Measurement of Lens Focus Adjustment While Wearing a See-Through Head-Mounted Display

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Abstract. In recent years, many visual devices have been produced for consumers. The development of see-through smart glasses has attracted much attention. These glasses overlap virtually images by using Augmented Reality (AR) technology. Epson released the BT-2000 see-through smart glasses, which change distance of display by changing convergence. It is not confirmed that changing distance of display allow to change distance of lends accommodation. In this experiment, we measured lens accommodation of subjects viewing images displayed on see-through smart glasses. The results found that lens accommodation moved with the image position for over one hundred people. Therefore, our study verified that correct reaction occurred visual physiologically.

Keywords: See-through · Smart glasses · Lens accommodation · AR

1 Introduction

Various electronic devices equipped with an array of sensors have been made mobile by the down-sizing of electronic parts [1]. Devices designed to wear are termed wearable devices. In this study, we focused on an eyeglass-type device that is attached to the head, a see-through head-mounted display. See-through head-mounted displays are capable of superimposing information on one's view of the real world employing Augmented Reality (AR) technology [2].

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Studies on the use of see-through head-mounted displays to improve work support for users have recently been actively performed. In 2014, Makita et al. superimposed information on road damage on a head-mounted display and stated its usefulness [3], and Makibuchi et al. proposed a hands-free work support system using head-mounted displays in 2015 [4].

Work support systems using head-mounted displays are expected to proliferate in the future. On the other hand, the display position of contents on conventional head-mounted displays is fixed, but, for hand-related work in which the visual distance changes, the content display position should follow the hand position, otherwise an uncomfortable feeling may develop that influences the work. Thus, automatic modification of the perceived position in the depth direction of the content while using a head-mounted display may be significant for work support. One method to change the display position in the depth direction is changing the congestion focus position. In the visual function, when one sees a nearby object, lens accommodation occurs. The focus is adjusted by increasing the lens thickness in conjunction with convergence of the bilateral eyes toward the medial side, with which miosis of the pupils also occurs. These 3 reactions are termed the near reflex, and the occurrence of one reaction induces the others [5]. A lens accommodation response changes convergence, and this is termed accommodative convergence, while changes in convergence induce a lens accommodation response and this is termed convergence accommodation [6].

In this study, convergence accommodation was induced by moving the content display position in the lateral direction in a head-mounted display, and the influence on perceiving the depth direction of contents while using the display was investigated.

For the see-through head-mounted display, EPSON MOVERIO Pro BT-2000 was used. BT-2000 independently projects images for the bilateral eyes. In addition, it is capable of changing the center distance in the lateral direction. Thus, using an original application utilizing these 2 characteristics, the center distance was changed to alter the convergence, and the following of the convergence by an accommodation response was investigated. The head-mounted display used in this experiment, BT-2000, is presented as HMD (Head Mounted Display) below.

2 Materials and Methods

This study involved 128 subjects aged 14 to 88 years old (66 males and 62 females). Generally, the accommodative function starts to decline after the mid 40s [7]. Thus, the subjects were divided into those younger than 45 years old as a young group (58 subjects) and 45 years old or older as an older group (70 subjects). All subjects performed the experiment with naked eyes or wearing glasses and contact lenses usually used. As an ethical consideration, sufficient informed consent was obtained from the subjects before they participated in the experiment. This study was approved by the Ethics Committee of Graduate School of Information Science, Nagoya University. Lens focus adjustment was measured using an autorefractometer (WAM-5500, Shigiya Machinery Works, Ltd.). The temporal resolution of this device was 5 Hz. HMD and WAM-5500 used in the experiment are shown in Fig. 1.

