

Accommodative Lag Under Habitual Seeing Conditions: Comparison Between Adult Myopes and Emmetropes

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Purpose: To clarify whether myopes show poor accommodative response and thus have a larger accommodative lag under natural seeing conditions.

Methods: Forty-three adults without other ocular abnormalities were classified into the early-onset myopia (EOM, $n = 28$) and the emmetropia (EMM, $n = 15$) groups. The subjects wore glasses or contact lenses that they habitually used, and accommodative responses to four accommodative targets (16.0–50.5 cm from their eyes) were measured under a monocular or binocular condition using an open-field infrared autorefractometer.

Results: Under a binocular condition, the accommodative lag for each target was significantly smaller in the EOM group (analysis of variance, $P < .01$), but the mean slope of the accommodative stimulus-response function did not significantly differ between the EOM and EMM groups (1.05 ± 0.11 and 1.02 ± 0.10 D/D, respectively). The mean slope under a binocular condition was significantly steeper than that under a monocular condition in both groups (paired t -test, $P < .05$).

Conclusions: In adults with EOM, the accommodative stimulus-response function was not impaired, and the habitual accommodative lag was rather small, probably due to the reduced accommodative demand by a vertex distance and/or the intentional undercorrection of spectacles. **Jpn J Ophthalmol 2003;47:291–298** © 2003 Japanese Ophthalmological Society

Key Words: Accommodation, accommodative lag, binocularity, convergence, myopia.

Introduction

Even in the normal accommodation range, 100% accommodative responses to accommodative demands are not assured. With an increase in the accommodative demand, the response generally becomes poorer. The relationship between the accommodative demand and the response is expressed by the slope of the accommodative stimulus-response function. In general, when the accommodative demand is in the range of 0–5 diopters (D), the slope of this function is 0.8–0.9.^{1–6} Therefore, as the distance to the visual target becomes shorter, a difference in the position between the visual target and the retinal conjugate point, ie, a hyperopic focal error, occurs. This hyperopic focal error is called accommodative lag. Because accommodative lag does not usually increase above the focal depth of the eye, blur images are seldom noticed.

Recent studies have suggested that the hyperopic focal error associated with extended near work causes the progression of functional myopia via the visual regulation mechanism of the axial length.^{7,8} This speculation has been supported by the finding that there is a larger accommodative lag in children with myopia than in those with emmetropia,^{2,5,9} and poorer accommodative responses to blur of retinal images⁹ and a larger accommodative lag in adults with myopia than in those with emmetropia.²

However, these studies evaluated accommodative responses only under experimental conditions such as monocular occlusion^{4,6} and full correction of refractive errors with disposable soft contact lenses,^{2,4,6} which is not characteristic of the way people view the world. A simulation study using an accommodation-convergence control model⁸ suggested that accommodative lag is increased by esophoria and uncorrected hyperopia, and decreased by exophoria and uncorrected myopia under a binocular fused condition. To debate the role of accommodative lag in myopia progression, we still need to investigate accommodative lag under habitual seeing conditions.

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In this study, we evaluated accommodative responses in subjects wearing glasses or contact lenses that they habitually used if they used them under monocular or binocular conditions. We hoped to clarify: (1) the characteristics of accommodative lag under habitual seeing conditions, and (2) whether accommodative lag or accommodative stimulus-response function in adults with stable myopia (early-onset myopia) is different from that in emmetropic adults.

Materials and Methods

The subjects were 43 prepresbyopic adults (12 men and 31 women) without previous or present ophthalmological disorders other than ametropia. The exclusion criteria were: (1) residual astigmatism after correction by habitually using glasses or contact lenses >1.50 D; (2) right-left difference in residual astigmatism >0.50 D; (3) high myopia <-6.00 D; and (4) use of hard contact lenses. The age of the subjects ranged from 19 to 38 years (mean \pm SD = 26.9 ± 5.3 years). The refractive error varied from 0.0 to -5.9 D (mean \pm SD = -2.7 ± 2.1 D). The corrected vision was 20/20 or better in all subjects.

