Original Contribution Kitasato Med J 2013; 43: 133-140

Accommodative and pupillary responses for a central target and peripheral stimuli

Yuko Shibata,[1] Hiroshi Uozato[1,2]

[1] Department of Ophthalmology and Visual Sciences, Kitasato University Graduate School of Medical Sciences
[2] Department of Orthoptics and Visual Science, Kitasato University School of Allied Health Science

Objective: To investigate the additive influence of peripheral stimuli, we examined accommodative and pupillary response for a fixation target with peripheral stimuli of different luminance at various distances.
Methods: The refractive error and size of pupil diameter were measured monocularly by an autorefkeratometer, looking at a central target of 1 degree of arc at a distance of 100 cm through a hole of 5 degrees of arc on three different test boards of black, white, and random dot texture consisted from black and white at a distance of 33 cm.
Results: No statistically significant difference was found among the three groups of three test boads in regard to accommodation. There was a significant value of pupil diameter between black and white test boards ($P < 0.05$), but no significant differences among others. There was individual variability in accommodative and pupillary responses for peripheral stimulus of random dot texture.
Conclusion: When each different peripheral stimulus was given, the pupil diameter grew less in magnitude as the luminance of peripheral surroundings increased, but the accommodative response varied with individuals. It is necessary to consider both refractive and pupillary changes to access the individual accommodative responses of additive influence of peripheral stimuli.

Key words: peripheral stimuli, accommodative response, pupillary response, depth of focus

Introduction

Accommodation is the ability of the eye to change its power to bring objects of interest at different distances into focus.[1] It has long been assumed that accommodation mainly occurs in response to a central object one is trying to see clearly, but in several previous studies it has been shown that peripheral stimuli also affect accommodation.[2-6] Human beings naturally live surrounded by many objects at various distances, and we always see one or more objects in the immediate setting in our field of vision. You may have seen someone form a ring with his thumb and forefinger in order to get a better look at something. And you may have noticed that the view through a cylinder differs from the "unaided" view by seemingly clarifying it. Therefore, there is a possibility that both central and peripheral stimuli induce the accommodative response simultaneously in certain situations, or both the central and peripheral stimuli may cause a conflicting situation in human optical accommodation.

Though the refractive change of the lens is its main function, accommodation results in an increase in the optical power of the eye to focus on a near object. Convergent eye movements direct the eyes towards the nearest most central object and pupil constriction increases depth of focus.[7] We can therefore expect that when peripheral stimuli appear, the accommodative response is accompanied by a pupillary response like near pupil constriction.

In the present study, we investigated pupillary response to peripheral stimuli and the relationship of refractive change and pupillary change as a resultof peripheral stimuli. We examined refractive and pupil diameter changes with a fixation object through a hole of 5 degrees of arc on a random-dot-patterned test board and compared our observations with those found using uniform, black or white color test boards as controls.

Received 24 January 2013, accepted 6 March 2013
Correspondence to: Yuko Shibata, Department of Visual Science, Kitasato University Graduate School of Medical Sciences
1-15-1 Kitasato, Minami-ku, Sagamihara, Kanagawa 252-0373, Japan.
E-mail: dm10021e@st.kitasato-u.ac.jp

Materials and Methods

Subjects

Fifteen subjects (6 men and 9 women), ranging in age from 20 to 31 years (mean: 22.7 ± 3.6 years), participated in this study. All subjects were free of any ocular pathologies. Their spherical equivalent refraction errors were in the range of -6.25 to 0 diopters (D) (mean, -1.30 ± 2.00 D). The subjects had a distance visual acuity of 20/20 or better, corrected in some cases by glasses or contact lenses.

The present study was performed according to the tenets of the Declaration of Helsinki. Informed consent was obtained from participants after an explanation of the nature of the study had been provided. Approval to conduct this study was given by the Kitasato University Ethics Committee.

