Development for Tablet-Based Perimeter Using Temporal Characteristics of Saccadic Durations

Naoki Maeshiba(✉), Kentaro Kotani, Satoshi Suzuki, and Takafumi Asao

Department of Mechanical Engineering, Kansai University, Suita, Japan
{k238630,kotani,ssuzuki,asao}@kansai-u.ac.jp

Abstract. Visual field examination is essential for the early detection of glaucoma. The purpose of this study was to construct a visual field inspection system using a tablet terminal for early detection of glaucoma. In this study, the presentation time of numbers used for visual recognition was optimized to construct a visual field inspection system using a tablet terminal. The optimization was based on human optical characteristics. That is, experiments clarified the relationship between the viewing angle and the presentation time of numbers, and the optimal presentation time at the presentation position of each target was obtained. Next, to evaluate the effectiveness of the optimized system, a visual field test was performed using a tablet-type perimeter to incorporate the system, and the accuracy of Marriott blind spot detection was obtained as a substitute index for the visual field abnormality. As a result of the evaluation experiment, the detection rate of Marriott blind spots was 66.7%. In this paper, we discuss the detection rate of Marriott blind spots and individual differences. In conclusion, it was shown that the accuracy of visual field measurement was improved by using the perimeter that incorporates the proposed system.

Keywords: Glaucoma · Perimeter · Saccade

1 Introduction

Glaucoma is the leading cause of blindness in Japan, with 1 in 20 Japanese over 40 years old having glaucoma [1]. Glaucoma is a disease in which the visual field is narrowed due to optic nerve damage. Since the prevalence increases with age, the number of glaucoma patients increases as the elderly population increases [2]. In general, there are almost no subjective symptoms in the early stage of glaucoma, and the symptoms may have considerably progressed when it is noticed that vision loss or visual field loss occurs. The current mainstream treatment method for glaucoma is to prevent the progression by prescription of eye drops to reduce the elevated intraocular pressure. However, in the current medical treatment, it is essential to detect the disease early because it is not possible to recover the lost visual acuity or restore the visual field [3]. Therefore, a device that can adequately determine the presence or absence of glaucoma development is needed.

Devices such as Goldmann perimeter and Humphrey perimeter have been introduced as typical ones in the clinical field. These perimeters are medical devices for diagnosing

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the progress of visual field defects and do not function as consumer devices that promote early subjective symptoms. Furthermore, these perimeters are required to continue to fixate one point for 10 to 20 min for the examination of one eye due to the measurement principle peculiar to the perimeter. As a result, the patient's concentration decreases during the test, and it is challenging to keep their eyes on from the fixation point, which increases the burden on the patient [4]. Also, it has been reported that in preschool children and the elderly, the test procedure is often difficult to understand, and the test results are not reliable [5]. Furthermore, these perimeters have a mechanism in which the patient operates the button based upon the subjective judgment of the patient. There may be a substantial delay in time, which causes the problem that the reliability of the test results becomes low [5]. Another problem with the current mainstream perimeters is that they are installed only in large hospitals with ophthalmology because they are relatively large-scale devices. Therefore, there is a problem that glaucoma patients with no subjective symptoms do not have the opportunity to undergo the examination. We have solved these problems and developed a small visual field inspection system using a tablet terminal that can easily measure the visual field for early detection. Tablet terminals can be carried at a low cost. They can be used in situations such as homes, waiting rooms at clinics as well as remote locations [6], thus increasing the number of opportunities for visual field examination.

In the proposed system, we developed a Superimposed fixation pattern to solve the difficulty of keeping the patient gazing at the fixation point. The superimposed fixation pattern [4] works effectively because there is the principle of the visual field, defining that the visual field around the target is constant if the optical axis captures the target. Using this principle, it is possible to extract the visual field area only by moving the line of sight naturally. This natural behavior-based technique eliminates the need to gaze at one point for a long time, shortens the examination time, and reduces the burden on the patient.

Furthermore, we decided to introduce the voice recognition function to automatically evaluate whether or not the user correctly recognized the target, instead of users' subjective evaluation. Previously, we proposed a system for objective visual judgment by determining whether the numbers presented after the target presentation could be read out correctly. If the numbers were read out correctly, it was determined that eye movements were performed appropriately. The size of the target was the same as the target used in a conventional perimeter. However, the numbers presented after the target had to be displayed relatively large so that the patient could read without stress. Then, even though the target itself was not visible due to the visual field abnormality, the number presented right after the target disappeared may be perceivable due to its large size. As a result, eye movement occurs after perceiving a number, and vocal data is recorded by chance. When such an unexpected eye movement occurs, the area that should be judged to be abnormal visual field may be misdiagnosed as "area without visual field abnormality." We analyzed the temporal factors related to the target and number presentation that caused this misdiagnosis. As a result, this problem would be solved by optimizing the target presentation time and the number presentation time, respectively. The time required for eye movement is related to the distance between the fixation point and the target, as well as the distance between the eye and the display. In this study, the viewing angle is used as an index to express the distance from the fixation point to the target position.

