Dependence on The Display Methods of Change in Accommodation and Convergence When a Target Moves Along the Depth Direction

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Abstract

We have studied human behavior while using a small tablet or a digital book in terms of eye movement. These display media are widely used in conditions that cause hand movement, like on a moving bus or train. Therefore, we focused on the tracking accuracy of accommodation and convergence while subjects viewed a display that was moving in the depth direction. We developed an experimental device that measures the lens accommodation and convergence eye movement simultaneously and can be combined with equipment that moves a small tablet or a digital book linearly in the depth direction. We then evaluated changes in accommodation and convergence angle during depth-direction movement with different kinds of display media, fonts and font sizes. The amount of change in accommodation showed a tendency to depend on the display medium and the size of the font, and the type of font to the motion of a depth direction. The change in the angle of convergence was not dependent on the type of display medium, and the size of the font and the type of font depended only on the depth movement of the target. The tendency overshot in the direction approaching a subject was seen.

1. Introduction

Small tablets and digital books have become so popular that they are used widely and in all kinds of situations especially during passenger commutes on the bus or train. Takahira and others studying the legibility and/or ease of use of these devices in terms of human eye movements. A significant difference in eye movement during new page operation was observed between E-books and paper books, and the time to complete the page turning was different. The average page-turning time for E-books was shorter than that for paper books, and the average displacement length of E-books was shorter than that for paper books [1]. As shown in this research, it is considered that reading behavior or style will change from that with which we have been accustomed because digital books do not require a grasping and turning operation.

Although electronic tablets have the potential to replace books, it cannot yet be said that they are equivalent to conventional books in terms of legibility or ease of use. Our research on eye movement while reading E-books has forced us to study more fundamental characteristics of reading behavior because the display characteristics of the electronic terminals are not necessarily equivalent to that of the paper media. Thus, we have paid attention to the focusing characteristics of the crystalline lens - called accommodation - which is where visual information first enters the eye. We considered that the accommodation response would be influenced by the shaking of the display in a moving vehicle. Here, we will report change of accommodation and convergence when gazing at a target moving in the depth direction according to the type of device, font, and font size.

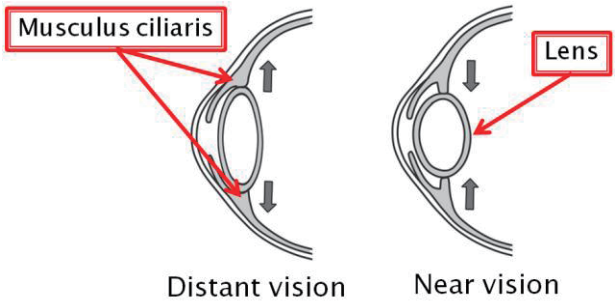

Figure 1. Lens accommodation function

2. Accommodation and Convergence

2.1. Accommodation

The lens accommodation function focuses on an object by adjusting the thickness of the crystalline lens (Fig.1) The lens is supported by the ciliary muscle, and, in the case of near vision, this ciliary muscle shrinks, and the crystalline lens thickens. In the case of more distant vision, this ciliary muscle relaxes, and the crystalline lens becomes thinner. Diopter (D) are the units of refractive power of the lens. It takes the reciprocal of the viewing distance of sight and is computed by D = 1/m. 1D corresponds to the necessary accommodation ability when a subject gazes at a target 1 m from his eyes.

2.2. Convergence

The normal function humans have of watching an object with both eyes to obtain depth information is called binocular vision (Fig. 2). When seeing a nearby object with binocular vision, both eyes approach the inside in a convergent eye movement. In contrast, when gazing at a more distant subject with binocular vision, the eyes move toward the outside of the orbit in a divergent eye movement. We perceive depth because of these fine binocular adjustments.

3. The Experimental Device

Figure 3 shows the configuration of the experimental device. WAM-5500 by Shigiya Seiki Co., which can