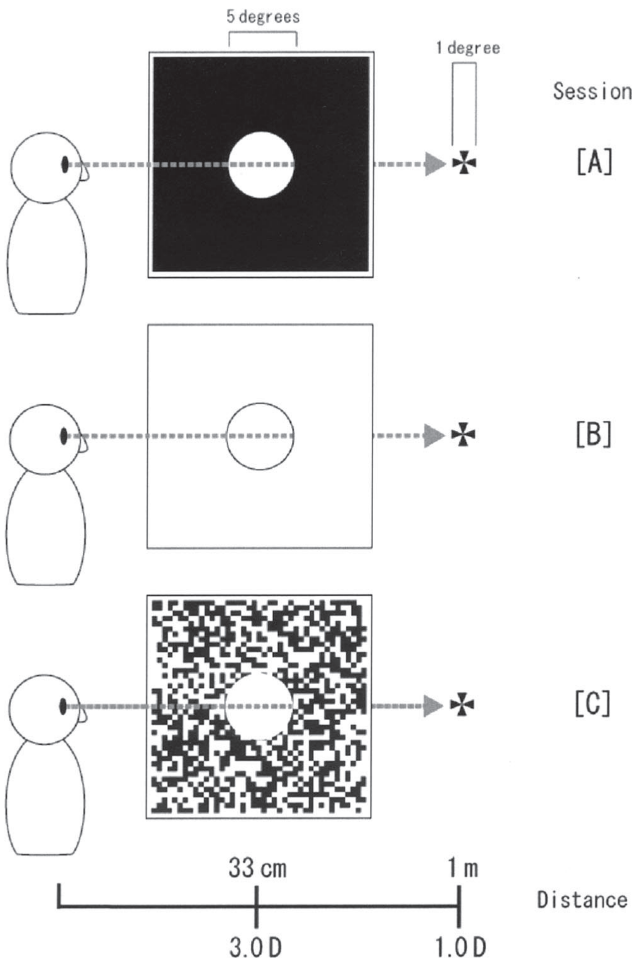

Figure 1. Schematic of the experimental situation of each session. We used a black Maltese cross of 1 degree of arc with a white background as a central fixation target. For peripheral stimuli, three test boards were prepared with a hole of 5 degrees of arc in the center of each.

Stimulus

The central target was a black Maltese cross of 1 degree of arc (Figure. 1) on a white background at a distance of 1 m. This was used as a fixation target. For peripheral stimuli, three test boards with a hole of 5 degrees of arc in the center were prepared. All the test boards of a given size were larger than the aperture of the open-field autorefractor used in this experiment. One test board was black [A], one was white [B], and the third was a texture board of a random dot pattern [C], in each of which the dot square size was 0.25 degrees of arc (Figure 1). The random "dot" pattern consisted of an equal number of small black and white squares, so that for the total area of the test board, and the white and black areas were equal [C]. We used this random dot pattern as our peripheral stimulus because a random dot pattern is meaningless as a figure, so we could avoid any effects of proximal or psychological accommodation as in Heath's criteria in 1956.[8,9]

The illumination of the experimental room was kept at about 300 lx. The luminance output of the black test board was 66 cd/m^2, that of the random dot test board was 69 cd/m^2 and that of the white test board was 77 cd/m^2. All the luminance outputs of the three test boards were measured with a digital spot photometer (Minolta Luminance Meter LS 10) through the infrared filter of an autorefkeratometer WAM-5500.

Procedure

Measurements were taken with the binocular accommodation Grand Seiko Autorefkeratometer WAM 5500. This instrument provides dynamic measurements of refractive error and pupil diameter simultaneously at 0.2-second intervals. The subject's head was positioned in a chin rest/head rest assembly, and one eye of the

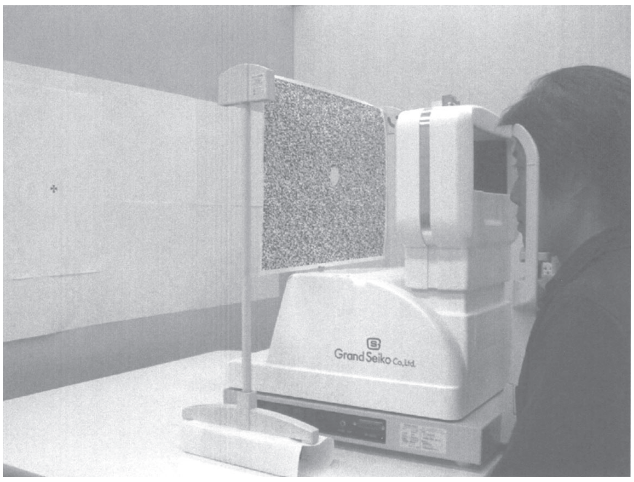

Figure 2. Photograph of the [C] session of the present experiment.

subject was aligned with the video camera of the WAM-5500. The other eye was fully occluded with a black eye patch throughout the procedure.

