Accommodative relaxation by extending the viewing distance through the simple optical design of a double-mirror system

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Abstract

This paper discusses the accommodative relaxation of myopic adults by using a simple double-mirror design. This optical design can extend the viewing distance to 2.285 m and magnify the image up to 3.79 times, and it results in the accommodative relaxation of a single human eye. We recruited 32 subjects with an average age of 20.8 ± 0.95 years old. After an examination of their refractive status, the disposable contact lenses with a corresponding refractive error were corrected, and the dynamic accommodative response and the change in pupil size were measured by using an open-field auto-refractor. The dynamic accommodative responses and pupil size data were collected under two viewing distance conditions. When the subjects gazed at a real object that was 0.4 m away, or a virtual image that was 2.285 m away, the mean value of the accommodative response was 1.69 ± 0.31D or 0.11 ± 0.05D, and the pupil size was 3.79 ± 0.49 mm or 4.09 ± 0.72 mm, respectively. The accommodative response decreased and the pupil size increased by using the double-mirror system, and therefore, accommodative relaxation can be achieved by using this new optical design. In this study, we first successfully proposed a simple optical design to relax the accommodation, and the fluctuations of the accommodation response were stable, with the extended viewing distance of 2.285 m. This design may be applied for the improvement of visual function, such as the reduction of asthenopia and the control of myopia.

Introduction

With the advancement of science and technology, people have changed their reading habits [1] and have been more exposed to digital products. As a result, the need for close work has increased, and accommodation has been considered to be involved in the occurrence and progression of myopia [2, 3]. After using digital devices at a close distance over a long period of time, symptoms such as eye fatigue, dry eyes, double vision, blurred vision and headaches tend to occur [4]. In the early years, the symptoms were collectively known as 'Computer Vision Syndrome (CVS)' [5, 6]. With the popularization of electronic products in recent years, the term was changed to 'Digital Eye Strain (DES)', which is caused by working at close distances [7–9].

Plenty of evidence suggests that the lag in accommodation is related to myopia. At the same stimulus distance, myopic people have a higher accommodation lag than emmetropic people. In addition, compared with emmetropic children, myopic children read at a closer proximity, which may lead to an increase in the accommodation lag, due to the increased demand for accommodation. When reading in closer proximity, a larger accommodation lag is more likely to cause the progression of myopia. An extended viewing distance can also stabilize the accommodation fluctuation [8, 9].

Remote accommodation is a training method that induces periodic pupil constriction, thereby improving the eyesight of myopic children. A previous study used LCD screens to simulate the changes in two gazing positions (70 cm and 25 cm), in an attempt to improve the eyesight of myopic children [10].

Tsuneto et al. presented the effects of accommodative relaxation by using far point shift stimuli to improve the visual function and to reduce eye fatigue [11]. In this study, we first proposed a simple optical design that consisted of a concave mirror and a convex mirror to extend the viewing distance from 40 cm to 2.285 m, so that the accommodation can be relaxed. The accommodation fluctuation also presented stably. The results may be applied in slowing down the progression of myopia and mitigating the problems caused by close work.

Method

Design of the proposed double-mirror system

In this study, we first proposed the application of a double-mirror system for extending the viewing distance. The system consisted of two mirrors, one concave and one convex. The convex mirror first reduces the image and enlarges the field of view, and then the concave mirror enlarges the image. Finally, the image is viewed by the human eye.

The diopters of the two mirrors were + 2.83 D and − 2.83 D, respectively. The distance between the human eye and the concave mirror was 400 mm, that between the concave mirror and the convex mirror was 145 mm, and that between the convex mirror and the object was 280 mm.

The imaging of the double-mirror system can be illustrated in the example of thin lens imaging. A concave mirror is equivalent to a convex lens, and a convex mirror is equivalent to a concave lens for simulation. Based on this, the distance from the eye to the image can be up to 2.285 m, and the magnification of the image is 3.79X, as shown in Fig. 1.

