Accommodative Response while Gazing Moving Objects and the Effects of Aging

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***Abstract*—**Human beings can recognize stereoscopic images mainly by capturing images with binocular vision. With such sensory abilities, individuals can follow moving objects. For binocular vision, the processes of convergence and accommodation are important. In such visual functions, there are significant effects on accommodation that occur due to aging while there is little deterioration on the convergence ability.

In this study, we asked 135 people (ages 17 to 85) to be subjects. We measured accommodative change while the subjects gazed moving object (the Rubik's Cube). The moving object has oscillated between 1D (100cm) and 2D (50cm) from the front of the eye of the subject. There were three patterns of movement (a sign curve movement to perform 3 cycles per 30 seconds, a sign curve movement to perform 4 cycles per 10 seconds and object stopped for 5 seconds at each distance of 1D, 1.5D (67cm), and 2D from the front of the eye of the subject (step movement)). We obtained a relationship between aging and response speed of accommodative focus for various movements of visual targets.

We used the results of measurement of the subjects which had less error of 2 or 3 cycles. The younger subjects who met the conditions were 31 out of 64 individuals in the under 44 years old group. Accommodation was changed in accordance with the position of the moving object.

The data of 13 subjects in the middle-aged (aged from 45 to 64) group (out of 37 people) was similar to the results of the younger group. In the case of three elderly (over 65 years) subjects (out of 34 people), accommodation changed a little. In comparison with younger and middle-aged people, accommodation of the elderly changed at a position away from the subject than the actual position of the moving object.

***Keywords*—convergence, accommodation, aging, target movement, velocity.**

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I. Introduction

Human beings can recognize stereoscopic images mainly by capturing images with binocular vision. With such sensory abilities, individuals can follow moving objects. For binocular vision, the processes of convergence (crossing point of binocular eye movement target) and accommodation (crystalline lens focus) are important. In such visual functions, there are significant effects on accommodation that occur due to aging, while there is little deterioration on the convergence ability.

In this study, we asked more than 100 people (from teens to those in their eighties) to be subjects. Using a transfer robot, we set several speed levels on moving real objects. The subjects were asked to focus on the moving objects. We measured accommodative change of the subjects as they gazed upon these objects. We obtained a relationship between aging and response speed of accommodative focus for various movements of visual targets.

II. Method

The devices used in these experiments were an auto ref/keratometer, WAM-5500 (Grand Seiko Co. Ltd., Hiroshima, Japan) and WMT-1 (Grand Seiko Co. Ltd., Hiroshima, Japan). The WAM-5500 provides an open binocular field of view while a subject is looking at a fixed distant target. This instrument has two measurement modes: a static and dynamic mode. We used the dynamic mode in this experiment. The manufacture's supplied model-eye (of power -4.50 D) assisted in evaluating the accuracy of the WAM-5500 in measuring refraction in the dynamic mode of operation.

The WAM-5500 was set to Hi-Speed (continuous recording) allowing for refractive data collection at a temporal resolution of 5 Hz. The software recorded results in dynamic mode, including time for the reading of each pupil size (in seconds) and the MSE (mean spherical equivalent) refraction in the form of an Excel Comma Separated Values (CSV) file [4, 5].

The WMT-1 is a system that records received data over time from the start of the measurement. The WMT-1 vacillated back and forth with the object. At the same time, the WAM-5500 measured the movement of the eyes of the subject who gazed at an object. A Rubik's Cube was the moving object that subjects were asked to view.

The experiment was carried out with 135 people (ages 17 to 85) as subjects. Informed consent was obtained from all subjects and the experiment was approved by the Ethical

Review Board of the Graduate School of Information Science at the Nagoya University.

We measured accommodative change while the subjects gazed at moving object (the Rubik's Cube). At this time, the subjects were asked to gaze upon the center of the Rubik's Cube. The moving object oscillated between 1D (D = Diopter, 1D = 100cm) and 2D (50cm) from the front of the eye of the subject.

There were three patterns of movement. The first pattern was a sign curve movement to perform 3 cycles in 10 seconds. The second pattern was a sign curve movement to perform 4 cycles in 2.5 seconds. The third pattern stopped for 5 seconds at each distance of 1D, 1.5D, and 2D from the front of the eye of the subject (step movement). The order of precise stopping was 1D, 1.5D, and 2D.