The refractive error (far point of accommodation) was monocularly measured using an open-field infrared autorefractometer, WV-500 (Grand Seiko, Fukuyama), while the subject fixed on a target placed 5 meters in front of the eyes, and this value was used as a reference. This apparatus make it possible to measure the refractive value of the unilateral eye while the subject fixed on the target at a certain distance with both eyes through an infrared reflection mirror placed before the eyes. A recent clinical study on this apparatus showed reliable refractive values of the eye.¹⁰ This refractive value was confirmed by the red-green duochrome test as a subjective test.

All subjects with myopia reportedly began to wear glasses before the age of 15. Accordingly, the subjects were classified according to the obtained refractive error (spherical equivalent) into the early-onset myopia (EOM, 28 subjects: -5.90 to -1.00 D) and the emmetropia (EMM, 15 subjects: >-1.00 to 0.00 D) groups. Table 1 shows the characteristics of the subjects in both groups. No significant difference was observed in the mean of age, far phoria, near phoria, or residual refractive error and residual astigmatism after correction by habitually using glasses or contact lenses.

According to the Helsinki Accords, the subjects gave informed consent to the purpose and methods of the experiment before participating in the study.

Measurement of Accommodative Responses

Accommodative responses were measured using the same autorefractometer.

Table 1. Characteristics of the Early-onset Myopic (EOM) And Emmetropic (EMM) Groups

	EMM Group (n = 15)	EOM Group (n = 28)	P Value*
Refractive error (D)	-0.41 ± 0.33	-3.82 ± 1.64	–
Age (y)	26.8 ± 5.6	27.0 ± 5.1	NS
Far phoria (prism diopters)	-2.9 ± 5.3	-1.9 ± 3.4	NS
Near phoria (prism diopters)	-5.6 ± 6.6	-5.6 ± 7.0	NS
Residual or uncorrected refractive error (D)	-0.37 ± 0.32	-0.46 ± 0.34	NS
Residual or uncorrected astigmatism (D)	-0.53 ± 0.30	-0.52 ± 0.22	NS

Values are expressed as mean \pm SD.

*Unpaired *t*-test.

The accommodative target was a high-contrast ($>90\%$) Maltese cross (15×15 mm) projected from a 35-mm slide film. The slide was illuminated from the back (60 cd/m²). Measurement was performed only for the right eye under both monocular and binocular conditions. Under a monocular condition, the left eye was covered with an opaque occluder. For the measurement of accommodative responses, subjects who habitually used glasses or contact lenses used them. All glasses and contact lenses were monofocal lenses.

The direction of the target toward the right eye was constantly consistent with the measurement axis of the autorefractometer. The target was moved on a 50-cm track from a distant site toward the subject, and measurement was performed five times each at distances of 50.5, 32.5, 20.9, and 16.0 cm in front of the eye (corresponding to 1.98, 3.08, 4.78, and 6.24 D as accommodative demands in the subjects with emmetropia). Because of the asymmetric placement of the target, the difference in the accommodative demand between the two eyes increases as the target comes closer to the test eye. Assuming that the interpupillary distance is 64 mm, the accommodative demand in the left eye is lower than that in the right eye (test eye) by 0.0, 0.1, 0.2, and 0.5 D, when the target is placed 50.5, 32.5, 20.9, and 16.0 cm from the eye, respectively.

Measurement at each distance required about 10–15 seconds. During measurement, the subjects were asked to keep the target as clearly in sight as possible. Using the WV-500, refractive values in a 2.3-mm diameter range were obtained. There were no subjects for whom measurement was impossible because of miosis.

Measurement sessions were performed twice at an interval of 3 minutes or more, and the mean value (spherical equivalent) was used as a representative value for the subsequent statistical analysis (n = 10). In addition, the

distribution of the difference in the value between the two measurement sessions (five values for each) was calculated, and the repeatability of measurement values (95% confidence interval of agreement)¹¹ was obtained. Multivariate analysis of variance (MANOVA), unpaired *t*-test and paired *t*-test were performed, and *P* < .05 was considered to be significant.