Research Subjects

The subjects of this study were recruited from the Chung Shan Medical University and the Da-Yeh University. Their ages ranged between 18 and 22 years, and the average age was 20.8 ± 0.95. The inclusion criteria were as follows: those who had no prior eye or systemic diseases, those with a spherical diopter ranging from 0D to -5.00D, those with an astigmatism diopter ≥-2.00D, those with binocular vision ≥ 0.8, and those with a normal binocular vision function.

Informed consent was obtained from all the subjects, and the experiment was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board of the Chung Shan Medical University Hospital (Taichung, Taiwan, ROC) (Approval number: CS2-18104).

Research Process

The experimental procedure included the following two steps: The first step was an examination of the basic visual function. Each subject received an initial examination of his/her refractive status, vision, phoria, stereoscopic vision, etc. After the basic examination, disposable contact lenses were provided to the subjects with a corresponding refractive error (Cooper Vision, water content: 55%, base arc: 8.6 mm, diameter: 14.2 mm).

The second step was to measure the subjects' dynamic accommodative responses and pupil sizes. The indoor brightness will affect the pupil size. In the dark state, the pupil size is larger. Because this optical design is for reading purposes, we measured the accommodative responses and pupil size in the state of brightness. The luminance of the laboratory is around 588 lux. Two viewing distances were set for the experiment: (1) the subjects gazed at a real object that was placed at a distance of 0.4 m; and (2) they gazed at a virtual image that was located at a distance of 2.285 m through the double-mirror system. An open-field autorefractor (Grand Seiko WAM WR-5500) was used to measure the dynamic accommodative responses and pupil sizes of the subjects. Each detection time was 30 seconds, and the average value of the three measurements was taken. Only the data of the right eye were measured in the experiment, and the subjects were required to cover their left eye with a occlude covering. During the detection, the subjects were allowed to blink naturally, but they were asked to maintain their gaze at the target. The unit of the accommodative response is a diopter (D), and the unit of the pupil size is mm.

Data Analysis

During the experiment, an open-field autorefractor was used to record the subjects' dynamic accommodative responses and pupil sizes every 0.2 seconds. The dynamic accommodative responses and the pupil sizes of the right eye were recorded on the computer. All the data were analyzed by SPSS Statistics 21.0, and an independent sample t-test and paired samples t-test were conducted for statistical analysis.

Results

Accommodative response and pupil size

The accommodative responses and pupil sizes of the subjects, when they gazed at a real object at a viewing distance of 0.4 m, are shown in Table. 1. The mean value of the accommodative response of the male subjects was 1.55 ± 0.25 D, while that of the female subjects was 1.82 ± 0.21 D.

The accommodation stimulus changed with the different viewing distances, and resulted in an accommodative response. The viewing distance was converted into the accommodation stimulus, and the accommodation stimulus formula is expressed as follows:

Ac (D) = 1/d (m)

where, d is the viewing distance, which is measured in meters, and the unit of the accommodation stimulus is a diopter (D). The accommodative stimulus is 2.5D (1/0.4 = 2.5D) when the viewing distance is 0.4 m, and the measured data of all subjects are less than 2.5D, dropping an average of 0.81D.When the accommodative response is smaller than the accommodative stimulus, it is called the 'lag of accommodation', the expected value of which also varies with age. For 20-year-old adults, the expected value of the lag of accommodation is 0.75 ± 0.64D, and the lag of accommodation observed in this study was within the expected value [12].

The pupil size was measured for 30 seconds, and then the mean value was calculated. The average pupil size of the male subjects was 3.82 ± 0.50 mm, while that of the female subjects was 3.67 ± 0.55 mm. The results showed that there is no significant gender difference ($p = 0.51$).

