Characteristics and Variability of Vertical Phoria Adaptation in Normal Adults

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Abstract: We evaluated the characteristics of phoria adaptation for vertically induced retinal disparity. An adaptive change in the fusion-free ocular alignment, phoria adaptation, was measured with a computer-aided mirror haploscope at 10, 30, and 60 minutes after the start of wearing of a 3-prism-diopter base up prism by 35 normal subjects ranging in age from 21 to 67 years (mean: 37 years). The relationships between phoria adaptation and the subject's age, the vertical fusional amplitude, the amount of heterophoria, and the starting time of the examination were evaluated. All subjects showed phoria adaptation, with the mean (±SD) degree of 0.78 ± 0.28°, 0.96 ± 0.26° and 1.02 ± 0.30° at 10, 30, and 60 minutes, respectively, after wearing the prism. The repeatability (95% confidence interval) for the measurements was less than ±0.24°. There was a significant correlation between the vertical fusional amplitude and the gain of phoria adaptation (at 10 and 60 minutes, $P < 0.05$). The gain of phoria adaptation measured at 60 minutes showed a significant decrease with age ($P < 0.01$). The results indicate that the time course of phoria adaptation in the vertical direction is similar to that in the horizontal direction and its gain differs considerably among subjects. **Jpn J Ophthalmol 1998;42:363–367** © 1998 Japanese Ophthalmological Society

Key Words: Aging, fusion-free ocular position, phoria adaptation, vertical fusional amplitude.

Introduction

If a retinal disparity is induced by placing a prism in front of one eye, the phoria changes by an amount equal to the strength of the prism, provided that there is no tropia and the new disparity is within the fusional range. In minutes to hours, the subject undergoes a phoria adaptation, so that both the phoria and the fixation disparity revert to their preprism values. Phoria adaptation is thought to be one of the neurological adaptive mechanisms serving to maintain binocularity against functional or anatomical changes caused by growth, aging, illness, or spectacle wearing.[1]

Schor[2,3] presented a neurological model for vergence movements that consisted of a fast and a slow neural integrator from the viewpoint of systems engineering. The fast neural integrator immediately corrects for fusional disparity by fusional vergence eye movements, and the slow neural integrator maintains the ocular position by compensating for a continuous load to the fast integrator. In this model, phoria adaptation is considered the output of the slow neural integrator.

Clinically, dysfunction of phoria adaptation is noted by asthenopia,[4] abnormal AC/A ratio,[5] and cerebellar disease.[6] Previous studies revealed that the maximum amount of phoria adaptation and time required for full adaptation vary among subjects.[7,8] In measurements of phoria adapatation in the horizontal direction, accommodative fluctuations can easily affect the fusion-free ocular position; therefore, it is difficult to distinguish between phoria adaptation and measurement error induced by accommodative vergence.[9,10]

In this study, we studied the faculty of phoria adaptation in the vertical direction with a computer-aided haploscope, and we evaluated the relationships between the gain of phoria adaptation and age, the vertical fusional amplitude, the degree of phoria, and the starting time of the experiment.

Received: October 27, 1997

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Jpn J Ophthalmol 42, 363–367 (1998)

Published by Elsevier Science Inc.

0021-5155/98/$19.00
PII S0021-5155(98)00034-3

Jpn J Ophthalmol
Vol 42: 363–367, 1998

Materials and Methods

Subjects

We examined 35 normal healthy volunteers (16 men and 19 women), ranging between 21 and 67 years of age (37.4 ± 13.8; mean ± SD). We excluded individuals who had any of the following conditions: history of ophthalmological or neurological diseases; corrected vision less than 1.0 (refractive errors were from +1.5 D to −8.25 D, astigmatism was less than 1.75 D); threshold of near stereoacuity greater than 120 seconds (TNO random dot test); and heterophoria of more than 5 prism diopters for distance and more than 15 prism diopters for near (when, there is large heterophoria at near, a subject's head position can bias the measurements). Informed consent was obtained from each of the subjects, and all procedures were conducted in accordance with the principles embodied in the Declaration of Helsinki.

Procedures

Figure 1 shows a diagram of the experimental set-up. Using a newly developed computer-aided mirror haploscope, we measured the fusion-free ocular position by dissociating the visual images. A red point on a target (visual angle of 30′) was seen by the left eye, and a green cross (visual angle of 120′) on a video monitor (PCKD854n, NEC, Tokyo) was seen by the right eye. The distance from each eye to its target was 50 cm. A track ball was interlocked to the cross on the monitor, and the subject was asked to move the cross, using the track ball, to align the green cross with the red point. We recorded the sequential changes of the fusion-free ocular position by automatically storing the coordinates every 10 seconds for 3 minutes, using a computer program (N88BASIC, NEC) on a microcomputer (PC9801, NEC).