Fig. 1. Left: EPSON MOVERIO Pro BT-2000, right: WAM-5500

In this study, contents were displayed on HMD and a liquid crystal display (LCD), and lens focus adjustment was measured while viewing each content. The content position displayed on both devices was set at 1.43 (0.7 m), 0.8 (1.25 m), and 0.3 D (3.33 m) from the eyes of the subject. Diopter (D) is the unit of accommodative ability, and it is a reciprocal of the distance in meters (m). Using each device, the subjects viewed the contents for 10 s twice at each visual distance. Considering the order of the effect, the order of the device was alternately changed in each subject, and the visual distance was set in random order. The horizontal illuminance was 956 ℓx. The experimental environment and set-up are shown in Figs. 2 and 3.

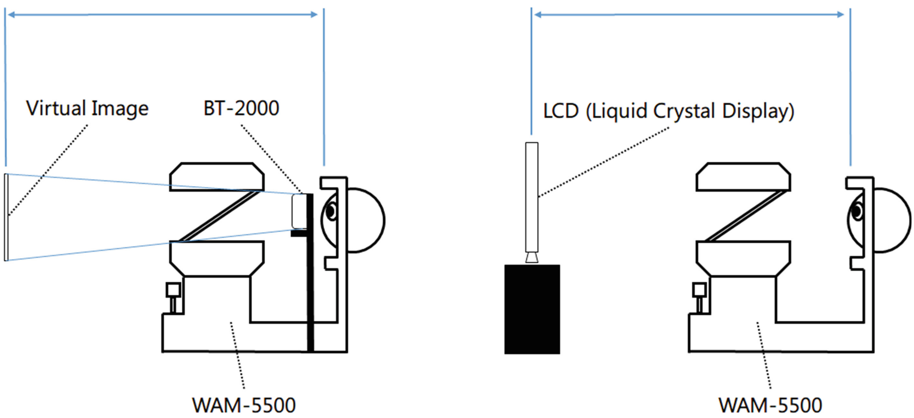

Fig. 2. Experimental environment

From time-series data of accommodation values collected in the experiment, 3-s time-series data were extracted because their distribution was the smallest in order to exclude factors, such as blinking, and the mean of the extracted 3-s time-series data was calculated as a representative value of the visual distance. When 3-s time-series data could not be extracted under any of the 6 conditions (2 device conditions with 3 visual distance conditions), the subject was excluded.

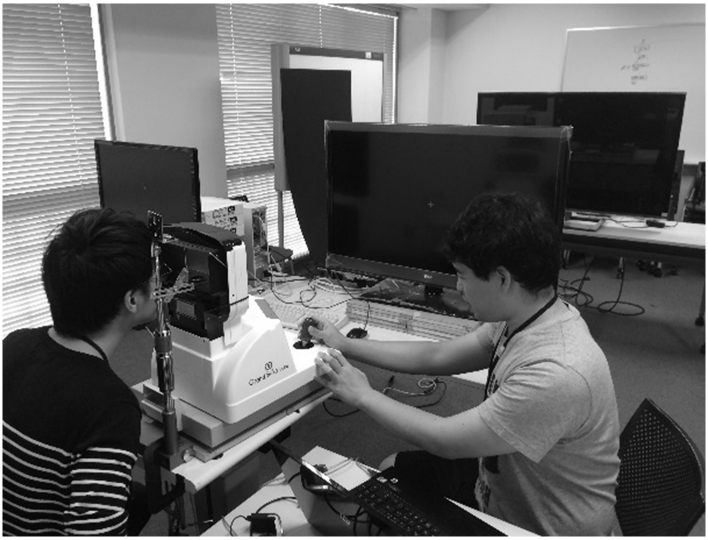

Fig. 3. Experimental set-up

The calculated representative values in each age group were subjected to 2-way layout analysis of variance with the device (LCD, HMD) and visual distance (1.43 D, 0.8 D, and 0.3 D) as factors, followed by the paired t-test regarding the absence of a difference in the population mean as a null hypothesis and multiple comparison. In addition, the paired t-test regarding the absence of a difference in the population mean as a null hypothesis was performed between the 2 devices at the same visual distance. The significance level was set at 5 % or lower.