Table 1
The baseline of the subjects

	Average (Standard deviation)		*P*
	Male (*N* = 16)	Female (*N* = 16)	
Age (y/o)	20.82 ± 0.88	20.81 ± 1.08	0.99
Equivalent sphere (D)	1.90 ± 1.43	2.17 ± 1.46	0.97
Accommodative response (D)	1.55 ± 0.25	1.82 ± 0.21	0.08
Pupil size (mm)	3.82 ± 0.50	3.67 ± 0.55	0.51

Comparison of the dynamic accommodative response and the pupil size at different viewing distances

This experiment set two viewing distances, namely, 0.4 m away from the object and 2.285 m in front of the subjects' eye through the double-mirror system. The changes in dynamic accommodative response and pupil size were detected and compared, as shown in Fig. 2. The results show that the mean value of the accommodative response was 1.69 ± 0.31D when the viewing distance was 0.4 m, while it was 0.11 ± 0.05D when the viewing distance was 2.285 m through the double-mirror system, and the accommodative response showed a significant difference between gazing at 0.4 m and 2.285 m ($p < 0.001$). The pupil size was 3.79 ± 0.49 mm and 4.09 ± 0.72 mm when the viewing distances were 0.4 m and 2,285 m, respectively, and a significant difference was also found in the pupil size ($p < 0.001$).

As indicated by the above results, compared with the double-mirror system imaging, the accommodative response is larger and the pupil size is smaller when the subjects looked at a closer distance; on the other hand, when the viewing distance increases from 0.4 m to 2.285 m (double-mirror system imaging), the accommodation response is reduced, and the pupil size is enlarged. At a viewing distance of 2.285 m, the accommodation can be relaxed by using the double-mirror system. The larger pupil size also reflects a reduction in accommodation.

To understand the effect of the double mirror system on the accommodative response, we compared the accommodative response of directly seeing the real object, seeing the virtual image through a single plane mirror at various viewing distances from 0.4 m to 2.285 m, and seeing the virtual image at 2.285 m through the double-mirror system, as shown in Fig. 3. Since the viewing distance of the double-mirror system is fixed, there is only one accommodative response at 2.285 m. When the subjects are looking directly at the real object and seeing the image through a single plane mirror, the accommodative response decreases with the increase of the viewing distance. When the viewing distance reaches 2.285 m, the accommodative response of the above two observation methods is very close to the accommodative response obtained by the double mirror system, which is around 0.13 ± 0.02D. The pupil size increases significantly with a viewing distance from 0.4 m to 0.6 m. When the viewing distance reaches 1.2 m the pupil size decreases significantly. When the viewing distance reaches 2.285 m, the above two observation methods are very close to the pupil size obtained by the double mirror system, which is around 4.19 ± 0.07 mm. The results indicated that the accommodative response and pupil size are consistent in these three ways at a viewing distance of 2.285 m. The advantage of this optical design is that the object can be imaged at a longer distance, and the enlarged image is easier to observe. Compared to single plane mirror imaging, the image is the opposite to the left and the right, and the double-mirror system has no such problem.

Fluctuations in accommodation

Figure 4 plots the fluctuations of the accommodative responses of 5 subjects gazing at a real object at a distance of 0.4 m, and gazing at a virtual image at a distance of 2.285 m for 30 seconds. The corresponded refractive corrections were – 0.5, -1, -2, -3, and – 4D, respectively. It is evident that although there is a considerable variation in the amplitude of accommodative fluctuations among the subjects, the fluctuations of 5 subjects were small at a viewing distance of 2.285 m through the double-mirror system. Moreover, the fluctuations increase at a viewing distance of 0.4 m. It is worth noting that the double-mirror system not only contributes to the accommodative relaxation, but also to the stability of the accommodation fluctuations.

Conclusions

This study proposed a new simple optical design with a double-mirror system to extend the viewing distance to 2.285 m and to magnify the image up to 3.79X. The results confirm that the accommodative response decreased and that the pupil size increased significantly at a viewing distance of 2.285 m through the double-mirror system. The mean value of the accommodative response can be reduced to 0.11 ± 0.05D, and the fluctuations of the accommodative response can also be stabilized. This simple optical design can achieve accommodative relaxation, and may be applied to slow down the progression of myopia and to mitigate the problems caused by close work.