In the procedure, each subject was put through three sessions [A], [B], and [C] with each of the three test boards [A], [B], and [C], respectively. When the subject looked at the central target at a distance of 100 cm through a hole of one of the three test boards at a distance of 33 cm with peripheral stimuli, refractive errors and size of pupil diameter were measured for 30 seconds (Figures 1, 2). All subjects were clearly and uniformly instructed to try to make the central target as sharp as possible while fixating (Figure 2). The order of the three sessions was randomized among the subjects.

Analysis

Data were analyzed using a computer analysis program (StatView 5.0 for Windows [Hulinks, Tokyo]). A repeated-measures analysis of variance was used to gauge any statistically significant difference within the different sessions. Post hoc multiple comparison testing was performed using the Scheffe method. P values of <0.05 were considered to indicate statistically significant differences.

Results

Figure 3 shows an example of records for 1 subject (ID No.3). In this subject, the accommodative response with the white test board was of the smallest amplitude and that with the random dot test board was the largest in amplitude. On the other hand, the pupil diameter was the smallest in the white board session and the largest with the black board.

Table 1 presents the results of group mean of total accommodation and pupil diameter of each test session.

The group mean of total accommodation of session [A], looking at the central target through a black board, was 1.12 ± 0.47 D. With the white board, the group mean was 1.14 ± 0.54 D. With the random-dot pattern, the group mean was 1.36 ± 0.66 D. There was no significant value in the ANOVA nor the Scheffe test ($P > 0.05$) (Figure 4).

The group mean total pupil diameter looking at the central target through the black board was 6.06 ± 0.91 mm. For the random dot pattern, this value was 5.36 ± 0.98 mm, and for the white board it was 5.01 ± 0.91 mm. There was a significant value in both the ANOVA and the Scheffe test ($P < 0.05$). There was a significant value with the size of pupil diameter (Figure 5).