3 Results

As an open-field-type device, WAM-5500, is capable of measurement under natural conditions while wearing glasses. However, this experiment required avoiding the image projection optical system (half mirror) of the see-through head-mounted display and projecting infrared light for measurement from an oblique. Thus, the measurement was contraindicated for some subjects even though the measurement range of WAM-5500 was 20° in the lateral direction in the front-open type. As a result, the numbers of the subjects were 15 and 26 in the young and older groups, respectively.

The results for the lens focus adjustment in the young and older groups are shown in Figs. 4 and 5. In the young group, when the content was displayed on LCD at 0.3, 0.8, and 1.43 D, the means were about 0.7, 0.9, and 1.2 D, respectively. When the content was displayed on HMD at 0.3, 0.8, and 1.43 D, the means were about 0.8, 1.0, and 1.1 D, respectively.

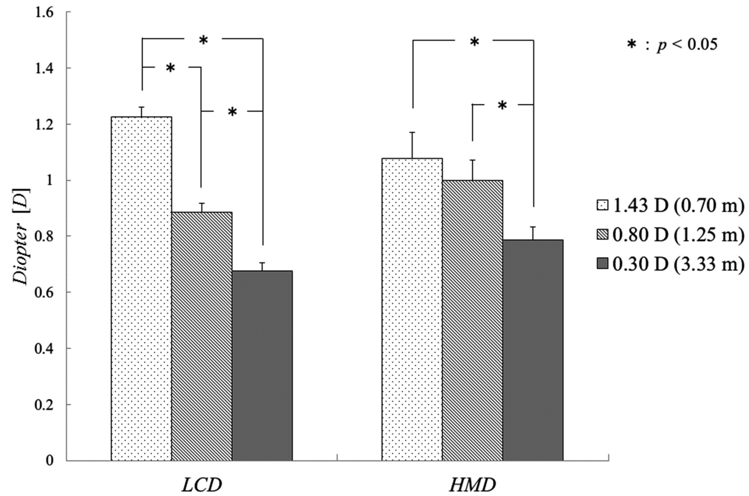

Fig. 4. Lens focus adjustment in the young group

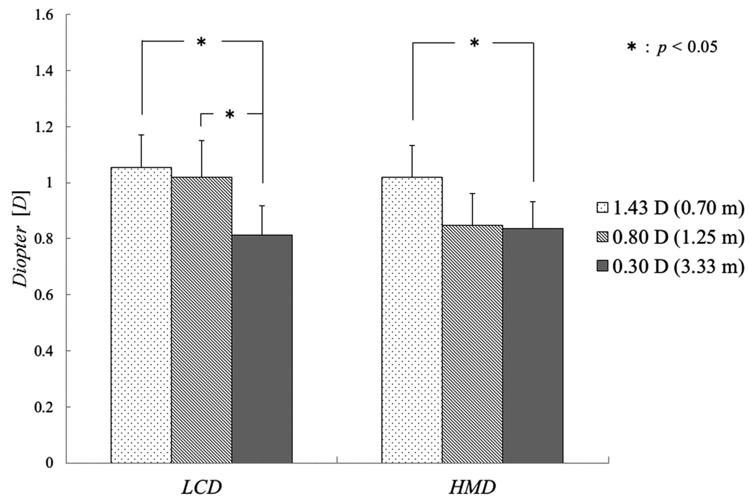

Fig. 5. Lens focus adjustment in the older group

In the older group, when the content was displayed on LCD at 0.3, 0.8, and 1.43 D, the means were about 0.8, 1.0, and 1.0 D, respectively. When the content was displayed on HMD at 0.3, 0.8, and 1.43 D, the means were about 0.8, 0.8, and 1.0 D, respectively.