Correction of Optical Errors Derived From the Back Vertex Distance of Glasses

The myopia group consisted of subjects who wore glasses (n = 18) or contact lenses (n = 10). Even when the target is placed at the same distance, the accommodative demand for clear vision differs according to (1) the degree of refractive errors, (2) the power of correcting lenses, and (3) the back vertex distance of the correcting lenses. Therefore, we corrected optical biases due to the use of glasses or contact lenses by the equations described by Gwiazda et al.⁴

Effective accommodative demand

$$= \frac{\frac{1}{DTE} - LENS + Rx + DLE \times \frac{1}{DTE} \times (LENS - Rx)}{1 - DLE \times (LENS + Rx)} \quad (1)$$

Accommodative response

$$= \frac{Rx}{1 - DLE \times Rx} - \frac{LENS}{1 - DLE \times LENS} - R \quad (2)$$

$$\text{accommodative lag} = \text{effective accommodative demand} - \text{accommodative response} \quad (3)$$

R = measurement value obtained using the autorefractometer (D), *Rx* = spherical equivalent of the completely correcting lens power (D), *DTE* = distance between the accommodative target and corneal apex (m), *DLE* = distance between the correcting lens and corneal apex (0.012 m for spectacles and 0.000 m for contact lens), *LENS* = spherical equivalent of the glasses or contact lenses (D). To adjust for the distance between the corneal apex of the right eye and the accommodative target, the *DTE* value was corrected by setting a scale for reading the corneal site by the side of the headrest of the autorefractometer.

Results

To evaluate the repeatability¹¹ of the accommodation measurement values, the difference in the value between the first and second measurements was plotted against the mean value of the first and second measurements in Figure 1. Differences between the first and

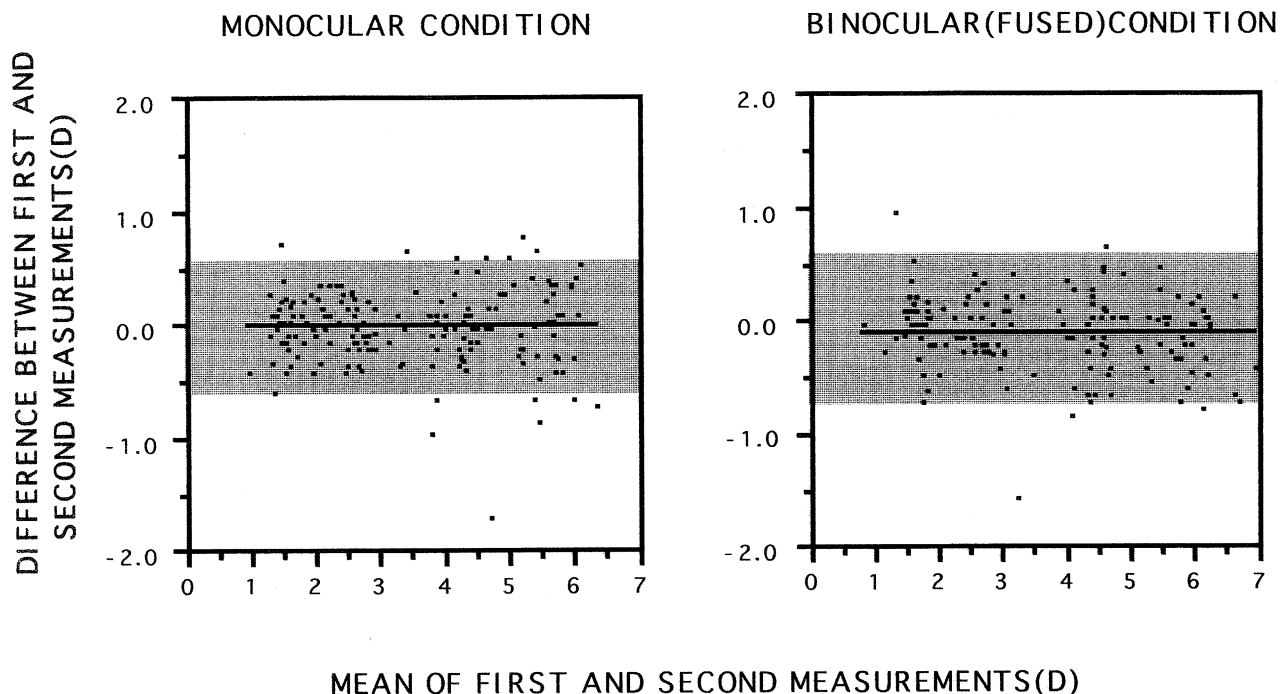


Figure 1. Repeatability of accommodation measurements. The horizontal axis represents the mean of the values obtained in the first and second measurements, and the vertical axis represents the difference between the two values. The 95% confidence intervals showing consistency between the two measurement values (mean ± 1.96 × SD) under monocular and binocular viewing conditions are 0.61 D and 0.62 D, respectively (shaded areas).