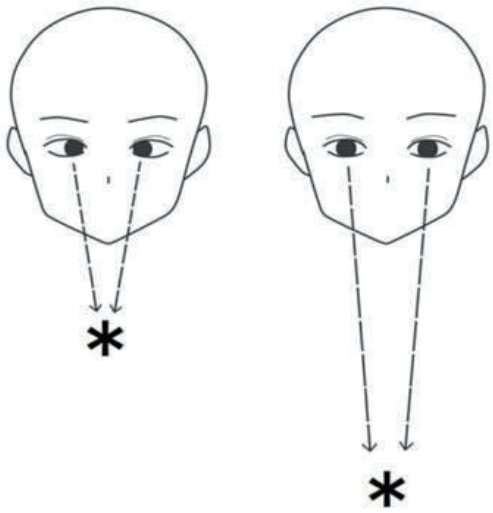

Figure 2. Convergence and divergence

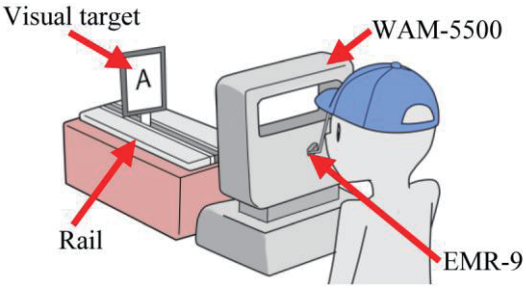

Figure 3 Configuration of the experimental apparatus

measure accommodation at 7 Hz continuously, was used for part of the device. Shepperd and Davis reported that WAM- 5500 had an accuracy between -0.01D ～ 0.38D when measuring distances between -6.38 and 4.88D [2]. EMR-9 by NAC Imaging Technology was used to measure convergence. Shiomi and others have shown that they could carry out simultaneous measurement of convergence eye movement and accommodation satisfactorily, since WAM-5500 uses 950- nm near infrared light and EMR-9 use 850-nm near-infrared light for measurement and these wavelengths do not interfere with one another [3]. Convergence eye movement was measured at 60 Hz. An automatic motorized X-axis linear stage KXL06200-N2-FA (Suruga Seiki Co. LTD) was used for the target presentation.

4. Experimental Method

The subject was instructed to continue gazing at a target during the experiment. A set of data was collected when the target was moved from 60cm → 40cm and from 40cm → 60 cm; we measured two sets of data at a time. The movement speed on the rail was 12 mm/sec. EMR-9 was offset so that the angle of convergence might be 0°in the center position of 60cm of distance of sight, which was the experimental onset point. We chose "A" presented as the visual target. Experimental conditions are shown in Table.1. The subjects included seven students from the university (men aged 20-22 years old). We confirmed that the fonts we prepared this time can be visually recognized clearly by them in this experimental conditions beforehand. However, there were subjects in whom accommodation did not necessarily change. Therefore, we analyzed the data for five subjects who exhibited changes in accommodation. All subjects had eyesight more than 0.9.

5. Experimental Results

Even when the accommodation response reached the target point, it is known there were some characteristics which continued moving for a while [4]. Since the measurement interval of the accommodation measuring device (WAM-5500) was 7 Hz, accommodation took moving average between one second using each 3 samples around the current sample. The data deficit was included in measurement data by the measurement noise and blinks. Therefore, the part considered to be an error was put in and corrected for by the previous value. Similarly, since the measurement interval of the convergence eye movement was 60 Hz, convergence also took the moving average between one second.

Typical examples of measurement results are shown in Fig. 4. Figure 4 shows the measurement result of accommodation, with the vertical axis showing the diopter value and the horizontal axis showing time. The position of the target is converted to a diopter value to show the relations among the convergence response, accommodation response and a target movement. The results of the accommodation response in Fig. 4 show that the accommodation value (diopter) is near the actual position of a target and changes according to the motion of the target. When the target is located at 40 cm (-2.5D), the accommodation value indicates a relatively distant place from the position of the target as shown in Fig. 4. It is known the accommodation does not always correctly respond to focus on the target position, there is a gap to some extent, and individual difference also exists [5]. Shiomi et al. has reported that the accommodation response is often at a place 0.4D from the position of the object [3, 6-9].

Figure 5 shows the measurement result of convergence with the vertical axis showing the convergence angle, and the horizontal axis shows the time. The convergence angle was 0°at the initial viewing distance of 60 cm, took a negative value when focusing behind this position and a positive value when focusing in front of this position. In the example shown in Fig. 5, when a target was in the position of 40 cm (approx. 1°of the convergence angle), the convergence overshot nearer to the subject.

However, although not illustrated other than by this example, the convergence suited the target position accurately and the tendency overshot in the direction approaching a subject was seen.

