism Wear	30 min after Prism Wear	60 min after Prism Wear	*P* for Time Course Changes*
With Eyes Open						
Length, cm	60.679 ± 15.848	58.817 ± 18.765	60.507 ± 18.620	59.840 ± 17.545	61.114 ± 21.015	0.8939
Length/time, cm/s	1.012 ± 0.265	0.982 ± 0.313	1.008 ± 0.310	0.997 ± 0.292	1.019 ± 0.350	0.9051
Length/enveloped area, cm^{-1}	29.413 ± 11.823	25.824 ± 10.590	26.996 ± 10.920	25.644 ± 12.458	26.612 ± 10.643	0.4807
Enveloped area, cm^2	2.461 ± 1.316	2.841 ± 1.885	2.657 ± 1.321	2.827 ± 1.404	2.997 ± 2.609	0.4586
Rectangular area, cm^2	6.206 ± 3.896	6.352 ± 3.860	6.133 ± 3.017	6.801 ± 3.472	7.021 ± 6.069	0.7677
Root mean square area, cm^2	1.366 ± 0.817	1.800 ± 1.498	1.434 ± 0.825	1.638 ± 1.028	1.838 ± 2.173	0.3889
Mean of x-axis, cm	0.141 ± 0.410	−0.046 ± 0.655	−0.024 ± 0.700	−0.044 ± 0.938	−0.275 ± 0.657	0.1966
Mean of y-axis, cm	−2.685 ± 1.507	−3.219 ± 2.162	−2.834 ± 1.848	−2.734 ± 1.861	−2.560 ± 2.251	0.3590
With Eyes Closed						
Length, cm	74.366 ± 29.495	66.534 ± 27.141	66.503 ± 21.970	65.323 ± 24.445	65.412 ± 23.381	0.0355
Length/time, cm/s	1.239 ± 0.492	1.108 ± 0.454	1.108 ± 0.365	1.089 ± 0.406	1.090 ± 0.389	0.0359
Length/enveloped area, cm^{-1}	32.992 ± 13.025	30.659 ± 11.794	32.274 ± 12.937	33.634 ± 15.222	31.999 ± 12.735	0.8836
Enveloped area, cm^2	2.836 ± 2.246	2.676 ± 1.876	2.537 ± 1.641	2.417 ± 1.749	2.529 ± 1.681	0.6385
Rectangular area, cm^2	6.481 ± 5.907	6.147 ± 4.497	5.992 ± 4.003	5.527 ± 4.304	5.826 ± 4.385	0.8498
Root mean square area, cm^2	1.351 ± 1.054	1.309 ± 0.884	1.475 ± 1.434	1.287 ± 1.402	1.384 ± 1.040	0.8960
Mean of x-axis, cm	0.034 ± 0.557	−0.094 ± 0.599	0.035 ± 0.580	0.073 ± 0.897	−0.162 ± 0.712	0.5812
Mean of y-axis, cm	−2.558 ± 1.651	−2.852 ± 2.188	−2.529 ± 1.677	−2.435 ± 1.880	−2.598 ± 1.874	0.6618
Romberg Quotients						
Length, cm	1.219 ± 0.302	1.127 ± 0.222	1.103 ± 0.155	1.094 ± 0.215	1.088 ± 0.226	0.1479
Length/time, cm/s	1.219 ± 0.302	1.127 ± 0.222	1.103 ± 0.155	1.094 ± 0.215	1.088 ± 0.226	0.1479
Length/enveloped area, cm^{-1}	1.230 ± 0.602	1.250 ± 0.375	1.290 ± 0.562	1.423 ± 0.581	1.293 ± 0.479	0.7868
Enveloped area, cm^2	1.191 ± 0.600	0.980 ± 0.352	1.026 ± 0.474	0.874 ± 0.335	0.960 ± 0.402	0.1429
Rectangular area, cm^2	1.117 ± 0.665	1.001 ± 0.454	1.060 ± 0.548	0.841 ± 0.373	0.993 ± 0.529	0.4283
Root mean square area, cm^2	1.093 ± 0.573	0.876 ± 0.369	1.055 ± 0.573	0.853 ± 0.509	0.912 ± 0.386	0.3480

*Repeated-measure analysis of variance (ANOVA)

study, we measured stabilometric changes in children with strabismus, including both exotropia and esotropia, before strabismus surgery and also on the third day after the surgery [11]. Body sway significantly increased in the entire group of exotropic and esotropic patients and also in the subgroup of exotropic patients, in both conditions of the patients' eyes open and closed. We also showed that the absence of stereoacuity at near viewing and the presence of abnormal head posture were 2 clinical factors associated with preoperative postural instability when the patients' eyes were open.