The results for the young group were subjected to 2-way layout analysis of variance with the visual distance and device as factors. A main effect was detected when the factor was the visual distance, but no main effect was detected when the device was the factor ($p < 0.05$). No interaction was observed. Then, the results with LCD in the young group were subjected to the paired t-test. The mean significantly decreased at a visual distance of 0.8 D compared with that at 1.43 D ($p < 0.05$), at a visual distance of 0.3 D compared with that at 1.43 D ($p < 0.05$), and at a visual distance of 0.3 D compared with that at 0.8 D ($p < 0.05$). The results with HMD were subjected to the paired t-test. The mean significantly decreased at a visual distance of 0.3 D compared with that at 1.43 D ($p < 0.05$), and at a visual distance of 0.3 D compared with that at 0.8 D ($p < 0.05$).

The results for the older group were subjected to 2-way layout analysis of variance with the visual distance and device as factors. No main effect of either factor ($p < 0.05$) or interaction was noted. The results with LCD were subjected to the paired t-test. The mean significantly decreased at a visual distance of 1.43 D compared with that at 0.3 D ($p < 0.05$), and at a visual distance of 0.3 D compared with that at 0.8 D ($p < 0.05$). The results with HMD were subjected to the paired t-test. The mean significantly decreased at a visual distance of 1.43 D compared with that at 0.3 D ($p < 0.05$).

The values with the devices at the same visual distance were subjected to the paired t-test. No significant difference was noted at any visual distance between the results with LCD and HMD.

4 Discussion

Using EPSON MOVERIO Pro BT-2000, induction of an accommodation response in conjunction with convergence movement by changing the center distance in the lateral direction while using HMD was investigated. Convergence accommodation was induced while using HMD, confirming changes in the perception concerning the depth direction.

The mean lens focus adjustment deviated from the theoretical value, suggesting that the depth of the field increased due to the myopic tendency of the subjects and indoor lighting. The accommodation ability was decreased in the older group compared with that in the young group, and variation of the mean lens focus adjustment was small at all visual distances. On measurement of the lens focus adjustment during viewing the content displayed on HMD and LCD, a significant difference was noted in the mean lens focus adjustment between the visual distances of 1.43 and 0.3D while using HMD regardless of the age groups, confirming that the content displayed to the bilateral eyes changed the center distance of the content and induced an accommodation response.

On 2-way layout analysis of variance in the young group, no main effect was noted in either device, and a main effect was noted in the visual distance. Since the young group had sufficient accommodation ability, an accommodation response occurred corresponding to the visual distance, which may have caused transition of the lens focus adjustment. No significant difference was noted between the devices, confirming that visual-physiologically correct accommodation responses occurred while using HMD.

On 2-way layout analysis of variance in the older group, no main effect was noted with either the device or visual distance. The results with LCD and HMD confirmed that lens focus adjustment changed corresponding to the visual distance. It was confirmed that normal accommodation responses also occurred in the older group while viewing the content displayed on HMD.

5 Summary

With recent developments of mobile technology, various wearable devices have become available. Head-mounted displays are attracting attention as a new method of information presentation by superimposing information on one's view of the real world using AR technology. Omori et al., Hasegawa S. et al., and Hasegawa A. et al. measured lens focus adjustment while viewing 3D-images displayed on a head-mounted display [8–10]. However, these studies did not measure lens focus adjustment during viewing AR technology because a non-see-through head-mounted display was used. Makita et al. investigated the usefulness of displaying road information on a head-mounted display, and Makibuchi et al. performed a study on hands-free work support using a similar display. Improvements in work efficiency using head-mounted displays are expected. However, it is impossible to change the image display position in conventional head-mounted displays, and for hand-related work, an uncomfortable feeling may occur that reduces the work efficiency. Thus, using EPSON MOVERIO Pro BT-2000, which independently projects images for the bilateral eyes with a changeable convergence angle, we measured lens focus adjustment as a basic study for the improvement of work efficiency. The occurrence of accommodation responses corresponding to the visual distance was investigated by changing the content display position, and it was confirmed. Accordingly, it was also confirmed that visual-physiologically correct accommodation responses occurred when the content displayed on HMD was viewed, and it was suggested that the head-mounted display is useful for prolonged work.

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