In this study, we conducted an experiment to optimize the presentation time of numbers used in the developed visual field measurement system and clarified the relationship between the presentation time of numbers and the viewing angle of a person. This experiment and its results are summarized as Experiment 1. Furthermore, we improved the tablet-type visual field inspection system that introduced the optimum presentation time determined in Experiment 1. The evaluation experiment of this system and its results are summarized as Experiment 2.

2 Proposed System for Optimizing Presentation Time of Targets and Numbers for Voice Recognition

We developed a tablet-based perimeter for screening diseases such as glaucoma. This system consists of a tablet terminal with a visual field inspection app, a stand for fixing the tablet terminal, and a visual field drawing PC. MATLAB is used to generate the visual field from the inspection results. For the tablet terminal, Apple's iPad 6th Generation Wi-Fi (MR7G2J/A) was used.

Application for the perimeter was developed by based on Swift. The application works for the following steps:

1. When the app is started, a fixed viewpoint is presented on the tablet display as shown in Fig. 1. The patient gazes at the fixation point.
2. After a certain time, target 1 (T1) is presented in the predetermined visual field. The patient maintains his/her gaze at the fixation point and moves the gaze from the fixation point to the target when the presented T1 is perceived.
3. After the saccade is generated toward the location that T1 was presented, the target changes to the number, which is defined as target 2 (T2), shown in Fig. 1. The patient then reads out the number displayed at that position. Speech recognition system equipped on the tablet stores the value read by the patient.
4. T2 changes to a new fixation point and the patient repeats a series of procedures.

If the patient cannot see T1, the fixation point being focused disappears, and a new fixation point is presented at the same time. The system records the target that the patient could not perceive as suspected that potential visual field defect in the corresponding area might exist in the area of T2 vicinity.

The system covers a total of 54 locations of the whole visual field to be tested and it takes about five minutes for completing to test all locations for each eye. After completing the session, this system judges the visual field loss state by comparing the patient's answers stored by the voice recognition function with the presented numerical values and constructs the entire visual field image.

The coordinate position for the visual field examination used in this system was the same as that defined by the "center 24-2" used in Humphrey's perimeter, a visual field diagnostic device routinely used in ophthalmic practice. In this system, inspection positions were covered to draw the visual field within a viewing angle range of ±30°.

The fixation point was drawn as a red circle, and T1 was drawn as a black circle. One out of five single-digit numbers from 0 to 4 was shown as the T2 display. The size of the fixation point and the target T1 was the same as Goldman type-III (diameter: viewing angle 0.45°) used in Humphrey perimeter, and the number shown at T2 area was appeared at the center of the square. To make it easier for patients to read the numbers on the display, T2 is displayed at a viewing angle of 1.5° which is larger than the target T1. The time from duration between when the fixation point was presented and when T1 was presented was randomly determined from 2.5 s, 3.0 s, and 3.5 s. Also, DT1, which was the presentation time of T1, was randomly selected from 1.5 s, 2.0 s, and 2.5 s. This randomization was to prevent the generation of eye movements at the same tempo unintentionally by making the variable onset time of the target.

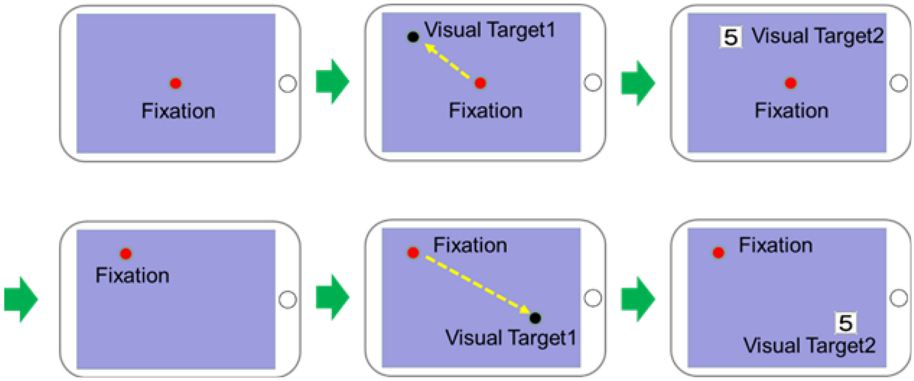


Fig. 1. Relationship between screen transition and subject's reaction when using visual field analyzer application developed in this study.