We measured the fusion-free ocular position before the subject wore the prism, and then a vertical retinal disparity was induced by placing a three-prism diopter, base up, with a Fresnel membrane prism (3M Health Care, St. Paul, MN, USA) on the right eye. The subjects wore their spectacles so they could fixate the targets clearly. We measured the fusion-free position immediately before and 10, 30, and 60 minutes after prism wearing.

Figure 2 demonstrates the measurement process in 1 subject. The gain of phoria adaptation was calculated by dividing the amount of phoria adaptation by that of the given fusional disparity of 3 prism diopters (or 1.65°).

The gain of phoria adaptation in each subject was calculated based on the data collected at 10, 30, and 60 minutes. The relationships between the gain of phoria adaptation and age, vertical fusional amplitude, the amount of heterophoria, and the starting time of the testing were studied.

To evaluate the repeatability of these measurements, we recorded the intrasubject temporal fluctuations of the fusion-free positions for 3 minutes in all of the subjects, and we compared the vertical fluctuations with the horizontal fluctuations of the measurements. We also compared the repeatability of the first and the third or later measurements in the individual subjects.

Statistical Analysis

Statistical significance was determined using Pearson's correlation coefficient and unpaired two-tailed t-test, and $P < 0.05$ was considered significant.

Results

The standard deviation (SD) of the temporal fluctuations for a three-minute period was 0.12° for the

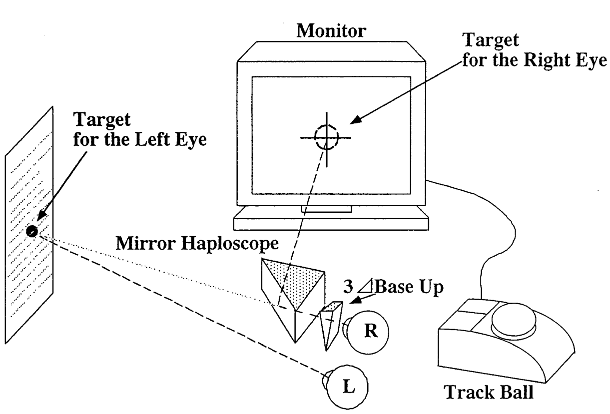

Figure 1. Diagram of experimental set-up.

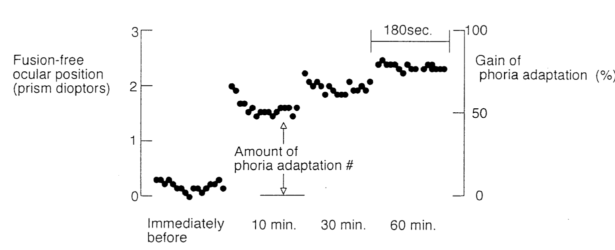

Figure 2. Sequential change of fusion-free ocular position under retinal disparity in vertical direction. Degree of phoria adaptation is expressed as difference between values measured before employing prism and at indicated interval thereafter.

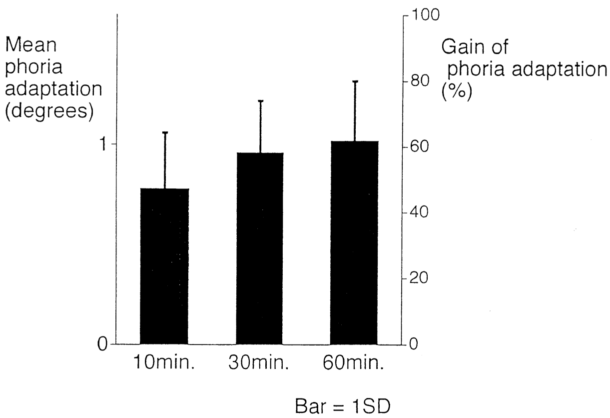

Figure 3. Time course of phoria adaptation. Mean (±SD) degree of phoria adaptation increased with stimulation time.

vertical fusion-free position using the haploscope. The 95% confidence interval (1.96 × SD) of this measurement was, therefore, less than ±0.24°. The mean of the fluctuations of the measurements in 3 subjects for the first test was 0.14° and that for the third test or later tests was 0.13°. This difference was not significant (unpaired two-tailed *t*-test). The fluctuations of the vertical fusion-free positions by our method ranged from 0.03° to 0.27°, and that for the horizontal direction from 1.10° to 1.40°. Compared with the measurements for the horizontal direction, those for the vertical direction were notably more stable and presumably less influenced by accommodative fluctuations.