6. Consideration

From the measurement results, we examined the variation of the measured values before and after the operation of the target. When the changes of accommodation became within ±0.3D in 2 sec, it was defined as stable accommodation. The amount of change in the

Table 1 Experimental conditions

Display media	KOBO mini (5 in., 200dpi) Paper iPod (4 in., 326dpi) PS Vita (5 in., 221dpi)	380 lux 122 cd/㎡ 102 cd/㎡	Reflective type Back-it type Organic EL
Font size	15mm (Visual angle: 1.432°) 10mm (Visual angle: 0.954°)		
Font	Arial Times New Roman		

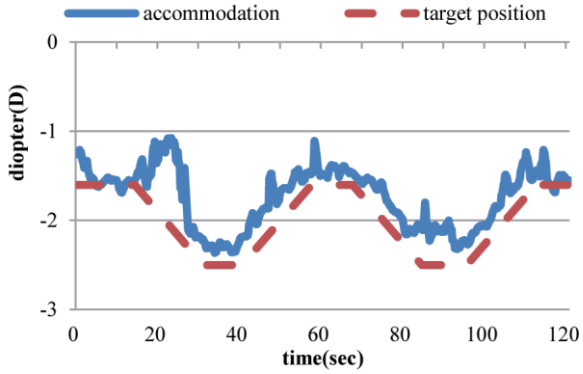

Figure 4. Accommodation and target position

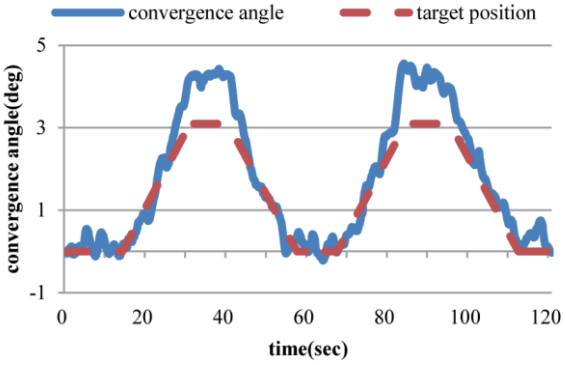

Figure 5. Convergence angle and target position

change of accommodation was calculated by the difference between the A before and after the operation of the target when both stable accommodations were obtained.

The amount of change of convergence was calculated at the same time when stable accommodation was obtained. The amount of change of accommodation and the amount of change of convergence which took all subjects' averages are shown in Figs. 6 and 7 for every size of display medium and every character, and every character font. In Fig. 6, the vertical axis shows the accommodation difference (D), and the horizontal axis shows the parameters. Since accommodation is -1.6D to -2.5D when a motion of 60-40 cm of a target is converted into diopters, the difference of diopter is 0.9D, which is indicated by the red line in Fig. 6. If the accommodation had accurately changed to the target position, theoretically the amount of change of accommodation should approach 0.9D. As shown at the top of Fig. 6, the accommodation changes for the iPod and Vita show almost the same values as the red line, Paper and KOBO showed smaller amounts of change, but the difference was small at approx. 0.1D. In the middle of Fig. 6, the accommodation change of the 10mm font size was smaller than that of 15mm font size. In the bottom of Fig. 6, the accommodation change of Arial was smaller than that of Times New Roman. The amount of accommodation changes of the 15mm font size and of Times New Roman are close to the actual amount of displacement of a target. However, when the t-test was performed, a significant difference was not obtained in any of the conditions examined. We think that this result was obtained because the capability of accommodation has large individual differences depending on the subjects' eyesight, age, etc.

In Fig. 7, the vertical axis shows the convergence angle difference (deg) and the horizontal axis shows the parameter. Here as in Fig. 6, the red line indicates the difference of convergence change, 3.1°, between the motion of 60-40cm of a target. In near-vision (40 cm), a tendency in which the convergence overshoots nearer to the subject by almost all measurement results was seen. Therefore, it seems that the entire amount of change of convergence became larger than that shown by the red line. Although, convergences of iPod mini and PS Vita showed larger than that of Paper and KOBO mini, clear differences among display media, font sizes and font types were not seen.

7. Conclusion

With the spread of electronic books and compact tablets, the available display styles vary greatly compared with the medium of paper. Small tablets and digital books are used widely and in all kinds of situations, especially during passenger commutes on the bus or train. We have paid attention to the focusing characteristics of the crystalline lens. At the same time, we examined convergence which is important movement to perceive depth as well as accommodation. We developed an experimental device that measures the lens accommodation and convergence eye movement simultaneously and can be combined with equipment that moves a small tablet or a digital book linearly in the depth direction. We focused on the accuracies of accommodation and convergence while subjects viewed a display that was moving in the depth direction. We evaluated changes in the accommodation and convergence angle during depth-direction movement with different types of display media, fonts and font sizes.