Table 2. Effective Accommodative Demand and Accommodative Lag at Each Target

	Target Distance (cm)			
	50.5	32.5	20.9	16.0
Effective accommodative demand (D)				
EMM group	1.59 ± 0.32	2.67 ± 0.33	4.34 ± 0.33	5.75 ± 0.34
EOM group	1.43 ± 0.32	2.47 ± 0.33	4.06 ± 0.34	5.41 ± 0.36
Accommodative lag under monocular conditions (D)				
EMM group	0.42 ± 0.16	0.45 ± 0.20	0.54 ± 0.25	0.63 ± 0.40
EOM group	0.30 ± 0.27	0.35 ± 0.35	0.41 ± 0.44	0.41 ± 0.55
Accommodative lag under binocular conditions (D)				
EMM group	0.36 ± 0.23	0.39 ± 0.25	0.27 ± 0.35	0.27 ± 0.43
EOM group	0.19 ± 0.34	0.16 ± 0.35	0.10 ± 0.35	0.00 ± 0.47

D: diopter. Values are expressed as mean ± SD.

second measurements showed uniform distribution irrespective of the mean value of the two measurements. The mean difference value ± SD in the monocularly and binocularly obtained measurements was 0.02 ± 0.30 D and -0.07 ± 0.28 D, respectively. No significant difference was observed between the mean difference and 0 (*t*-test). These results suggested no examination bias between the two measurements. Therefore, the 95% confidence interval (mean ± $1.96 \times$ SD) where the values in the two measurements were consistent was 0.61 D and 0.62 D, respectively.

The effective accommodative demand and the respective accommodative lag for the target placed at each distance are shown in Table 2. ANOVA showed a significantly smaller effective accommodative demand in the myopic group than in the emmetropic group (sum of squares = 2.28, *DF* = 1, *F* = 20.30, *P* < .0001). MANOVA showed a significantly greater accommodative lag in the emmetropia group than in the myopia group (sum of squares = 2.34, *DF* = 1, *F* = 16.66, *P* = .0001), and under a monocular condition than under a binocular condition (sum of squares = 4.63, *DF* = 1, *F* = 33.03, *P* < .0001), but accommodative lag did not significantly differ with the target distances (sum of squares = 0.0235, *DF* = 3, *F* = 0.0558).

The accommodative responses were plotted against the effective accommodative demand after correction of individual undercorrection of refractive error and of the apparent accommodation due to the back vertex distance of glasses in Figure 2, and the slope of the regression line was compared between the EOM and EMM groups. With an increase in the accommodative demand, the accommodative response was degraded under monocular conditions, and the difference between the accommodative demand and response, ie, the accommodative lag increased.

When monocular and binocular conditions were compared (Figure 3), the mean slope of the regression lines showing the accommodative stimulus-response function (mean ± SD) was significantly steeper (*P* < .01, paired *t*-test) under a binocular condition (1.03 ± 0.10 D/D) than under a monocular condition (0.96 ± 0.12 D/D), showing more accurate accommodative responses under a binocular condition.

The mean slope of the regression lines showing the accommodative stimulus-response function (mean ± SD) under a monocular condition (Figure 2, left) did not significantly differ between the EOM (0.97 ± 0.13 D/D) and EMM groups (0.95 ± 0.09 D/D). Under a binocular condition (Figure 2, right), again, the mean slope did not significantly differ between EOM (1.05 ± 0.11 D/D) and EMM groups (1.02 ± 0.10 D/D).

In Figure 4, individual slopes of the accommodative stimulus-response function against refractive error are shown. A poor correlation between the two parameters indicated that the refractive error did not affect the accommodative stimulus-response function within this range of refractive error.