In all subjects, an adaptive change of the vertical fusion-free ocular positions induced by retinal disparity was observed. The mean (±SD) degree of phoria adaptation was 0.78 ± 0.28°, 0.96 ± 0.26°, and 1.02 ± 0.30° at 10, 30, and 60 minutes, respectively. These values correspond to a percentage gain of 48 ± 17, 58 ± 16, 62 ± 18% (Figure 3).

The correlation coefficients for the relationship between the gain of phoria adaptation and the other variables examined are presented in Table 1. There was a significant positive correlation between the vertical fusional amplitude and the gain of phoria adaptation measured at 10 minutes (r = 0.47, P = 0.005) and at 60 minutes (r = 0.44, P = 0.026), indicating that the gain of phoria adaptation increased with the fusional amplitude (Figure 4). There was a negative correlation between the gain of phoria adaptation measured at 60 minutes (r = −0.65, P = 0.003) and age, indicating that the gain was lower in the older subjects (Figure 5). No correlation was found between the gain of the phoria adaptation and the amount of heterophoria or the starting time of the examination.

Discussion

We measured the fusion-free ocular position sequentially in the vertical direction using a newly developed haploscope. Involuntary accommodation is a barrier to measurements of the fusion-free ocular position in the horizontal direction; hence, conventional techniques, such as the Maddox rod tests or fixation disparity measurements, cannot quantify the precise fusion-free ocular position. We suggest that accommodative fluctuations affect the fusion-free ocular position in the vertical direction less than in the horizontal direction. We did not measure the accommodative power of each of the subjects and thus cannot rule out a relationship between phoria adaptation and accommodative power, but we suggest that the amount of difference due to accommodative factors is not important in the light of the measurement errors. The fluctuation in the measurements of the fusion-free positions in the vertical direction by our method was less than that in the horizontal direction. Moreover, our method is simple and easy to

Table 1. Relationships Between Gain of Phoria Adaptation and Associated Factors

	Pearson's Correlation Coefficient		
	Time		
Associated Factors	10 minutes	30 minutes	60 minutes
Age	−0.31	−0.29	−0.65*
Vertical fusional amplitude	0.47*	0.29	0.44†
Amount of heterophoria	−0.34	0.14	−0.06
Starting time of examination	0.20	0.23	−0.02

*Significant at 0.01 ($P < 0.01$).
†Significant at 0.05 ($P < 0.05$).

Jpn J Ophthalmol
Vol 42: 363–367, 1998

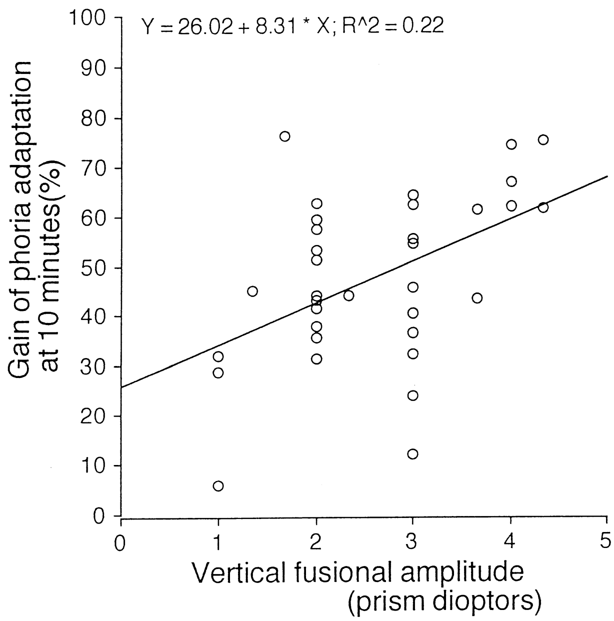

Figure 4. Scatter plot of gain of phoria adaptation measured at 10 minutes versus vertical fusional amplitude. Gain of phoria adaptation increased with increase in vertical fusional amplitude.

perform, and habituation or learning probably do not affect the results.

We observed a considerable degree of phoria adaptation in the vertical direction in all subjects. We, therefore, suggest that phoria adaptation is one of the neurological adaptive mechanisms serving to maintain orthophorization in the vertical as well as the horizontal direction.

In our examination of some of these subjects for 180 minutes (data not shown), we found that the time for complete phoria adaptation was about 60 minutes. This time for complete adaptation differs from those cited in earlier reports. Henson et al,[11] for example, reported that complete adaptation to 2 prism diopters required 3 minutes, and Ogle et al[12] reported that complete adaptation to 6 prism diopters required 10 minutes. Eskridge,[7] on the other hand, reported that complete adaptation to 2 prism diopters required 30 to 120 minutes. Our results are more in agreement with Eskridge that adapatation generally takes longer than previously reported. We are uncertain as to the reason for this discrepancy, although there may have been an influence of the methods for the measurements. There was, however large intrasubject variation in the phoria adaptation gain at 10 and 30 minutes. It is, therefore, difficult to identify a subject with abnormal adaptation with this test alone. In addition, the intrasubject variation is smaller when the stimulation time is longer. For accurate identification of a patient with abnormal phoria adaptation, 60 minutes or more should be allowed for adaptation.