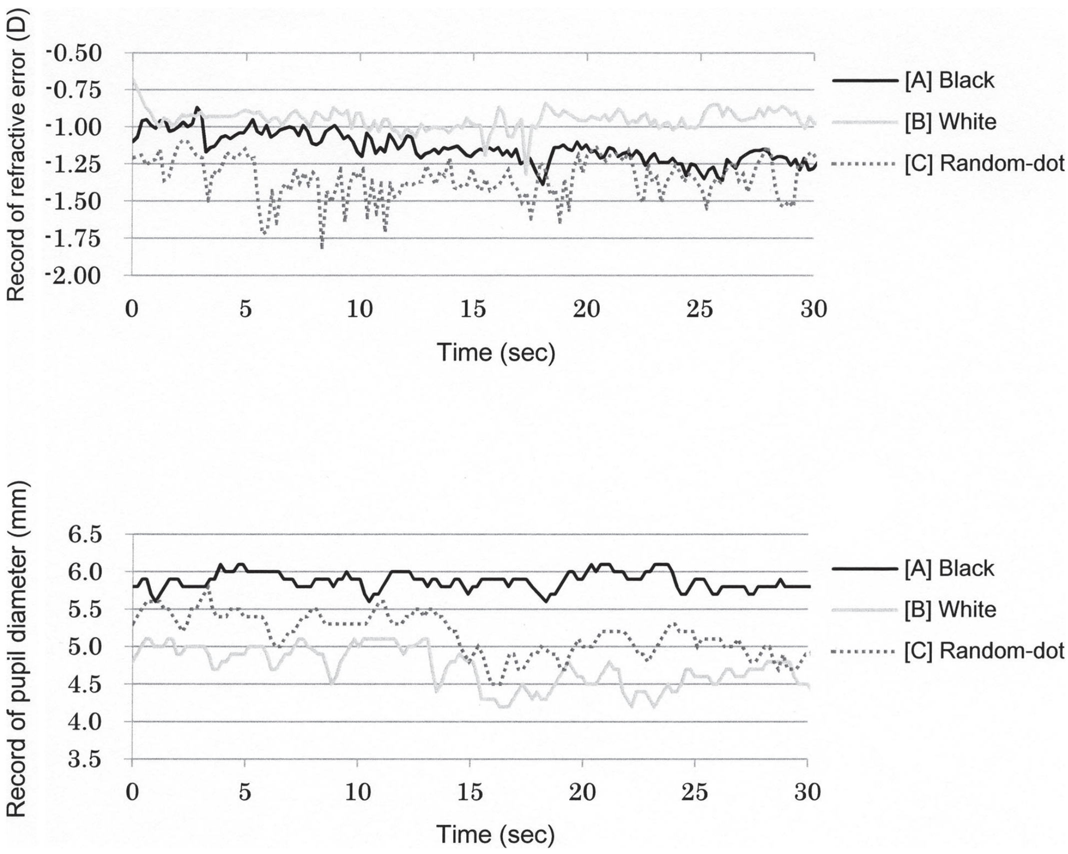

Figure 3. Example of recordings of refractive error (top plot) and pupil diameter (lower plot) in one subject

Table 1. Mean values for accommodative response and pupil diameter for each experimental session

	Experimental session		
	[A] Black	[B] White	[C] Random-dot
Mean accommodation (D)	1.12	1.14	1.36
	SD [0.47]	[0.54]	[0.66]
Mean pupil diameter (mm)	6.06	5.01	5.36
	SD [0.89]	[0.91]	[0.98]

N = 15

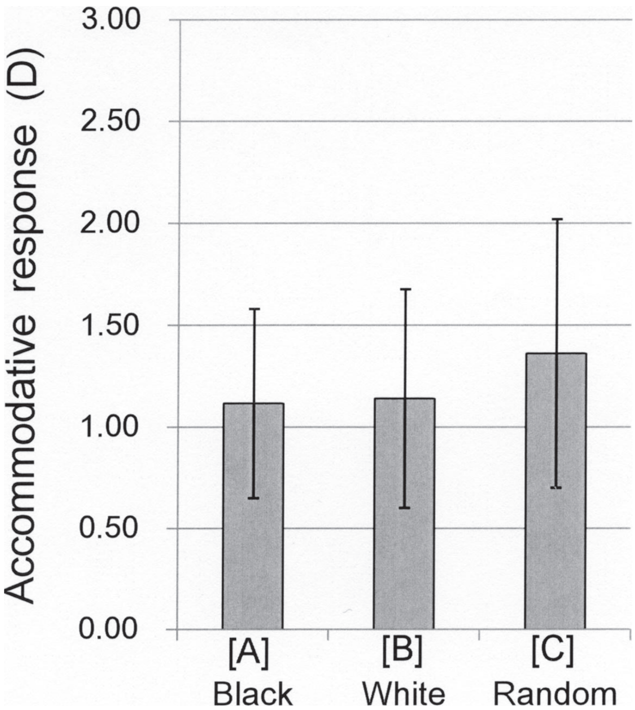

Figure 4. The group means of total accommodation was induced by each experimental session. Error bars indicate the standard deviation of the mean.

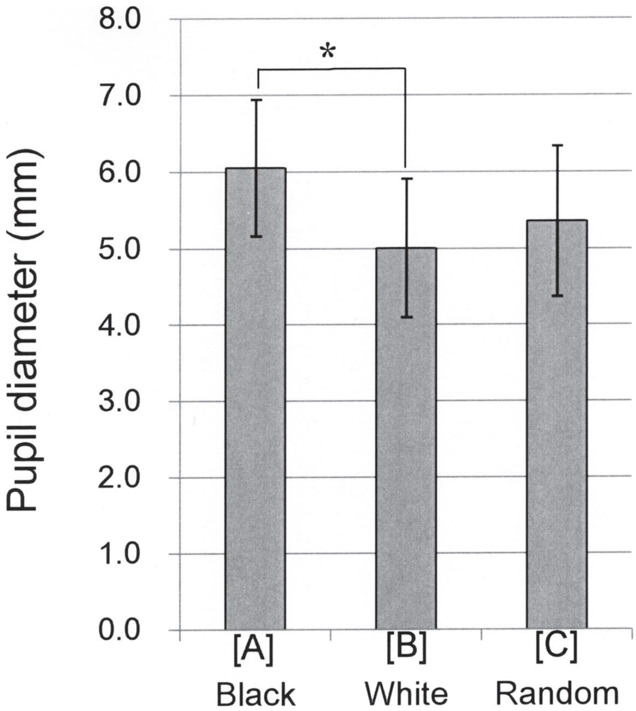

Figure 5. The group means of total pupil diameter was induced by each experimental session. Error bars indicate the standard deviation of the mean. $^{*}P < 0.05$

Figure 6 shows the difference of pupil diameter of session [C] from the average of pupil diameters of sessions [A] and [B] plotted against the difference of accommodative response of session [C] from the average of accommodative responses of sessions [A] and [B] as to each subject. This shows the individual relation between refractive change as accommodative response and pupil diameter change in each subject.