As a follow-up to our study [11], another group of researchers reported postural control in children with strabismus surgery for esotropia as a dominant manifestation and a small number of children with exotropia. In contrast to our results, obtained in as short a term as 3 days after the surgery, postural stability became better 2 or 3 months after the surgery than it had been before the surgery [13, 14]. The longer period of time for the eye alignment obtained after the strabismus surgery appears to have led to the improvement of postural stability in those studies [13, 14].

As an extension of our initial study [11], we have chosen, as a mode of intervention, the prism adaptation test [12], the effect of which is temporary but not so permanent as surgical correction. We analyzed stabilometric parameters during the 60 min time course of the prism adaptation test, using Fresnel

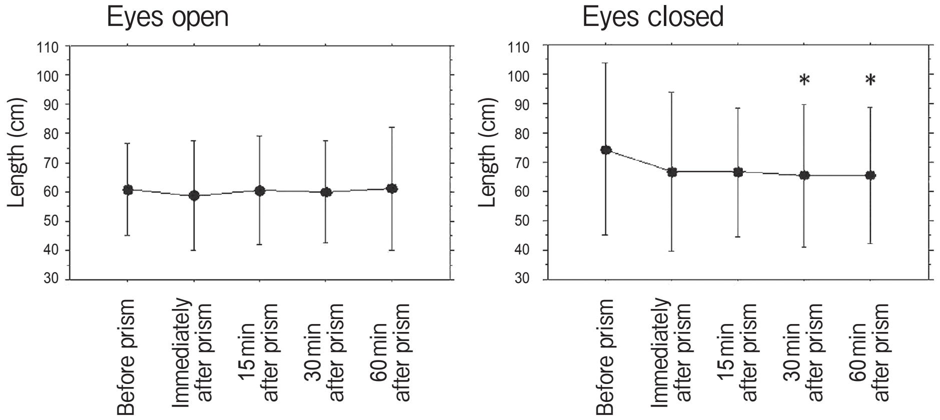

Fig. 2 The total linear length of the sway path (cm) with the individuals' eyes either open or closed during continuous wearing of a 3-prism-diopter prism with the base up in front of one eye and with the base down in front of the other eye for 60 min in 20 normal individuals with a mean age of 21 years. The length with the eyes open does not change significantly ($p=0.8939$) during the time course, while the length with the eyes closed becomes significantly shorter ($p=0.0355$, repeated-measure analysis of variance), namely, postural stability improves. In the post-hoc analysis, the length with the eyes closed both at 30 min and at 60 min after the prism-wearing becomes significantly shorter, compared with that before the prism-wearing ($p=0.0043$ and $p=0.0047$, Bonferroni-Dunn test, asterisks). T-bars indicate standard deviations.