Declarations

Acknowledgement

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Figures

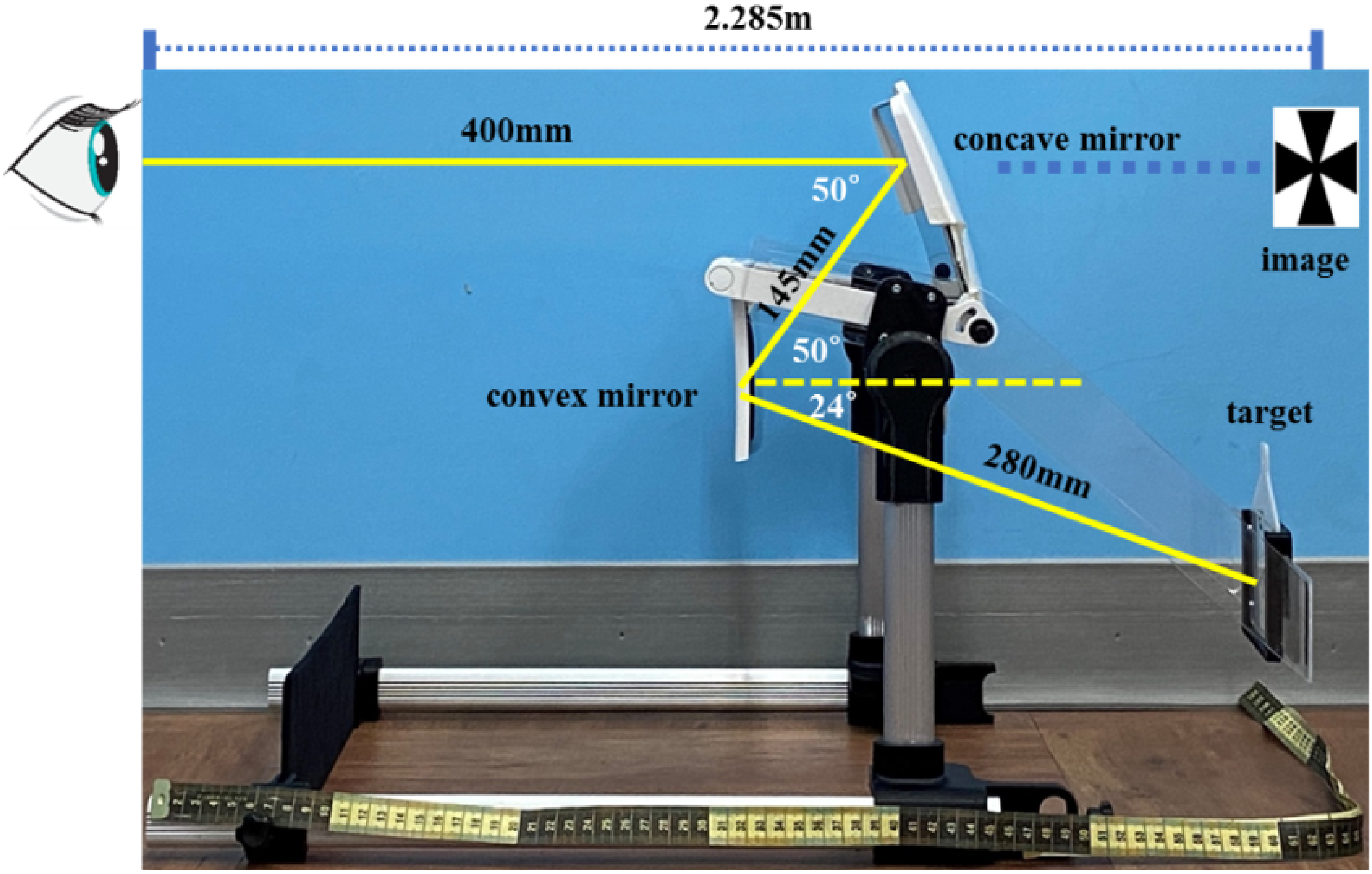

Figure 1

Design of the double-mirror system and