A"diopter or D" is the refractive index of lens. It is an index of accommodation power. This unit of measurement is the inverse of meters; for example, 0 D stands for infinity, 1 D stands for 100 cm, 1.5 D stands for 67 cm, and 2 D stands for 50 cm.

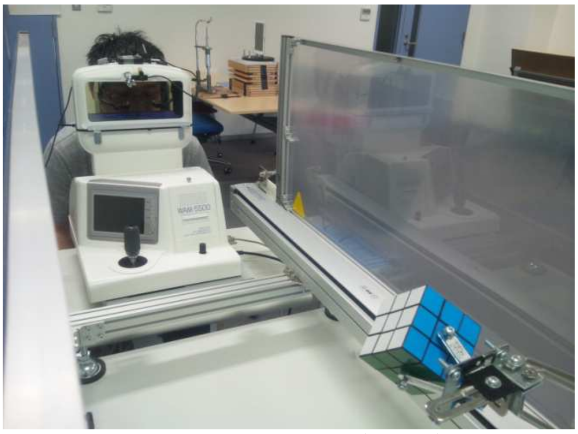

Fig.1 Experiment scenery (WMT-1)

III. Results

The experimental results are discussed with the help of three examples.

First, as an example, we show the results from the measurements of Subject A (Fig. 2: 22 years old, male) and B (Fig. 3: 72 years old, female) taken over a period of 10 seconds. Figs 2-3 show graphs in which the the horizontal axis represents the elapsed time in which these two subject were watching the real object. The vertical axis on the left reflects the distance from the subject to real object, and the vertical axis on the right is the size of the pupil diameter. The green line shows the "Position" of the moving object (Rubik's Cube). The red line stands for "Accommodation" and is a focal length of the lens focus adjustment. The blue line illustrates the change in "Pupil diameter".

When subject A gazed at a moving object (Fig. 2), accommodation changed in accordance with the position of the moving object between 1.12 D and 2.03 D. The amplitude of accommodation was in nearly the same period as the moving object. Also, the pupil diameter showed little change. On the other hand, when subject B was gazing at a moving object (Fig. 3), accommodation changed between 0.47 D and 0.9 D. Although the cycle of accommodation and moving object were almost identical, the amplitude of accommodation was small. In addition, the focus of accommodation was in a lower position than that of the moving object. In other words, the position of accommodation for Subject B was further away from the subject than the actual position of the object.

Furthermore, the changes in the pupil diameter were large compared to the case of younger individuals. Figure 2 shows that the pupil diameter is smaller when the moving object is approaching the subject.

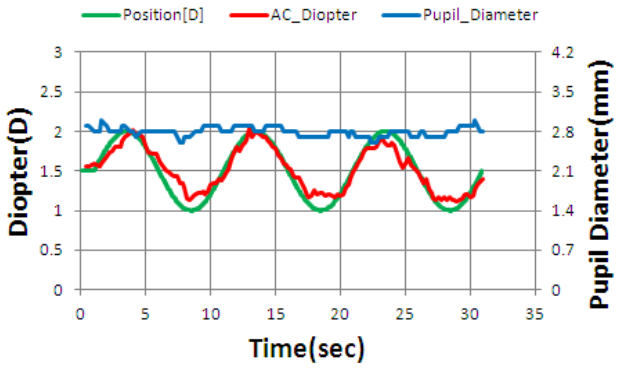

Fig.2 The cycle of 10 seconds: Subject A (22 years old, male)

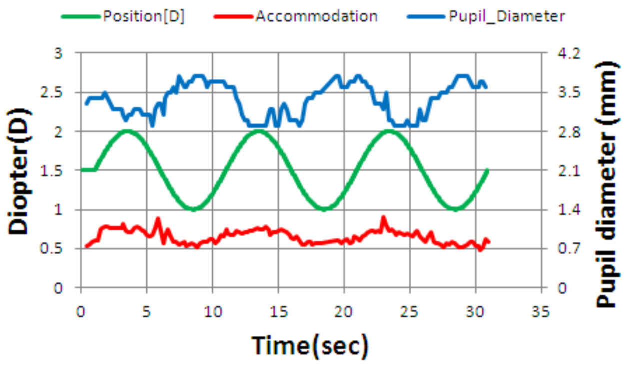

Fig.3 The cycle of 10 seconds: Subject B (72 years old, female)