3 Experiment 1

3.1 Objective of the Experiment

In the proposed system, it was judged that T1 could be visually recognized if T2 was read out correctly, and then it was evaluated as a "normal visual field area." On the contrary, if it was judged that T1 could not be visually recognized even though T2 was correctly read out, it was evaluated as a "abnormal visual field area". In other words, the judgment of the visual field defect of this system depended on the logic that T2 is read out only when the patient can see T1. However, since T2 was presented with a larger size than T1 so that the appearance of numbers can be detected without saccadic eye movement. In this case, T1 was not visible, so it had to be judged as a "abnormal visual field area" (Fig. 2). In other words, if the patient could not see T1 and changed to T2 and then saw T2 and performed a saccade, the target presentation time DT2 had to be set so that T2 could not be perceived, described as shown in Fig. 3, case 1. On the other hand, when the viewing angle was large, it seemed that the time required for saccade has become longer, and when DT2 was too short, T1 was visible, but T2 cannot be recognized (Fig. 3, case 2). Therefore, in order to introduce the target presentation time considering these viewing angles and saccadic duration, the purpose of this experiment was to find the optimum DT2 for each viewing angle.

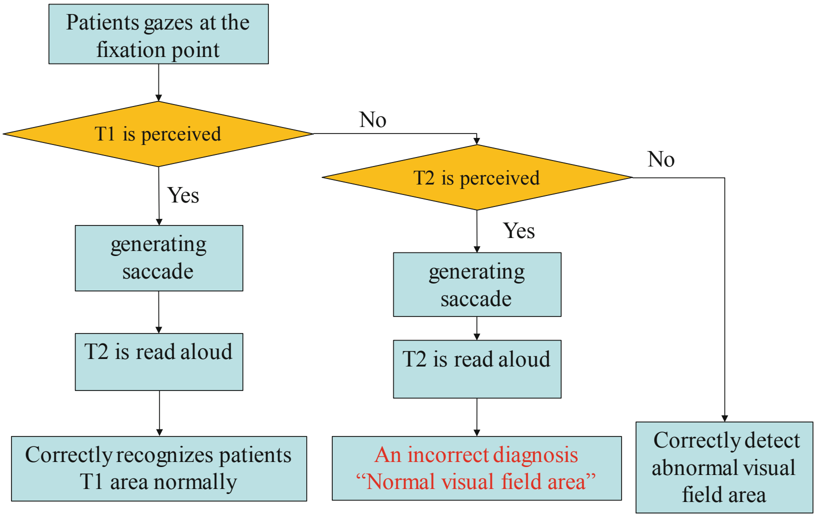


Fig. 2. Flowchart for patients' actions and system response

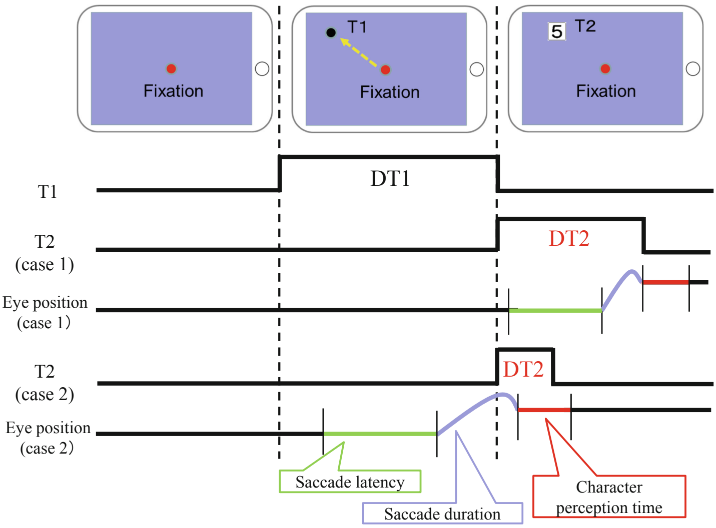


Fig. 3. Time chart of the proposed system. Eye position at the top indicates the case when T1 was recognized and eye position at the bottom shows the case when T1 was not recognized and T2 was recognized.

3.2 Participants

The participants were six healthy university students (21 to 22 years old). Both eyes were measured, and each eye was measured in order. The vision correction status of the participants was as follows: 1 person with eyeglasses, two persons without vision correction, and three persons with contact lenses.