Discussion

The results of this study clearly demonstrate that the accommodative lag which appears under a habitual seeing condition can be different from that under an experimental condition, ie, monocular viewing after full correction with contact lens.^{3,4,6} Therefore, the previously reported data obtained under the experimental conditions are not sufficient for discussing the causative relationship between accommodative lag and myopia progression.

Repeatability of Accommodative Response Measurements

The repeatability of our accommodative response measurement was under 0.62 D. A previous clinical study on the same type autorefractometer as that used in this study showed that the repeatability of measurement values of the far point of accommodation was 0.47 D.¹⁰ When compared with this value, the repeatability in our measurement was valid. The accommodative lag has been measured by dynamic retinoscopy.^{12,13} This method can be readily performed but has some disadvantages: Only one meridian can be simultaneously measured although astigmatism changes with accommodation.^{14,15} The measurement light is visible and can induce accommodation movements during the measurement session. Depending on the method, a lens should be placed in front of the

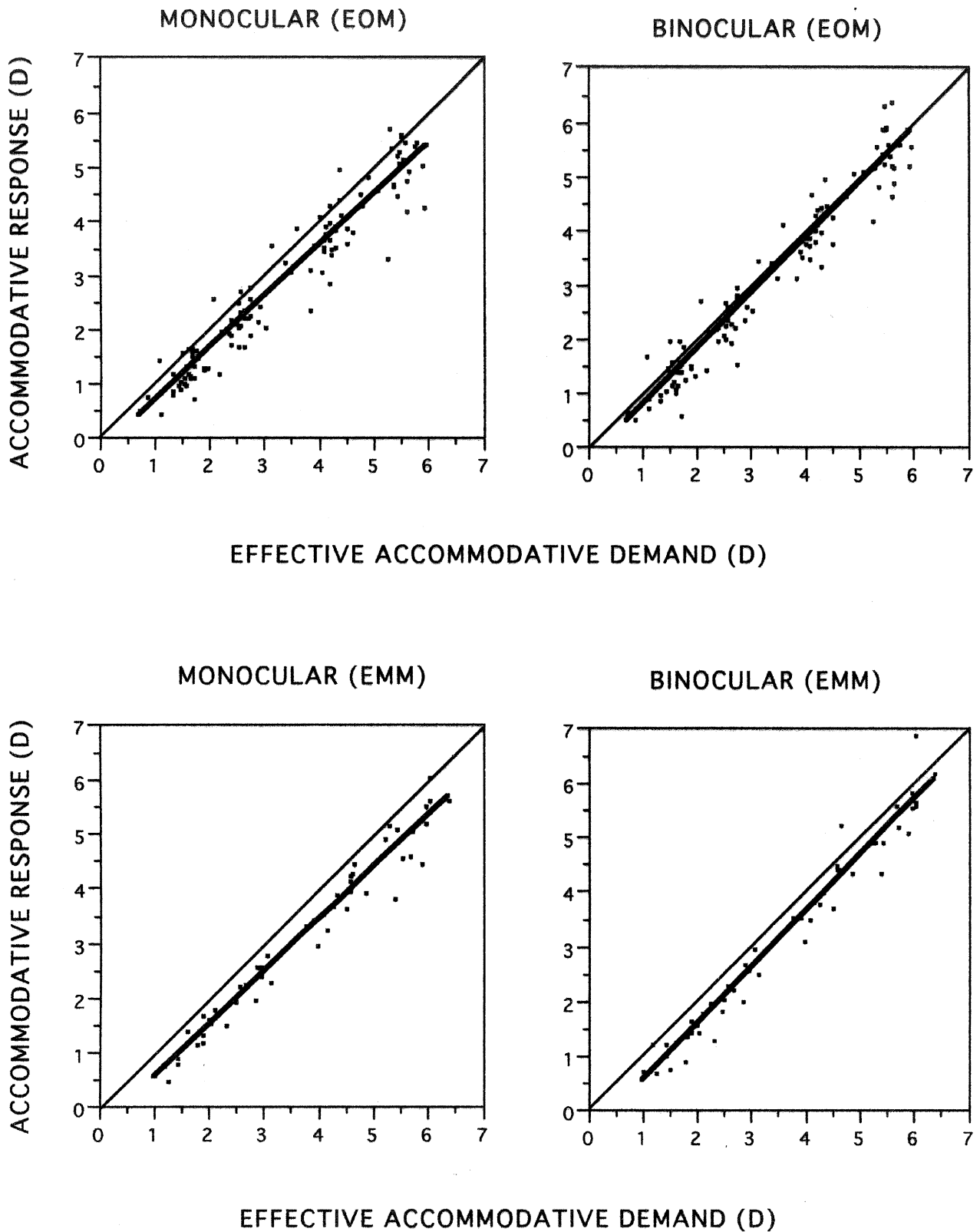


Figure 2. Accommodative stimulus-response function in early-onset myopia (EOM) and emmetropia (EMM) groups. The horizontal axis represents the effective accommodative demand after correction for the optical bias of the amount of the refractive undercorrection and the back vertex distance of the lens of the glasses. The vertical axis represents the accommodative response to this demand. Both under monocular (Left) and binocular (Right) conditions, the mean slope does not significantly differ between EOM (Top) and EMM (Bottom) groups. (Top) EOM group: (Left) $y = 0.95x - 0.21$ ($r^2 = 0.93$, $P < .001$). (Right) $y = 1.03x - 0.27$ ($r^2 = 0.95$, $P < .001$). (Bottom) EMM Group: (Left) $y = 0.95x - 0.33$ ($r^2 = 0.97$, $P < .001$). (Right) $y = 1.03x - 0.44$ ($r^2 = 0.97$, $P < .001$).