Discussion

Accommodative response with peripheral stimuli

While in general accommodation is mainly to the central target, several studies[2-5] have reported the ability of subjects to accommodate to peripheral stimuli. To investigate the accommodative response to peripheral stimuli, there are two kinds of experiments. One way to investigate is to give only peripheral stimuli in the absence of a central stimulus, and the other way is to give both peripheral stimuli and a central stimulus together.

Employing the peripheral-only procedure, Gu and Legge reported that the extent to which peripheral stimuli could evoke accommodation responses though the eccentricity of the peripheral field depended on the magnitude of the accommodation response.[2] Also, Hartwig et al. reported that the peripheral retina was sensitive to optical focus with accommodative responses weakening as the peripheral angle increases.[3]

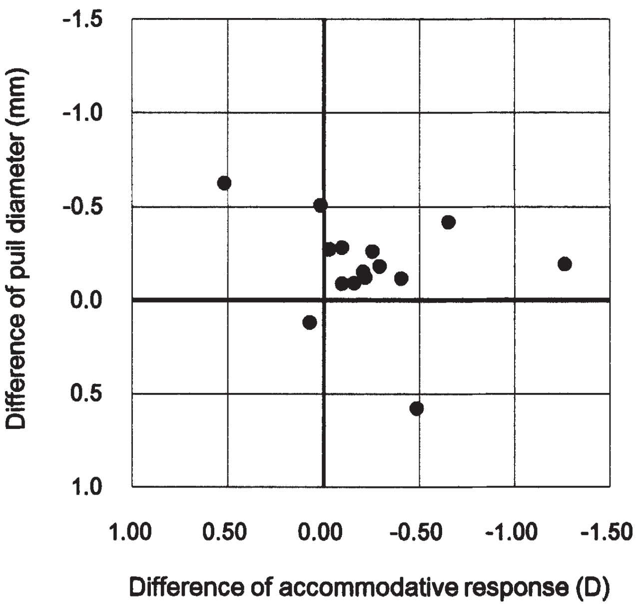

Figure 6. The relationship of refractive and pupillary changes of session [C] in each subject compared with sessions [A] and [B]. The plot of negative numbers of the difference of accommodation indicated that that of session [C] was more myopic than that of the average of sessions [A] and [B]. The plot of negative numbers of the difference of pupil diameter indicated that that of session [C] was more miotic than that of the average of sessions [A] and [B].

Using the method with a central stimulus as well as peripheral stimuli, Hennessy[4,5] and Leibowitz[4] gave both a central target and peripheral stimuli together in their experiments,[4,5] the method of those experiments was the same as that in the experiments in the present study. In the present experiments the amplitude of the accommodative response caused by the peripheral stimuli was smaller than those of the Hennessy studies,[4,5] possibly because of the rather smaller magnitude of contrast of the central and peripheral targets.

Generally, accommodation is driven by many possible cues of the objects seen, such as blur,[10,11] size of the target,[10,11] contrast of the target,[12] chromatic aberration,[10] binocular disparity, proximity, and psychological effects. Among these features, a defocused blur cue is regarded as the primary stimulus for accommodation.[13] However, under natural conditions, also non dioptric cues, such as size change of a chromatic aberration, contribute to accommodative and pupillary responses, and with many cues the near reflex can perform more successfully.[13]

In the accommodative response for peripheral stimuli, we could expect a high probability of accommodative cues, and we suspected that among those the blur was the most important cue for peripheral stimuli. According to this hypothesis, then, it came to a point regarding the DOF of the peripheral retina.