3.3 Experimental Apparatus

The experiment consisted of a PC (Dell Inspiron 3470) for image presentation and a monitor (24 inch). The size of the monitor was 50 cm × 26 cm, and the monitor was placed 480 mm away from the participants. Generation and presentation of the target stimulus used in the experiment and time management were performed by a program created in Unity. The experimenter confirmed the recording of the speech data of the participants.

3.4 Experimental Condition and Data Analysis

The fixation point and T2 (visual stimulus composed of numbers) were presented on the monitor. The fixation point always existed in the center, and T2 was shown on the circumference centered on the fixation point. The size of T2 was presented at a viewing angle of 1.5°. The T2 showed on the monitor and responses made by participants were recorded on the PC with assistance with experimenter in chronological order.

The independent variables were 1) viewing angle (degrees) and 2) presentation time DT2 (seconds). The viewing angle was the geometric angle from the fixation point to the location of presentation stimulus T2 (Refer to Fig. 4). Since the maximum viewing angle of the proposed system described in Sect. 2 was set to 30°, the viewing angle level was set to 6 patterns in 5° increments in the range of 5 to 30°.

The presentation time DT2 was set as the duration of T2. Focusing on human visual characteristics, the levels of DT2 were 6 levels of 0.4 s, 0.3 s, 0.25 s, 0.2 s, 0.15 s, and 0.1 s. This experimental model has three possible visual characteristics: saccade latency, saccade duration, and character perception time (Fig. 3). The time from the recognition of the target to the start of the saccade (latency) is generally said to be about 200 ms in a normal person without knowing the location of the target in advance [7]. The duration required for gaging movement with a viewing angle of 10° is about 110 ms [8]. Besides, the time required to recognize a number is about 100 ms [9] for a single digit. Therefore, the time needed to perceive a number after saccade generated by visually identifying T2 with peripheral vision is about 410 mseconds. In other words, T2 can be visually recognized in about 410 ms by a healthy person, and the problem of misdiagnosis shown in Fig. 2 occurs, thus we decided to consider DT2 as 0.4 s or less. On the other hand, it is necessary to set DT2 longer than 0.1 s because it takes about 0.1 s to recognize a single-digit number [9]. In the proposed system, T2 can be identified if DT2 is set to 0.1 s. However, if DT2 is 0.1 s at all target positions, problems such as case 2 shown in Fig. 3 are expected to occur. Therefore, it is necessary to give DT2 a time margin at the target position where the viewing angle is large. All in all, DT2 is set in the range of 0.1 s to 0.4 s, and the optimum value of DT2 was obtained from this range by experiments.

As a dependent variable, we defined accidentally identified rate as the rate of the correct verbal response of the numbers presented on the monitor among participants without taking proper steps. If DT2 becomes small, the time margin for recognizing the number decreases, thus the accidentally identified rate decreases. Also, the viewing angle affects the saccade distance. Since the time required for saccade increases as the saccade distance increases, the viewing angle is also an essential factor for setting DT2. Consequently, it was decided to experimentally verify the optimum value of DT2 using the viewing angle and the accidentally identified rate.

The viewing angle was presented four times for each level of DT2, and DT2 was evaluated at six levels, that is, 24 trials were performed per participant.

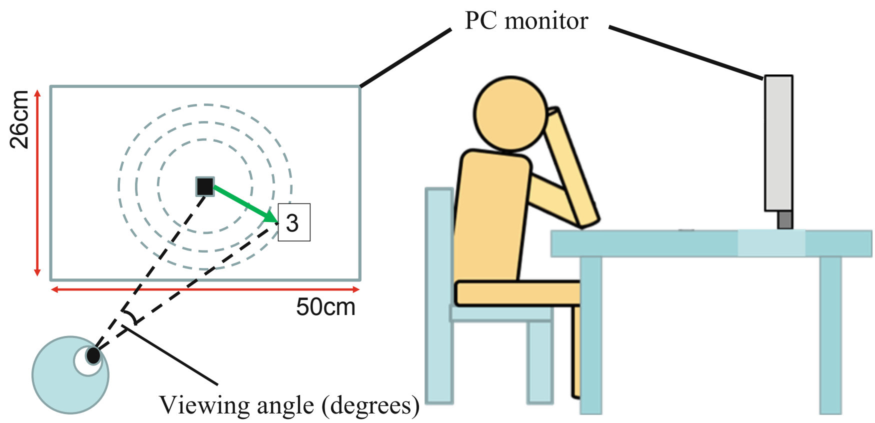


Fig. 4. Experimental condition

3.5 Experimental Procedure

The experimental procedure was as follows.