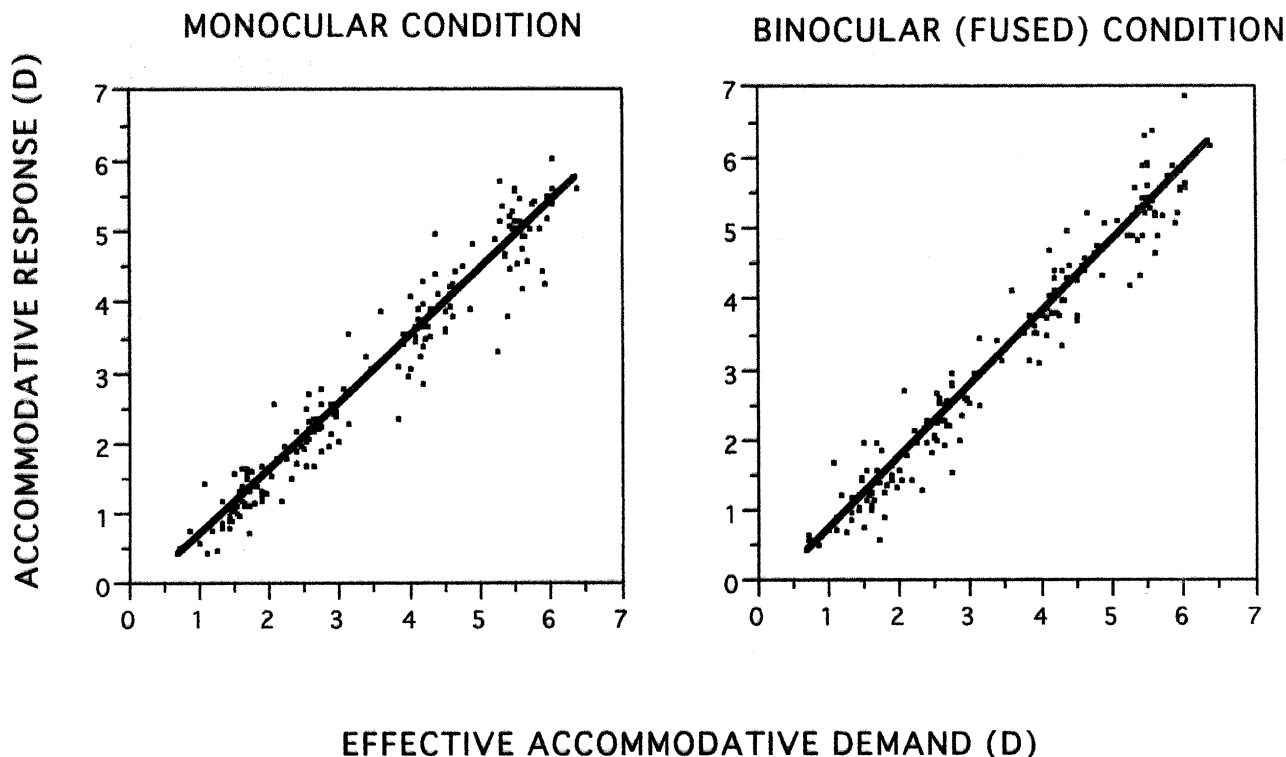


Figure 3. Comparison of the accommodative stimulus-response function between monocular and binocular conditions. The slope of accommodative stimulus-response function under a binocular condition is significantly steeper than that under a monocular condition (unpaired *t*-test, $P < .01$). (Left) $y = 0.95x - 0.24$ ($r^2 = 0.94$, $P < .001$). (Right) $y = 1.03x - 0.27$ ($r^2 = 0.95$, $P < .001$).

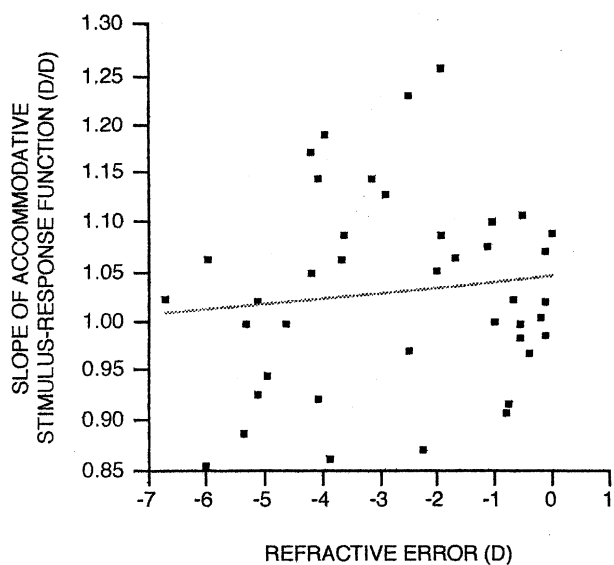


Figure 4. The relationship between the slope of binocular accommodative stimulus-response function and refractive error. Refractive error does not influence accommodative stimulus-response function under natural seeing conditions.

eye of the subject, which can cause an unnecessary accommodative response.¹³ In contrast, the WV-500 autorefractometer uses near-infrared light as measurement light, which would hardly be recognized by the subject, negligibly affecting the accommodation level. Because the eye is evaluated as a toric optical system, changes in astigmatism components are reflected by the spherical equivalent. Compared with dynamic retinoscopy, this method yields reliable measurements.

Accommodative Lag Under a Monocular Condition

The mean accommodative lag under a monocular condition in the EMM group was 0.42–0.63 D, increasing with an increase in the accommodative demand. This result was consistent with the characteristics of accommodative response reported previously and provides the normal range of accommodative lag for Japanese adults.