The amount of change of accommodation with the use of the Vita or iPod (which emit light by EL or a back light) were almost the same as the amount of target displacement, and that of the paper and Kobo of the reflective type display showed an even smaller change. The accommodation change of 10-mm font size was smaller than that of the 15-mm font size. The accommodation change of Arial was smaller than that of Times New Roman. The amount of change of accommodation showed the tendency to depend on the display medium

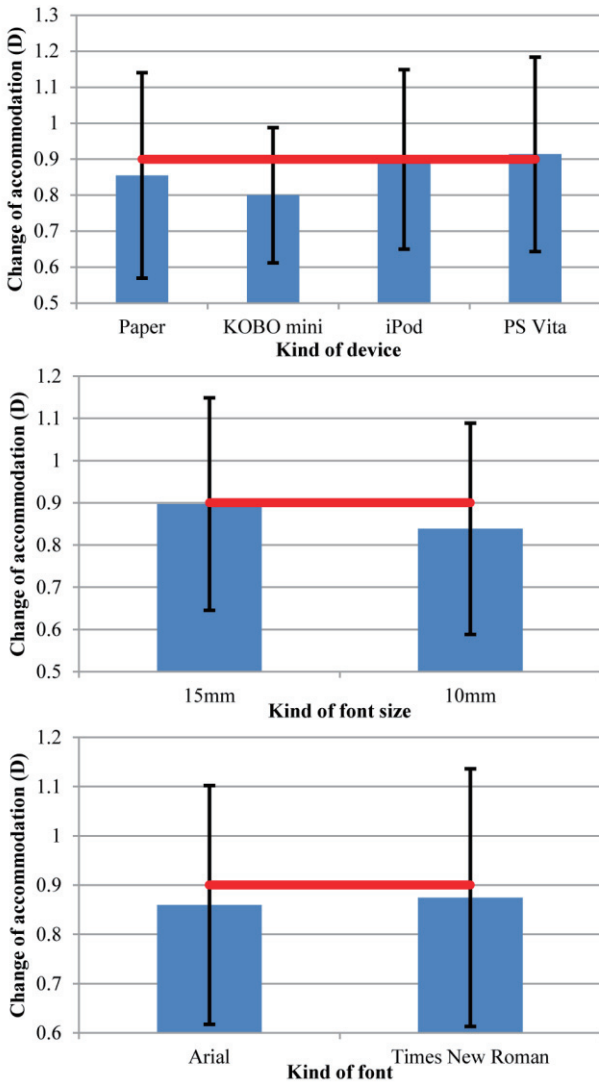

Figure 6. Change of accommodation

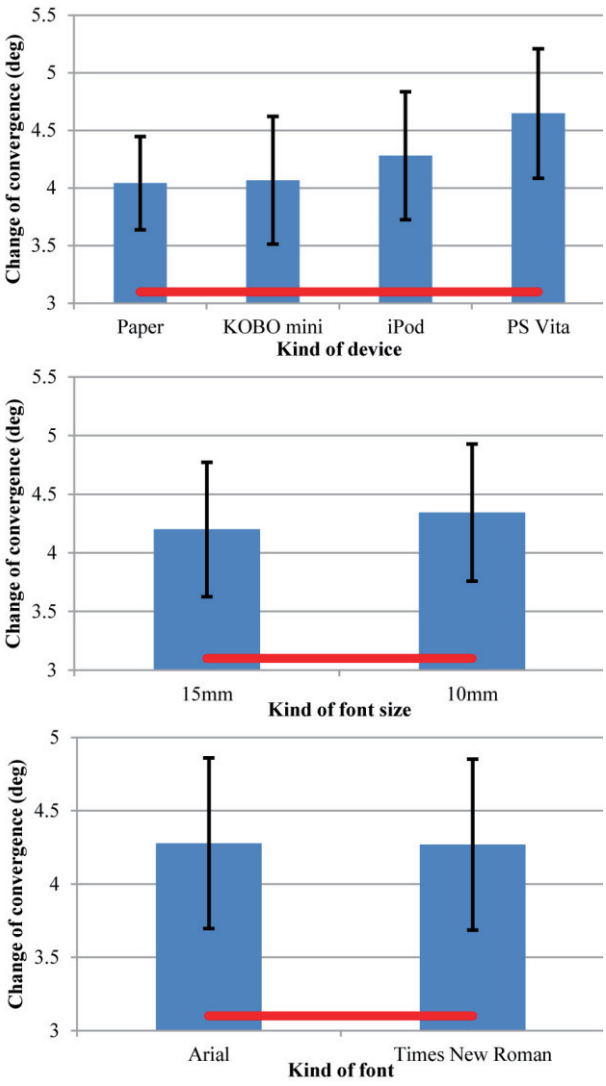

Figure 7. Change of convergence

and the size of the font, and the type of font to the motion of a depth direction. With the t-test, no significant differences were observed for any conditions. The change of the angle of convergence was not dependent on the type of display media, and the size of the font or the type of font. Only depending on the depth movement of a target, and the tendency overshot in the direction approaching a subject was seen.

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