The depth of focus (DOF) of the human eye serves a mechanism of blur tolerance, and the DOF of the peripheral retina is wider than that of the fovea. In Ciuffreda et al.'s studies,[14-16] peripheral DOF was 3.5 - 2.5 D at 8-30 degrees of retinal eccentricity compared with 0.9 D at the foveal retina.[14,15] But the DOF of the human eye can be affected by a variety of optical and neural factors,[16] and there are large amplitudes of DOF for resolution acuity for peripheral vision even when peripheral refractive errors are not fully corrected,[17] and in peripheral ocular aberration also gains a large amplitude of DOF.[18-20] In the present study, we put the peripheral test board at 3D distance with the central 1D distance target and we expected that the difference of dioptric location of two stimuli could be a driven cue of accommodation and pupillary response which is likely to occur in "near reflex."

Pupillary response with accommodation of peripheral stimuli

Pupil size has a number of effects on vision of DOF, retinal light level, retinal image quality and visual performance.[21] Generally, the pupil size is affected by illumination and direct light stimulation, which are referred to as the direct and consensual light reflex, as well as the near reflex. A strong relationship has been discovered regarding the illumination effects on pupil size.[21] Retinal illumination depends on pupil size but is free from the refractive and accommodative situation. In the present study, we measured pupil diameter to assess the pupillary response to peripheral stimuli and there was a clear difference of pupil diameter between the conditions of sessions [A] and [B]. This difference could explain the difference of refractive difference between the two sessions in that a large amplitude of DOF could compensate for a lesser amplitude of accommodation. But we noted that the latter difference of accommodative response had no statistical significance. To get the image clear, there is an advantage in a large amplitude of DOF and if the retinal luminance is in adaptive range, a small pupil diameter is better.[22] In many previous studies, the change of DOF has been shown to create a large effect when the pupil size is small, such as 1 to 3 mm,[23,24] and when the pupil diameter is over 4 mm there is only a small influence of DOF.[22] In the present study, almost all of the pupil diameter results in each subject were over 4 mm, so there was little influence in the gain of DOF.

Pupillary response with accommodation might be best known as a near vision triad which means that the cause of near fixation is associated with accommodation, convergence, and pupil constriction.[7,21,23,25-27] There are several studies that suggest that the accommodative response is related to near pupil constriction to a certain degree.[25-27] However, some studies show that sometimes pupil response could be significantly reduced or absent,[28,29] and that there was no support for the hypothesis that larger accommodative lags might be compensated for by greater accommodative miosis.[7]

In the present study, we were able to observe the pupillary response for peripheral stimuli. In some subjects the response of the pupil in session [C] turned more miotic than the average of the control sessions of [A] and [B] (Figure 6). This suggested individual differences in the possibility of increasing DOF, and it may be that peripheral stimuli appeared to cause the pupil to constrict in some subjects. But we noted that there were no statistical differences in the group means, so to further investigate the possibility of miotic response against peripheral stimuli, more accurate methods to investigate the degree of intensity of the pupillary response will be required.

Individual response for central and peripheral stimuli

There are several possible ways to see objects around us. For example, in the present study, given double objects in central and peripheral fields at once, each subject was either voluntarily or involuntarily forced to select a response from the following patterns to see something (Figure 7).

I. One looked only at the central target ignoring peripheral stimuli.

II. One looked at both the central target and peripheral stimuli together.

Moreover, as there were three patterns in Situation II, we used refractive change for accommodation (Figure 7 II-A), miotic change to get a large amplitude of DOF (Figure 7 II-B) or both refractive and miotic changes together. The present results (Figure 6) show that there were various types of subject responses, e.g., some subjects showed neither accommodative nor pupillary changes, and some subjects had a considerable amount of miotic change with nearly no accommodative change or negative refractive change of accommodation. We must, therefore, pay attention to the individual variability