We noted a negative correlation between the age and the gain of phoria adaptation at 60 minutes. A relationship between phoria adaptation in the horizontal direction and age has also been reported,[13] but until now there have been no reports about the relationship between age and the gain of phoria adaptation in the vertical direction. Winn et al[13] reported that phoria adaptation in the horizontal direction was reduced in older subjects, and, although their study is thought to be more influenced by accommodative fluctuation, this result may explain the clinical observation that older patients readily accept prismatic correction to control oculomotor imbalance. Phoria adaptation, which is the output for the slow neural integrator[2,3] of the fusional vergence in Schor's model, decreases in the vertical and horizontal directions with age, and we suggest that the function of the slow neural integrator in fusional vergence decreases with age, as does accommodative vergence.

Figure 5 shows large intrasubject variation at 60 minutes in subjects who were about 30 years old. In particular, the phoria adaptation observed in 1 patient was lower than that of other subjects about the same age. The subject had a smaller vertical fusional

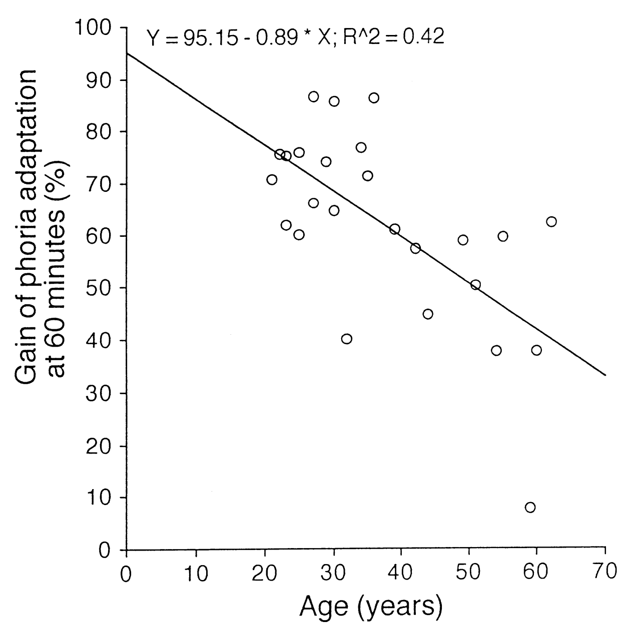

Figure 5. Scatter plot of gain of phoria adaptation measured at 60 minutes versus age. Gain of phoria adaptation decreased with age.

amplitude (1.7 prism diopters) than the others (2–4 prism diopters). We do not know the reason why the subject had a lower phoria adaptation, but we suggest that the narrow fusional amplitude influenced his phoria adaptation, because we have observed that there was a positive correlation between the vertical fusional amplitude and phoria adaptation.

We found a positive correlation between the gain of phoria adaptation measured at 10 and 60 minutes and the vertical fusional amplitude. The vertical fusional amplitude seems to influence phoria adaptation; the fusional amplitude, an important parameter, might be related to the function of the slow neural integrator in fusional vergence, although we are uncertain of the reason.

Clinically, dysfunction of phoria adaptation is suspected to be one of the factors for the decompensated types of strabismus.[4,5,8] However, there is no other report, to the best of our knowledge, that phoria adaptation in the vertical direction is influenced either by age or by fusional amplitude. If age-matching is taken into account in the clinical evaluation of phoria adaptation in the vertical direction, we might come to different conclusions than when age-matching is not taken into account.

In conclusion, the results of this study showed that the sequential changes and the gain of phoria adaptation in the vertical direction were similar to those in the horizontal direction. They also showed that the gain of phoria adaptation deteriorated with age. These results suggest that, in addition to accommodative factors, dysfunction of phoria adaptation can cause some of the decompensated types of strabismus, such as decompensated heterophoria or tropia, in older patients who complain of asthenopia, diplopia, or blurred vision. Because our measurement of vertical phoria adaptation was less influenced by accommodative fluctuations and hence showed good reproducibility, we think it will serve as a useful indicator to evaluate the faculty of vergence adaptation and to understand the causes of various types of strabismus.

An abstract of this study was presented at the 12th International Congress of Eye Research, Yokohama, Japan, October 1, 1996. The authors thank Dr. Nobuhiko Matsuo, Professor Emeritus at Okayama University, for his valuable guidance.

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