simulation of the image position

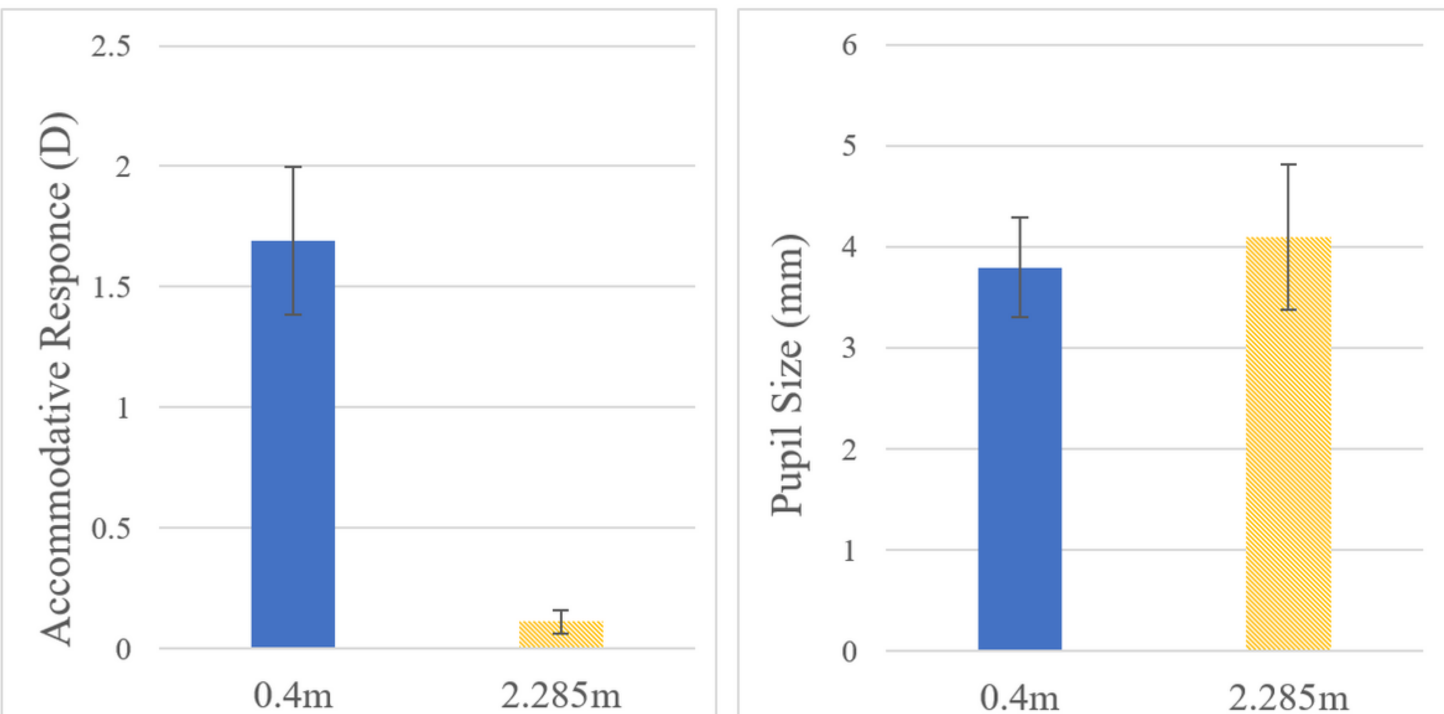

Figure 2

Comparison of (a) accommodative response, and (b) pupil size at two viewing distances of 0.4 m and 2.285 m