Second, we show the results of the measurements of Subject C (Fig. 4: 36 years old, female) and B (Fig. 5: 72 years old, female) as a typical example for a period of 2.5 seconds. When subject C was gazing at a moving object (Fig. 4), similar to the results of the 10 seconds cycle, accommodation changed according to the position of the moving object. However, accommodation lagged a little bit behind the movement of the moving object. In this case, delay of accommodation is 315ms on average. While the WAM-5500 may have shown no delay based on the typical average of accommodation at 5HZ, which is a sampling rate of 200ms, we found a slight delay in accommodation.

On the other hand, when subject B gazed at a moving object (Fig. 5), accommodation changed between 0.51 D and 0.82 D. In this instance, compared with the results of the 10 second cycle (Fig. 3), the subject's pupil diameter did not change to correspond to the motion of a moving object.

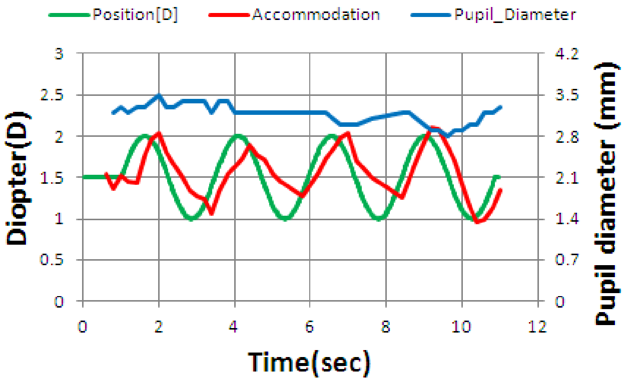

Fig.4 The cycle of 2.5 seconds: Subject C (36 years old, female)

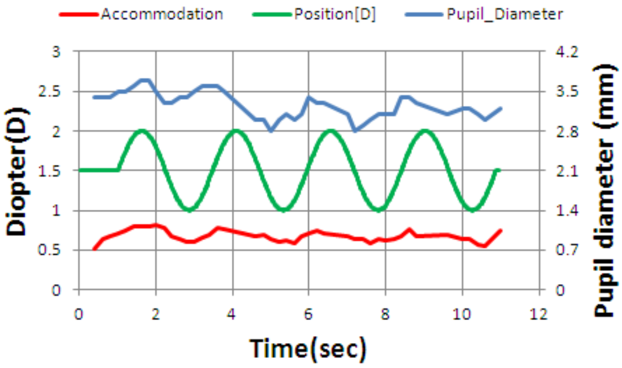

Fig.5 The cycle of 2.5 seconds: Subject B (72 years old, female)

Third, we show the results of measurement of Subject C (36 years old, female) and B (72 years old, female) as a typical example of step movement. The measurement changed to match the perspective of the moving object; the accommodation of Subject C was mostly in agreement (Fig. 6). When the moving object stopped, accommodation also stagnated in the position of the neighborhood of the moving object. When the position of the moving object shifted, accommodation also moved immediately. On the other hand, when Subject B gazed at a moving object (Fig. 7), her accommodation changed little. In addition, compared with previous measurement results of younger subjects (Fig. 6), the position of accommodation was further from the subject than the position of the moving object.

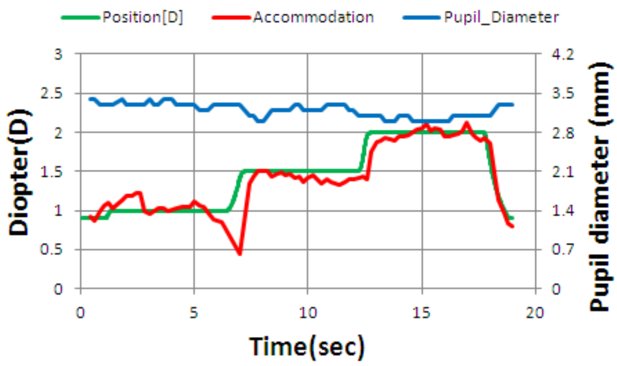

Fig.6 Step movement: Subject C (36 years old, female)