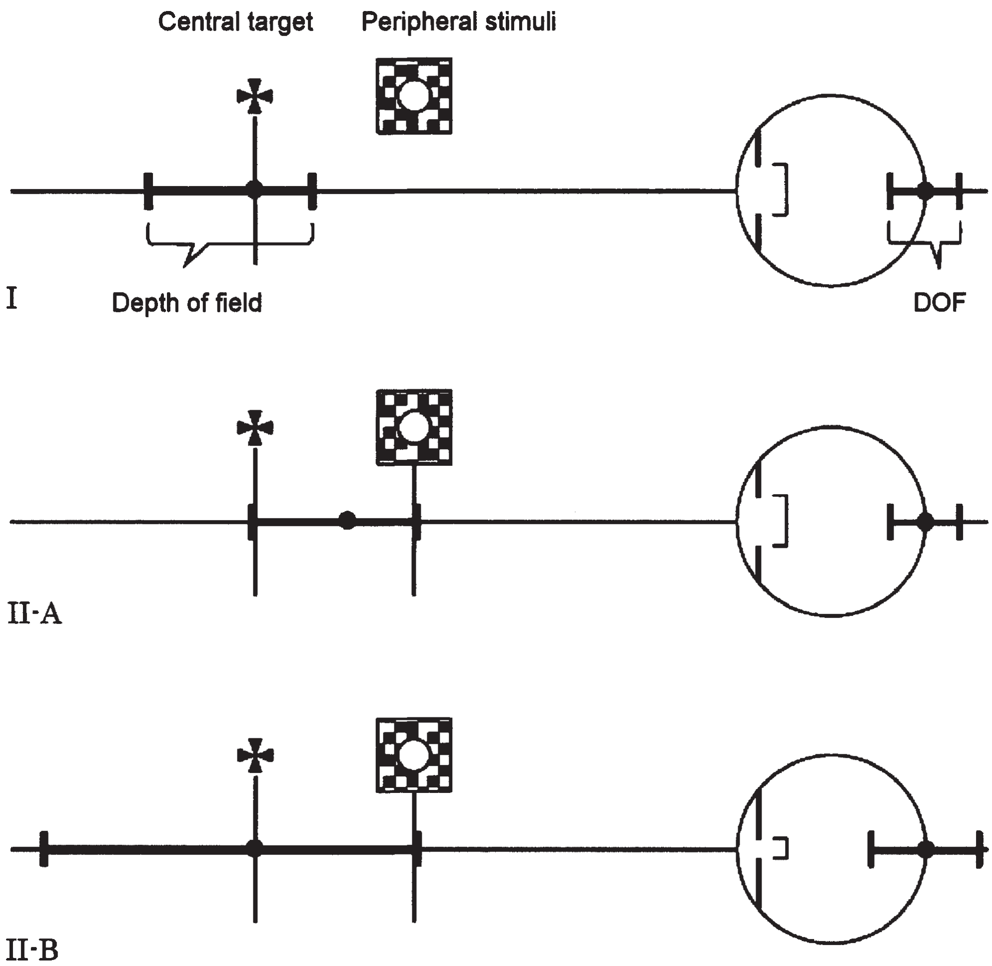

Figure 7. Schematic of response options for both central and peripheral stimuli presented together

in the relation between accommodation and pupillary response to peripheral stimuli. This relation might also be attributed to some kind of emotional factor which affects the variability in pupil diameter and pupil response.[13]

In the present study, accommodative response of some subjects suggested individual differences because the stimuli were in some range of DOF or out of the threshold range of accommodation, so they showed no changes in either refractive errors or pupil sizes. In monocular studies of failure of accommodation, there is a suggestion of the possible absence of any true reflex accommodation and that all accommodation may demand a voluntary input,[30] so as to affect the results of the present study. Therefore, to gain better knowledge of the thresholdsof stimuli on the peripheral retina, more studies are warranted about not only the subjects' foveal spherical equivalent refractions but also the curvature of images of their eyes among others.

In conclusion, we investigated both accommodative and pupillary responses to a central target and peripheral stimuli at the same time and tried to access the contribution of pupillary response for accommodation to peripheral stimuli. When different peripheral stimuli were given, the pupil diameter decreased as the luminance of the peripheral surroundings increased, but the accommodative response varied with individuals. A limitation of the present study was that the sample size was small, therefore, a strong claim cannot be made about the influence of accommodative and pupillary responses to peripheral stimuli. Further studies are warranted to clarify how these responses may be influenced by additive peripheral stimuli.

Acknowledgments

We thank Drs. Takushi Kawamorita and Ken Asakawa for their useful suggestions.