Gwiazda et al.⁴ performed a study after complete correction of refractive errors under a monocular condition in school age children (5–17 years). They found a significantly larger accommodative lag to accommodative stimulus with 3 and 4 D targets in children with myopia than in

emmetropic children, speculating that the accommodative lag plays a role in myopia progression. Contrary to this, however, our ANOVA analysis indicated the monocularly obtained accommodative lag was significantly “smaller” in the EOM group than in the EMM group.

As shown in Table 2, using the same target, the “effective” accommodative demand, which was obtained with a theoretical calculation, in the EOM group is lower than that in the EMM group. Why was the effective accommodative demand lower in the EOM group? Eighteen subjects (64%) in the myopic group wore glasses. The accommodative demand would decrease with an increase in the power of the convex lens due to the back vertex distance of the lens of the glasses (apparent accommodation) as shown by Equation (1). In addition, myopic refractive error is not fully corrected in the clinic; a slight undercorrection is the goal when glasses are prescribed. When myopia is undercorrected, the accommodative demand for clear vision of a certain target decreases by the amount of undercorrection. Actually, the mean residual or uncorrected refractive error was slightly larger in the EOM group than in the EMM group (Table 1), although the difference was not significant. An accommodative lag is generally proportional to an accommodative demand within the range of accommodation. Therefore, the smaller accommodative lag in the EOM group may be due to the smaller effective accommodative demand for a target placed at the same distance in the EOM group as in the EMM group.