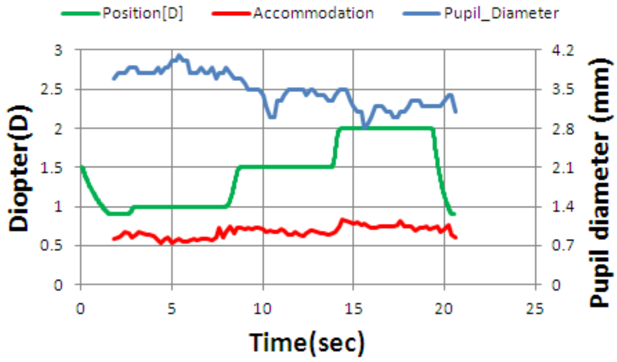

Fig.7 Step movement: Subject B (72 years old, female)

Figure 8 shows the average value of the position of accommodation of 10 seconds cycle in the under 44 year old group of subjects. We used the results of measurement of the subjects which had less error of 2 or 3 cycles. The younger subjects who meet the conditions were 31 out of 64 individuals in this group. Similar to a typical example (Fig.2), accommodation changed in accordance with the position of the moving object. When the moving object was 2 D from the front of the eye of the subject, accommodation of the subject was able to adjust to 1.75D on average.

Under the same conditions as the younger group (Fig 8), Figures 9-10 show the average value of accommodation for the middle-aged subjects (aged from 45 to 64) and elderly subjects (over 65 years). The data of 13 subjects in the middle-aged group (out of 37 people) was similar to the results of the younger group (Fig.8) and accommodation moved in accordance with the position of the moving object. When the moving object is 2 D from the front of the eye of the subject, the accommodation of the subject was able to adjust to 1.42D on average.

In the case of three elderly subjects (out of 34 people), accommodation changed between 0.51 D and 0.92 D, and they changed to match the perspective of the moving object. In comparison with younger and middle-aged people, the accommodation of the elderly changed at a position away from the subject than the actual position of the moving object.

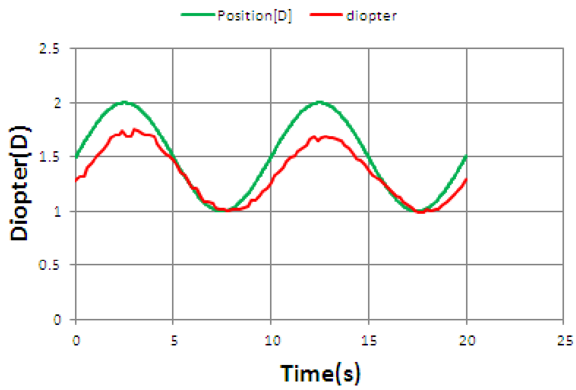

Fig.8 The average of accommodation: young subjects (n=31)

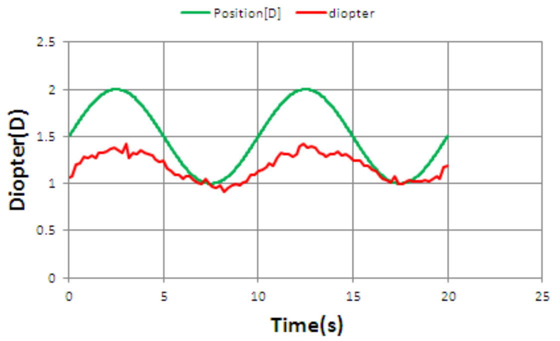

Fig.9 The average of accommodation: middle-aged subjects (n=13)