References

1. Atchison DA, Smith G. Accommodation and presbyopia. In: *Optics of the Human Eye*. Oxford: Butterworth-Heinemann; 2002; 223.
2. Gu YC, Legge GE. Accommodation to stimuli in peripheral vision. *J Opt Soc Am A* 1987; 4: 1681-7.
3. Hartwig A, Charman WN, Radhakrishnan H. Accommodative response to peripheral stimuli in myopes and emmetropes. *Ophthalmic Physiol Opt* 2011; 31: 91-9.
4. Hennessy RT, Leibowitz HW. The effect of peripheral stimulus on accommodation. *Percept Psycophys* 1971; 10: 129-32.
5. Hennessy RT. Instrument myopia. *J Opt Soc Am* 1975; 65: 1114-20.
6. Charman WN, Radhakrishnan H. Peripheral refraction and the development of refractive error: a review. *Ophthalmic Physiol Opt* 2010; 30: 321-38.
7. Charman WN, Radhakrishnan H. Accommodation, pupil diameter and myopia. *Ophthalmic Physiol Opt* 2009; 29: 72-9.
8. Heath GG. Components of accommodation. *Am J Optom Arch Am Acad Optom* 1956; 33: 569-79.
9. Charman WN. The eye in focus: accommodation and presbyopia. *Clin Exp Optom* 2008; 91: 207-25.
10. Kruger PB, Pola J. Stimuli for accommodation: blur, chromatic aberration and size. *Vision Res* 1986; 26: 957-71.
11. Kruger PB, Pola J. Accommodation to size and blur changing in counterphase. *Optom Vis Sci* 1989; 66: 455-8.
12. Okada Y, Ukai K, Wolffsohn JS et al. Target spatial frequency determines the response to conflicting defocus- and convergence-driven accommodative stimuli. *Vision Res* 2006; 46: 475-84.
13. Loewenfeld IE. *The light reflex*. In: The pupil. Edinburgh: Butterworth-Heinemann; 1999.
14. Wang B, Ciuffreda KJ. Depth-of-focus of the human eye in the near retinal periphery. *Vision Res* 2004; 44: 1115-25.
15. Ciuffreda KJ, Wang B, Wong D. Central and near peripheral retinal contributions to the depth-of-focus using naturalistic stimulation. *Vision Res* 2005; 45: 2650-8.
16. Wang B, Ciuffreda KJ. Depth-of-focus of the human eye: theory and clinical implications. *Surv Ophthalmol* 2006; 51: 75-85.
17. Wang YZ, Thibos LN, Bradley A. Effects of refractive error on detection acuity and resolution acuity in peripheral vision. *Invest Ophthalmol Vis Sci* 1997; 38: 2134-43.
18. Mathur A, Atchison DA, Scott DH. Ocular aberrations in the peripheral visual field. *Opt Lett* 2008; 33: 863-5.
19. Mathur A, Atchison DA, Charman WN. Effect of accommodation on peripheral ocular aberrations. *J Vis* 2009; 9: 201-11.
20. Yi F, Iskander DR, Collins M. Depth of focus and visual acuity with primary and secondary spherical aberration. *Vision Res* 2011; 51: 1648-58.
21. Atchison DA, Smith G. The pupil. In: *Optics of the Human Eye*. Oxford: Butterworth-Heinemann; 2002; 21.
22. Atchison DA, Smith G. Depth-of-field. In: *Optics of the Human Eye*. Oxford: Butterworth-Heinemann; 2002; 213.

23. Hennessy RT, Iida T, Shina K et al. The effect of pupil size on accommodation. *Vision Res* 1976; 16: 587-9.
24. Ward PA, Charman WN. Effect of pupil size on steady state accommodation. *Vision Res* 1985; 25: 1317-26.
25. Alpern M, Mason GL, Jardinico RE. Vergence and accommodation. V. Pupil size changes associated with changes in accommodative vergence. *Am J Ophthalmol* 1961; 52: 762-7.
26. Kasthurirangan S, Glasser A. Characteristics of pupil responses during far-to-near and near-to-far accommodation. *Ophthalmic Physiol Opt* 2005; 25: 328-39.
27. Kasthurirangan S, Glasser A. Age related changes in the characteristics of the near pupil response. *Vision Res* 2006; 46: 1393-403.
28. Takagi M, Abe H, Toda H, et al. Accommodative and pupillary responses to sinusoidal target depth movement. *Ophthalmic Physiol Opt* 1993; 13: 253-7.
29. Phillips NJ, Winn B, Gilmartin B. Absence of pupil response to blur-driven accommodation. *Vision Res* 1992; 32: 1775-9.
30. Charman WN. Keeping the world in focus: How might this be achieved? *Optom Vis Sci* 2011; 88: 373-6.