1. Participants were informed about inspection procedures 2) to 6). Participants were instructed (1) not to move their line of sight to anything other than the fixation point and the presented number, (2) not to move the position of the head or body, and (3) not to speak words other than the numbers.
2. The participants adjusted the position of their heads and took the posture of hiding their eyes opposite to the examination eye, with their hands and placing their elbows at the table. The experiment started from the right eye. Participants instructed to gaze at the fixation point displayed in the center.
3. First, a practice trial was conducted under the condition that DT2 was set to 0.5 s. The practice trial encouraged participants to understand the examination method. The results of the practice trials were not recorded.
4. After the practice trial, the experiment started.

5. Participants perform saccades when the numbers presented can be seen by peripheral vision, and read out the numbers when they are visible. If the participant could not see the number, he voiced it. After that, the viewpoint was returned to the central fixation point, and the next number was presented.
6. The experimenter recorded the numbers read out by the participants (or the answer that they could not see).

3.6 Results

Figure 5 shows the relationship between the presentation time DT2 for each viewing angle, and the average accidentally identified rate of the left and right eyes of all participants. Accidentally identified rates at 6 levels of DT2 = 0.1 s to 0.4 s are plotted. The purpose of Experiment 1 was to determine DT2 to minimize the risk of the misdiagnosis shown in Fig. 2. Based on this result, we conclude that it is appropriate to select DT2 with an accidentally identified rate of 0%.

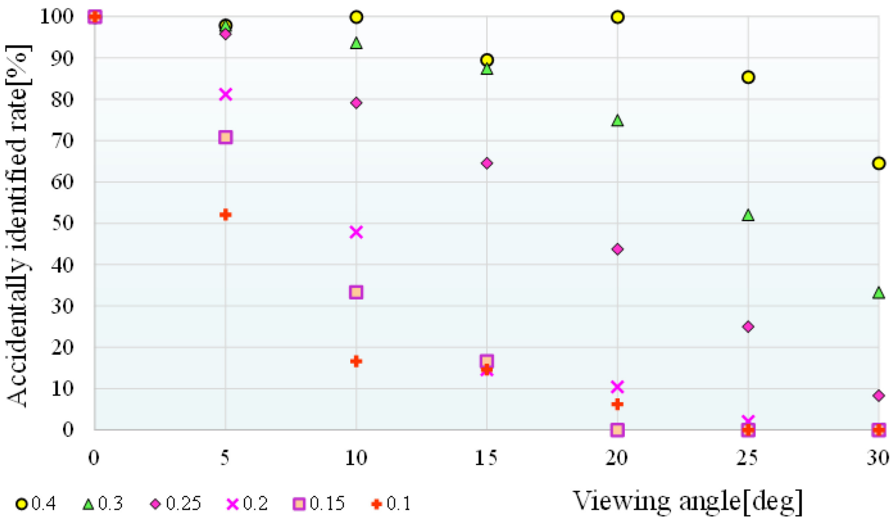


Fig. 5. Relationship between viewing angles and accidentally identified rate

In consideration of case 2, the largest value in the range of DT2 discussed in Fig. 2 was selected. According to Fig. 5, DT2 was in the range of 0.1 s to 0.2 s when the viewing angle was 30°, and the accidentally identified rate was 0%. Similarly, at a viewing angle of 25°, only 0.1 s to 0.15 s and at a viewing angle of 20° were 0.15 s. Therefore, DT2 at a viewing angle of 30° was set to 0.2 s, and DT2 at a viewing angle of 25° and a viewing angle of 20° was set to 0.15 s.

As a result of the experiment, there was no DT2 with an accidentally identified rate of 0% in the viewing angle range of 15° or less. Therefore, the optimum value of DT2 was discussed in the previous study. According to Obama et al. [10], the visual system was capable of recognizing characters presented within a radius of about 10° with the fixation point at that time as the center when the saccade was not programmed. In other words, T2 presented within 10° can be recognized unless the presentation time was set to 0.1 s or less (the time required for character recognition [9]). However, when DT2 was set to less than 0.1 s, it was considered that T2 could not be recognized even if T1 was generally recognized during the examination; thus, it was not suitable as a visual recognition condition. Therefore, it was necessary to set DT2 to a value exceeding 0.1 s. Therefore, the minimum value of DT2 was set to 0.1 s within the viewing angle of 10°. Finally, for 15°, DT2 has almost the same accidentally identified rate in the time range from 0.1 s to 0.2 s; thus, we examined which time should be appropriate. According to Fukuda [11], the appearance of letters in peripheral vision varies depending on the presented retinal region. Among them, 6.5° to 16° is defined as the far fovea. With this definition as a reference, DT2 = 0.1 s was set for a viewing angle of 15°, similar to 10° (Table 1).