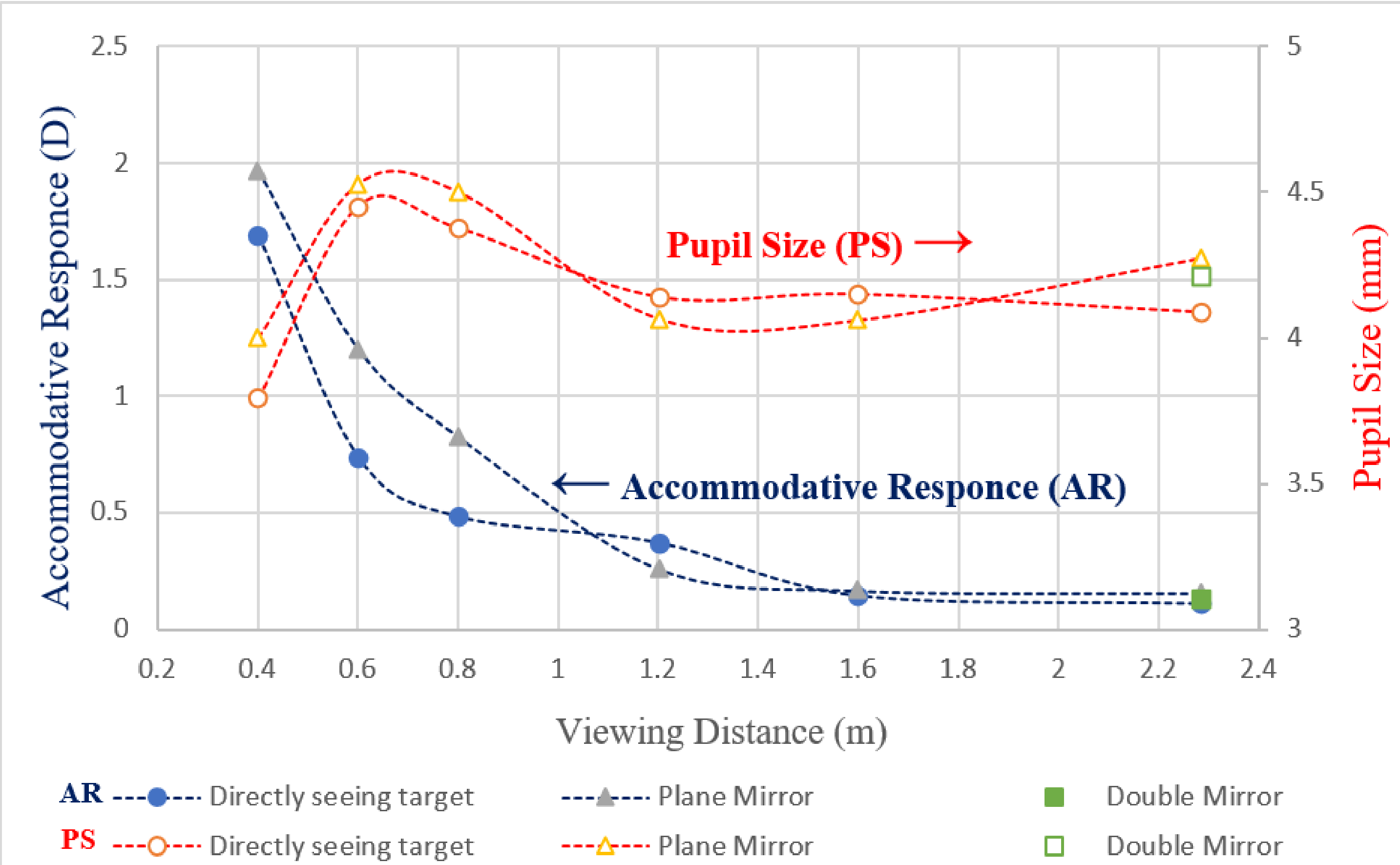

Figure 3

Dependence of the accommodative response and pupil size on the viewing distance with (1) directly seeing the real object, (2) seeing the virtual image through a single plane mirror, and (3) seeing the virtual image at 2.285 m through the double mirror system. A solid circle, a solid triangle and a solid square represent the accommodative response, while a hollow circle, a hollow triangle and a hollow square represent the pupil size corresponding to (1), (2) and (3).