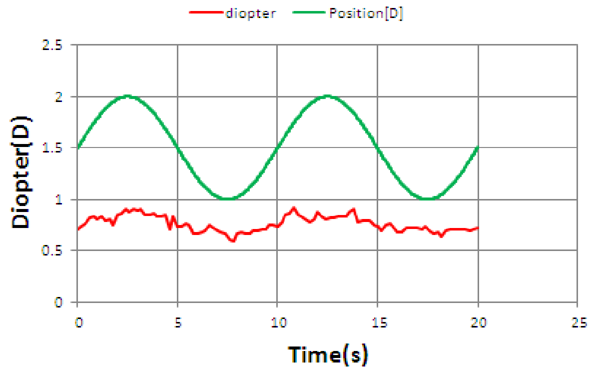

Fig.10 The average of accommodation: elderly subjects (n=3)

Figure 11 shows the average value of the position of accommodation of 2.5 seconds cycle in the younger subjects. We used the results of the measurement from the subjects which had less error of 2 out of 4 cycles There were 25 out of the 64 younger subjects who met the conditions. As with the typical example in Figure 4, the adjustment changed according to the distance of the moving object.

However, this data for younger subjects contrasts with the average value of the accommodation of middle-aged people and elderly people (Figs 12-13). The data for 12 out of 37 middle-aged subjects shows that when the position of an object is 2 D in front of view, the accommodation adjusted to 1.34 D on average. When compared with the results of 10 seconds cycles in middle-aged persons (Fig.9), the focal length of accommodation did not approach the actual position of the real object. For the data of 6 out of 34 elderly subjects, as can be seen in Fig.13, the position of accommodation did not change much.

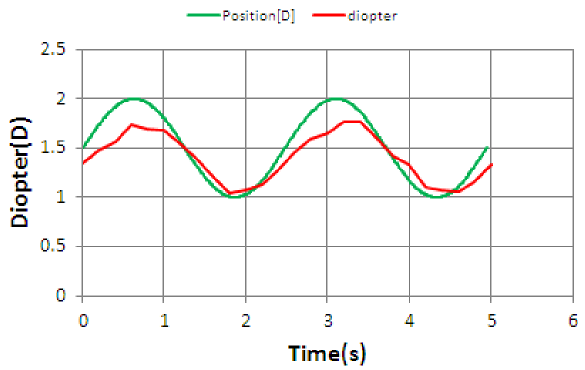

Fig.11 The average of accommodation: young subjects (n=25)

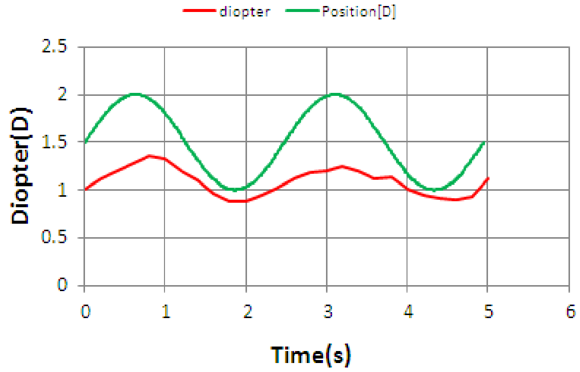

Fig.12 The average of accommodation: middle-aged subjects (n=12)

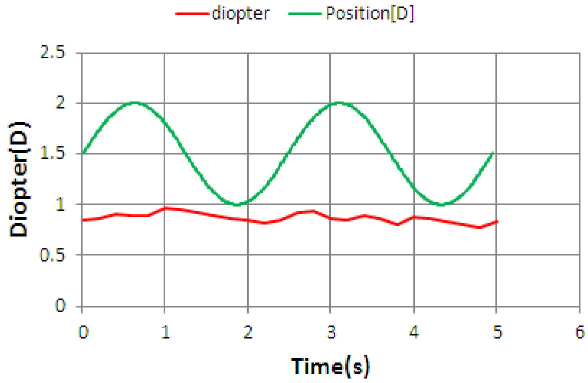

Fig.13 The average of accommodation: elderly subjects (n=6)

IV. Discussion

First, from a typical example of an average of 10 seconds cycles (Fig.2-3, 8-10), accommodation of the subject is synchronized with the movement of the moving object that they gazed upon. In particular, the accommodation of younger subjects (Fig.8) almost coincided with the position of movement of the moving object. In the middle-aged group, the difference between the position of the accommodation and the moving object increased. Furthermore, among the elderly group, accommodation changed at a position further than the actual position of the object. From these results, although lens accommodation among the younger subjects functioned well, as age increased there was a lack of regulation force affected by presbyopia.