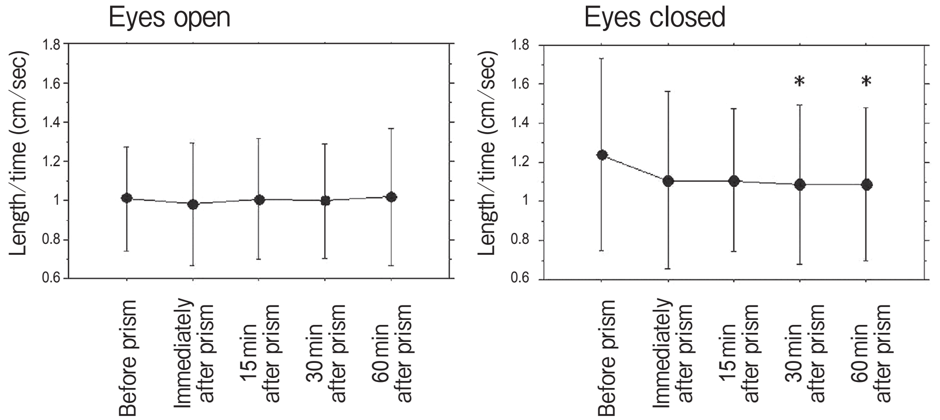

Fig. 3 The linear length of the sway path in a unit of time (cm/sec) with the individuals' eyes either open or closed during continuous wearing of a 3-prism-diopter prism with the base up in front of one eye and with the base down in front of the other eye for 60 min in 20 normal individuals with a mean age of 21 years. The unit length with the eyes open does not change significantly ($p=0.9051$) during the time course, while the unit length with the eyes closed becomes significantly shorter ($p=0.0359$, repeated-measure analysis of variance), namely, postural stability improves. In the post-hoc analysis, the unit length with the eyes closed both at 30 min and at 60 min after the prism-wearing becomes significantly shorter compared with that before the prism-wearing ($p=0.0044$ and $p=0.0047$, Bonferroni-Dunn test, asterisks). T-bars indicate standard deviations.

membrane prisms, in patients with intermittent exotropia or constant exotropia, in the usual clinical setting. The postural instability became more pronounced during the prism adaptation test in the patients with exotropia [12]. As a follow-up to our second study [12], the same group of researchers who followed up on our first study reported the postural control in children with strabismus who wore prisms for 60 min to correct the deviation [14]. The postural stability became poor after the prism-wearing, similar to the results in our second study [12]. The same group of researchers also reported poor postural stability in children with vergence abnormalities [15].

The results of our previous studies [11, 12] as well as those of the other group's studies [13-15] guided us to conduct the present study to test the effect of double vision, induced by prism-wearing, in normal young people. We included young people as participants in this study because young people would be more vulnerable to stimuli than be elder people. We chose vertical prism placement, since vertical diplopia is more difficult to bring to fusion than is horizontal diplopia. The range of fusional amplitude is narrow in the vertical direction and wide in the horizontal direction. At the start of the present study, we hypothesized that diplopia, induced by prism-wearing as an abnormal visual input, might lessen postural stability in the condition with the eyes open. In contrast to the hypothesis, the postural stability did not change in the condition with the eyes open, and it became better in the condition with the eyes closed during continuous prism-wearing for 60 min. The sequence of stabilometric testing from the condition of the eyes open to the condition of the eyes closed would not influence the analysis of the measurements, since statistical analysis was done for changes during the time course in 2 groups, the conditions of the eyes open or closed.

In previous studies, vertical heterophoria, naturally present in normal young individuals, influenced the postural stability [16], and vertical heterophoria, induced by wearing a prism with 2 prism diopters, also influenced the postural stability in young normal individuals [17]. In another study, non-fusional vertical diplopia, induced by a prism with 5 prism diopters, did not influence postural stability in normal individuals with their eyes open [18]. The lack of change in postural stability under a large magnitude of vertical diplopia in that study is consistent with the results of the present study.

Too great a magnitude of vertical diplopia could neither be suppressed monocularly nor be managed to obtain binocular fusion during the continuous prism-wearing for 60 min in this study. Abnormal visual input that could not be accommodated would not influence postural stability in young individuals. To our surprise, the postural stability improved when the individuals closed their eyes. The better postural control revealed in the condition with the eyes closed might be explained as follows. There are at least 2 large pathways of sensory inputs for the postural control mechanism: one is exerted by visual input and the other is exerted by the vestibular and cerebellar system [9]. In the continuous presence of abnormal visual input, such as non-fusional diplopia, vestibulo-cerebellar input to the postural control mechanism might be reinforced to maintain postural stability. When the individuals closed their eyes, the abnormal visual input was erased and a reinforced level for another mode of input, possibly the vestibulo-cerebellar input or control, might be detected by stabilometric measurements.

In conclusion, postural stability did not change with the eyes open in the condition of large vertical diplopia, induced by continuous prism-wearing for 60 min, while the stability did become better with the eyes closed. The center of gravity of the posture, in contrast, did not show significant change with the prism-wearing. Postural control other than that derived from visual input might be reinforced under abnormal visual input, such as non-fusionable diplopia. In future studies, the sequence of stabilometric measurements will be changed in an opposite direction from the eyes-closed condition to the eyes-open condition in order to gain more insight into the postural control mechanism. Stabilometric measurements may provide information about the effect of abnormal visual input on the whole body in patients with strabismus [11-15] and also a key for understanding the role of visual input on postural stability control.

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