Abbott et al.⁶ also monocularly evaluated accommodative error to 0–4 D accommodative demands after complete correction of refractive errors with contact lenses in adults aged 18–31 years. In this age range, which was similar to that in our study, they did not find a significant difference in the mean accommodative lag between EMM and EOM groups. Taken together with these previously reported results^{2,4,6} and our monocular data, it is plausible that the large accommodative lag observed in myopic children can be improved with age, while accommodative lag in the EMM group is stable regardless of the ages of subjects.

Accommodative Lag and Stimulus-Response Function Under a Binocular Condition

Different from a monocular condition, accommodative lag under a binocular condition was fairly small and seemingly decreased with an increase in accommodative demand. As methodologically described, the accommodative demand is smaller in the nontest (left) eye than in the test (right) eye due to the asymmetry of the relative position of the target. Therefore, accommodative

responses in the test eye can be slightly suppressed according to Hering’s law of equal innervation under a binocular condition.¹⁶ In either case, we can conclude that the accommodative lag usually decreased under a binocular condition.

A clinical study in children with myopia showed that large accommodative lag under a binocular condition is frequently observed in children with esophoria.¹⁷ This seems to be reasonable, because fusional divergence that compensates the esodeviation simultaneously reduces vergence accommodation via the near reflex. In our subjects, exophoria was usually observed in near vision (mean = -5.6 PD for both groups). When 0.75 D/MA, the average convergent accommodation (CA/C) ratio,⁸ is adopted, the increase in the accommodation response under a binocular condition is theoretically calculated to be 0.45 D (1 M.A. = 6 PD). The actual difference in accommodative level between monocular and binocular conditions was 0.06–0.19 D for a target at the same distance (32.5 cm), which was lower than this expected value. However, there is no inconsistency, considering that the actual values were obtained where the accommodation feedback loop was also closed. Even when innervation from the vergence control system to the accommodation control system increased, blur-induced accommodation activity decreased to maintain the total accommodation level at a constant level, resulting in only a partial increase in the accommodation level associated with binocular viewing.⁸

Comparison of the Accommodative Stimulus-response Function Between EOM and EMM Groups

To eliminate the influence of “apparent accommodation” induced by the lens of the glasses and to focus on accommodation function itself, we next compared the relationship between the “effective” accommodative demand and response (Figures 2 and 3).

The slope of the regression line both under monocular and binocular viewing conditions did not significantly differ between EOM and EMM groups (Figure 3), suggesting no difference in the characteristics of the accommodative functions themselves between the two groups, although they showed a different mean accommodative lag. This conclusion can be also derived from the comparison between the slopes of stimulus-response function and refractive errors (Figure 4).

McBrien et al.² also evaluated the slope of accommodative stimulus-response function under a binocular condition. Their slope values were 0.88 D/D for adults with EOM and 0.92 D/D for emmetropic adults, which were smaller than ours. We think this difference is because

the ultra-thin contact lenses they used to correct refractive errors left astigmatism uncorrected. In addition, they dilated pupils with a drop of phenylephrine hydrochloride, which increased the focal depth of the eyes of the subjects. To discuss the causative relationship between an accommodative lag and myopia progression, accordingly, a further investigation would be required in children with progressing myopia under the conditions similar to those we used in this study.

In conclusion, the accommodative response often differed between measurements under monocular and binocular conditions, which was probably due to accompanying heterophoria at near vision. The back vertex distance of spectacle lens and/or intentional undercorrection of myopia can reduce the accommodative demand and, consequently, the accommodative lag for a given accommodative target. In an environment close to natural seeing conditions, ie, binocular viewing through habitually worn glasses or contact lenses, we failed to demonstrate a larger accommodative lag in adults with EOM than in emmetropic adults.

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