In addition, the pupil diameter among the younger group did not change much (Fig.2). On the other hand, in the case of the elderly, the pupil diameter decreased when they gazed close to moving objects. By shrinking the pupil in order to compensate for the shortage of regulation, elderly people change the depth of field.

Patterson et al discussed the depth of field in detail, finding that when the depth of field was large, the average total depth of focus was on the order of 1.0 diopter [6, 7]. Based on this value, the range of total depth of field would be from a distance of about 0.1m in front of a fixed point to about 0.17m behind the fixed point of 0.5m. For a fixed distance of 1 m, the total depth of field would be from a distance of about 0.33m in front of the point to about 1.0 m behind the point. For a fixed distance of 2 m, the total depth of field would be from about

1m in front of the point to an infinite distance behind the fixed point.

These scholars also reported that the depth of field was affected in various ways by the pupil diameter and resolution. Other researchers found that pupil diameter was slightly over 6 mm for a luminance level of 0.03cd/m2 and near to 2 mm for a luminance level of 300cd/m2. For each millimeter of decrease in pupil size, the depth of field increases by about 0.12 diopters [6, 8].

From the above, even if eyes are not exactly in focus, we think subjects can see the visual target. We can say the same thing about pupil contraction in the step movement.

From the results of 2.5 seconds cycle, accommodation of the position of the younger subjects was almost identical with the position of the moving object (Fig.4, 11). In the case of advanced age, as can be seen from a typical example (Fig.5) and the average (Fig.13), the change in accommodation is smaller. When the movement of an object is too fast, elderly subjects found it difficult to follow the regulation.

As age increased, the position of accommodation was further from the position of the moving object. This is true both in the measurement result of the cycle of 2.5 seconds and 10 seconds. Therefore, it is considered that lens accommodation weakens by age (by presbyopia) [1-3].

V. Conclusion

In this experiment, we found differences between the pupil diameter of younger and elderly subjects as they viewed moving objects. When a younger subject gazed upon a moving object, their accommodation followed it depending on the position of the moving object. Because lens accommodation among younger subjects functions well, there is no visible shrinkage in pupil diameter. In the case of elderly subjects, the shrinkage of the pupil was confirmed as they focused further than the actual position of the object. Elderly people deepen the depth of field by the contraction of the pupil, and we think that they can gaze upon moving objects even if their regulation is weak by presbyopia.

Because the reference data decreased with age, we plan to take a lot of data in the future.

Acknowledgment

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References

[1] A. Glasser & P. L. Kaufman, 2003. Chapter 7. Accommodation and Presbyopia. P. L. Kaufman & A. Alm, Ed., Adler's Physiology of the Eye. Clinical Application. Mosby, Inc., St. Louis, Missouri, USA.

[2] Stark L. 1987. Presbyopia in light of accommodation. In Stark L., Obrecht G. (Eds), Presbyopia, pp 264-274. New York: Professional Press.

[3] Sun F., Stark L., Lakshminarayanan V., Wong J., Ngugen A., Mueller E. 1987. Static and dynamic changes in accommodation with age. In Stark L., Obrecht G. (Eds), Presbyopia, pp 258–263. New York: Professional Press.

[4] A. Queiro’s, J. Gonza’lez-Me’ijome and J. Jorge, 2008. “Influence of fogging lenses and cycloplegia on open-field automatic refraction.” Ophthal. Physiol. Opt. 28, 387–392.

[5] A. L. Sheppard and L. N. Davies, 2010. “Clinical evaluation of the Grand Seiko Auto Ref/Keratometer WAM-5500.” Ophthal. Physiol. Opt. 30, 143–151.

[6] R. Patterson, “Human factors of stereo displays: An Update.” Journal of SID, 17, 12, pp987–996, 2009

[7] B. Wang and K. J. Ciuffreda, 2006. “Depth of focus of the human eye: Theory and clinical applications.” Surv. Ophthal. 51, 75.

[8] K. N. Ogle and J. T. Schwartz, 1959. “Depth of focus of the human eye.” J. Opt. Soc. Am. 49, pp273–280.