Table 1. Relationship between viewing angles and the duration of T2 onset (DT2)

Viewing angles (degrees)	Duration of T2 onset (DT2) (seconds)
26–30	0.2
17–25	0.15
1–16	0.1

The following points should be noted regarding the results of Experiment 1.

1. In the result of Fig. 5, when T2 was vaguely seen, the answer of T2 contained guess or was not visible. There is an error due to individual decision making.
2. There was no value at which the accidentally identified rate was 0% in DT2 with a viewing angle of 15° or less. Therefore, when the visual field inspection was performed by actually operating this system, the range in which the problem in Fig. 2 did not completely occur, that is, the range in which the error was not included, was a viewing angle of 20° or more.

4 Experiment 2

4.1 Objective

We developed a tablet-type visual field inspection system that introduced the presentation time DT2 determined in Experiment 1. In Experiment 2, the effectiveness of the improved visual field inspection system was verified. In this experiment, healthy university students were recruited as experiment participants. In general, visual field inspection detects visual field abnormalities, and healthy people often do not have visual field abnormalities. Therefore, we decided to evaluate whether the Marriott blind spot, which is a physiological blind spot in humans, can be accurately detected. If the Marriott blind spot can be detected properly, it can be suggested that the inspection system detected the abnormal field of view, and the system's effectiveness can be shown [12].

4.2 Participants

The participants were eight healthy university students (21 to 22 years old). Only the right eyes were evaluated. The participants' vision correction status was as follows: 4 persons with eyeglasses, two persons without vision correction, and two persons with contact lenses.

4.3 Experimental Condition

Number of targets was presented to the Marriott blind spot was three times in one examination. The viewing distance from the tablet device was 320 mm. Figure 6 shows the experimental environment. An eye patch was attached to the unexamined eye. Participants were seated in a position where the right eye was in the center of the tablet. Since the face may move during the examination, we used a system that suspends the test when the position of the face changes to an area where the Marriott blind spot can be seen and prompts the re-correction of the face position. The developed system was designed to stop when the viewing distance between the front and rear is 275.9 mm to 380.9, and the left and right are over 320 tan 2.5° (radius 13.97 mm). In Experiment 2, we evaluated the target presentation scheme, thus, decided not to use the voice recognition function, but to record the numbers spoken by the participants manually.

Since the Marriott blind spot's position may slightly vary from person to person, we measured the visual distance at which the information about the Marriott blind spot was not visually obtained for each subject. The target was presented at the center of the tablet terminal and the Marriott blind spot, and the viewing distance was measured. The Marriott blind spot is assumed to be a circle with a center (horizontal 15°, vertical 3°) and a diameter of 5°. Lmin is the minimum visual distance at which the target at the blind spot is invisible, while Lmax is the maximum distance. (See Fig. 7)

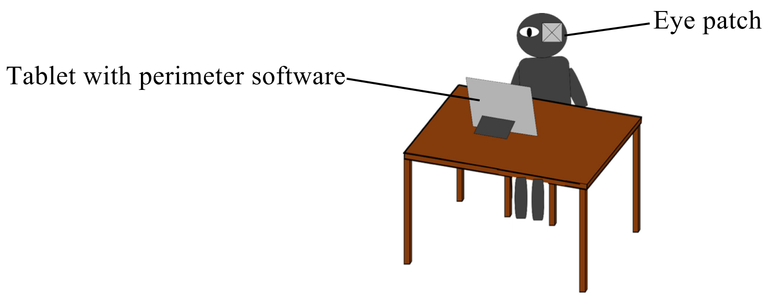


Fig. 6. Experimental condition

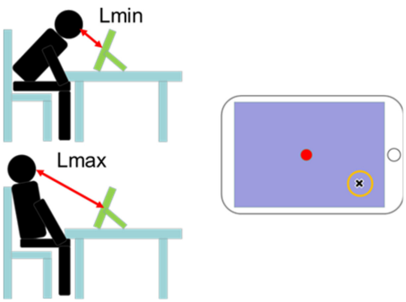


Fig. 7. Viewing distance measurement

4.4 Experimental Procedure

The inspection procedure was as follows.