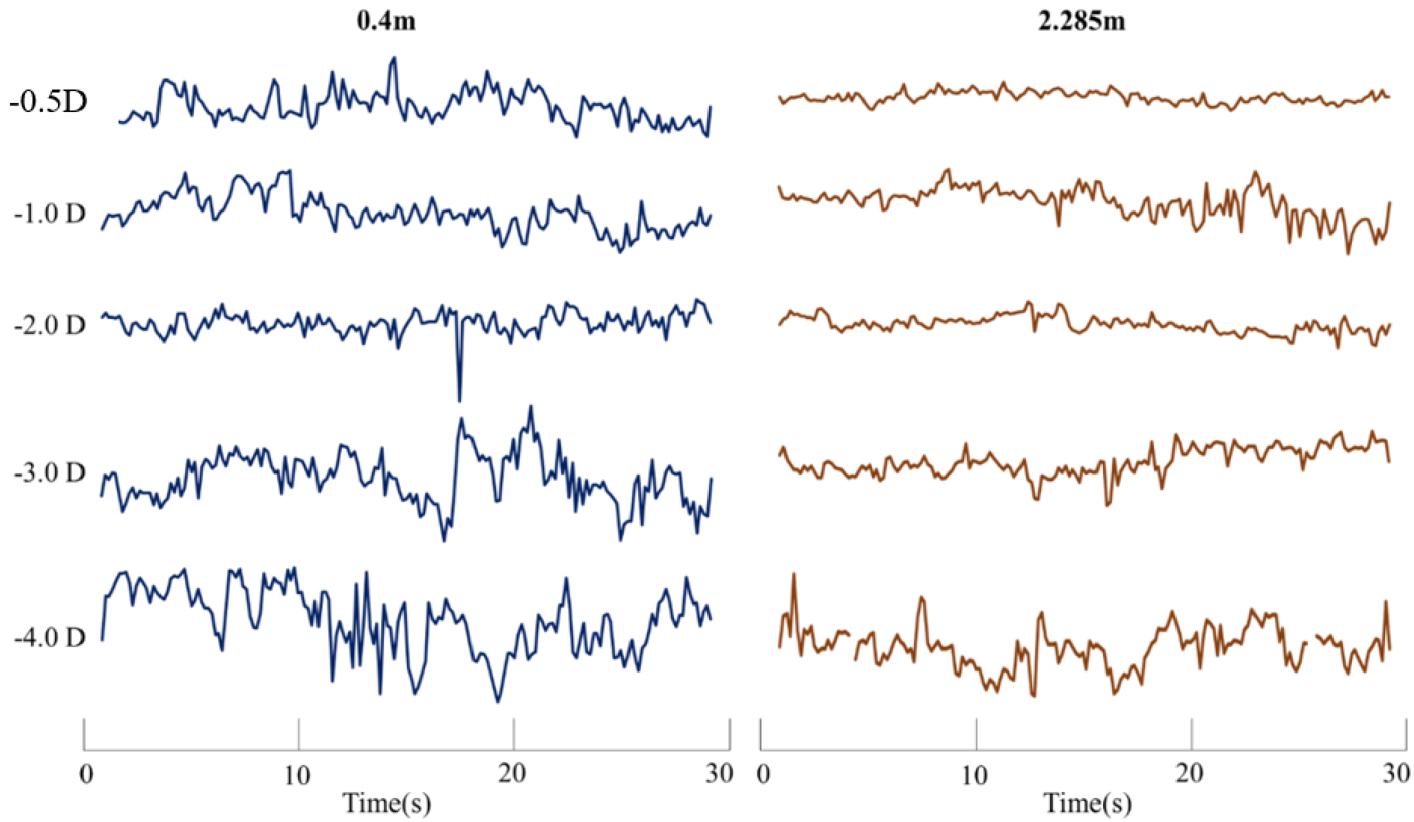

Figure 4

The fluctuations of the accommodation response for 5 subjects gazing at a real object at 0.4 m and gazing at a virtual image at 2.285 m for 30 seconds, and the corresponding refractive corrections are -0.5, -1, -2, -3, and -4D, respectively.