1. Participants received an explanation about inspection procedures 2) to 6). Participants were instructed (1) not to move their line of sight to anything other than the fixation point and the presented number, (2) not to move the position of the head or body, and (3) not to speak words other than the numbers.
2. Participants put the eye patch on their left eye and took a comfortable posture.
3. The position was adjusted so that the distance from the eye to the tablet surface was 320 mm.
4. The application was started, and the practice trial started. The practice trial encouraged participants to understand the examination method.
5. After the practice trial, the visual distance of 320 mm was measured again, and the primary inspection (target: 54 points) was performed.
6. The visual recognition results were shared with the PC, and the inspection results were printed.
7. Participants' visual distances Lmin and Lmax were measured.

4.5 Results

Figure 8 shows the correct detection rate for Marriott blind spots. Since the Marriott blind spot was originally a physiological blind spot in humans, the rate at which the test points presented to the Marriott blind spot were invisible was defined as the correct detection rate for Marriott spot. Figure 9 shows the results of visual field inspection (Participants A and D only). From Fig. 8, the detection rate of the Marriott blind spot position for all participants was 66.7%. Figure 10 shows the measured Lmin and Lmax for each participant. According to Fig. 10, it was found that the values of Lmax and Lmin and the difference between the maximum and minimum viewing distances (Lmax – Lmin) differ for each individual.

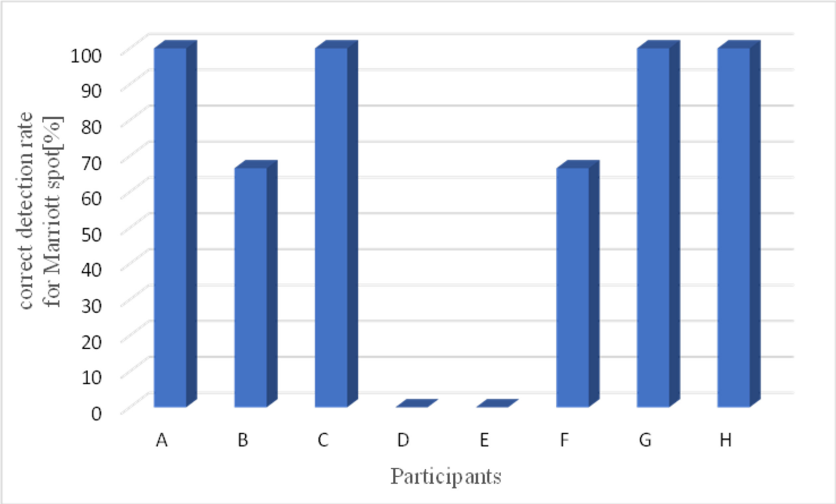
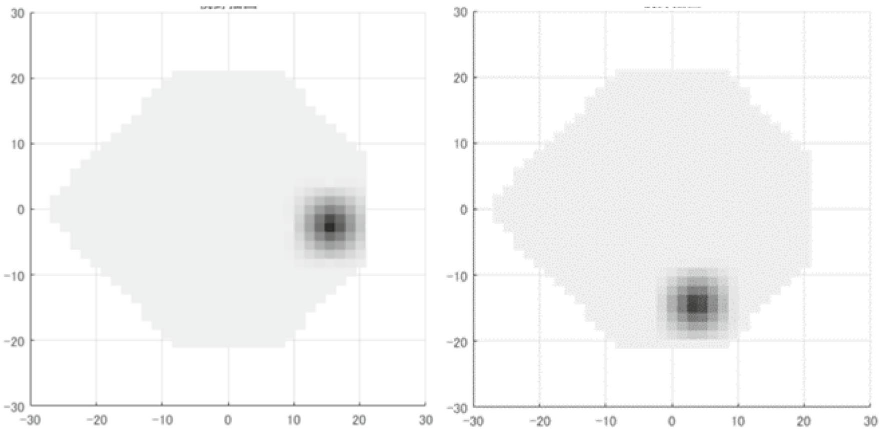


Fig. 8. Correct detection rate for Marriott blind spots



Participant A Participant D

Fig. 9. Results of visual field examination (Participant A and D)

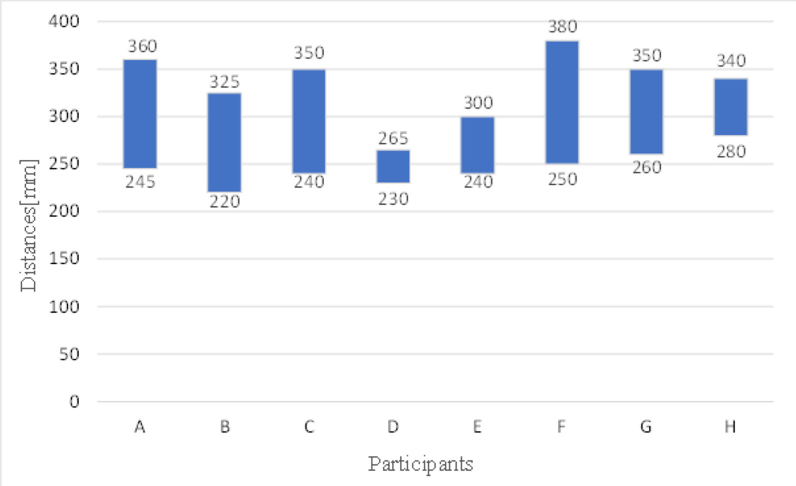


Fig. 10. Viewing distance and the range which target presented at Marriott blind spot is invisible for each participant

4.6 Discussion

There are three possible causes for the target to be visible at the Marriott blind spot position, which should not be theoretically visible.

1. The Marriott blind spot is located about 15° to the right of the right eye. In this system, the erroneous recognition shown in Fig. 2 may occur in the range of 20° or less that covers the Marriott blind spot, as described in (3–6).
2. During the examination, the participants were gazing at the fixation point and waiting for the target to be displayed somewhere on the screen. However, there were cases where blinking occurred while gazing at the fixation point. When blinking, the eyeball may move and deviate from the fixation point, and the target may be visible at that moment.
3. As can be seen in Fig. 8, it was found that there were some participants who could see all the targets presented at the Marriott blind spot. In addition, Fig. 10 suggests that the position of the Marriott blind spot varies greatly among individuals.

In this experiment, the visual distance between the eyes and the monitor was set to 320 mm. As shown in Fig. 10, in the case of participants D and E, the distance of 320 mm is outside the range of the Marriott blind spot, that is, the distance is visible even if the target is presented at the position of the Marriott blind spot. The results of the experiment confirm that participants D and E set the viewing distance at which the information presented at the blind spot was visible. For eliminating the variation between individuals, the detection rate was recalculated using the data of 6 people, excluding the data of these 2 participants and was 88.9%. In the study by Kobayashi et al. [13], 81.6% of the central positions of the Marriott blind spots were measured by visual field measurement using a Goldmann perimeter, which suggests that the present system was also appropriate.

5 Conclusion

In this study, we developed a visual field inspection system for the early detection of glaucoma. This system presents numbers in a size that is easy to visually recognize after the target offset so that the objective visual judgment can be performed. In this paper, the target presentation time DT2 was optimized based on the physiological characteristics of human saccades. Experiment 1 was performed to obtain the quantitative information necessary for optimization. For 6 participants, we obtained the accidentally identified rate when the viewing angle DT2 corresponding to the viewing distance moving in the saccade and the presentation time DT2 were changed. Based on the results of Experiment 1 and previous studies, the optimum presentation time DT2 for each viewing angle was DT2 = 0.1 s for viewing angles 1 to 16°, DT2 = 0.15 s for viewing angles 17 to 25°, and DT2 for viewing angles 26 to 30° = 0.2 s.

Furthermore, in Experiment 2, we conducted visual field inspection using the developed visual field inspection system and focused on the detection rate of Marriott blind spots, and examined the effectiveness of the system. As a result, the detection rate of Marriott blind spots was 66.7%.

There were three possible reasons why the target presented on the Marriott blind spot, which should not be perceived originally, was accidentally visible. First, there was an accidental saccade that cannot be covered by just optimizing the presentation time of the two types of targets, and second, there was a case in which the participants may have looked away from the fixation point. And, finally, it was inferred that there were cases where the individual differences in the position and shape of the Marriott blind spot could not be covered in this study. Therefore, we asked each participant to maintain the invisible state of the target presented at the theoretical Marriott blind spot position and observe the maximum and minimum values of the visual distance in that state. Then, it was found that the size and range of the viewing distance differed significantly among the participants. In particular, it was found that there was a participant who could see the target even if the target was presented at the theoretical position of the Marriott blind spot with the visual distance of 320 mm set as the experimental condition. The detection rate of Marriott blind spots was 88.9% when those participants were excluded.

In conclusion, the effectiveness of the proposed visual field inspection system was demonstrated. Although some participants could accidentally see the targets presented to the Marriott blind spot, it was thought that this was primarily due to individual differences among the participants. However, note that the visual field inspection practically did not aim at the detection of blind spots. The visual recognition of blind spots in this report did not lead to the conclusion that the visual field inspection system was unreliable. On the other hand, the existence of the gap between the Marriott blind spot positions among individuals suggested the necessity of system improvement in the future. It was considered that grasping the position and shape of the Marriott blind spot for each individual was a point to be solved for the generalization of the proposed system.

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