〈Regular Article〉

Development of a screening system for central visual field using the eye-tracking device

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ABSTRACT　**Background**: Visual field test with gaze movements do not require a subjective response because they are based on reflexive movements. In this study, we developed a visual field test system with gaze movements to perform a central visual field screening, and then examined the reproducibility of the measurements in healthy adult volunteers.

Methods: We examined 30 right eyes of 30 healthy volunteers (mean age, 22.7 ± 5.2 years) with a best-corrected visual acuity of at least 20/20. Gazefinder, an eye-tracking device, was used to measure gaze movements. Subjects with refractive correction were asked to follow a white target presented on a monitor. If a subject can accurately perform eye tracking with respect to the visual target, visual field with gaze movements measurements are theoretically possible in eight directions (horizontal/vertical to 15.3° and oblique to 21.5°). After a total of three measurements, the data were quantified using analysis software (CreateChart). Finally, the intraclass correlation coefficients of the measurement values were obtained.

Results: The difference between theoretical and actual measurement values, which is thought to reflect gaze accuracy, were −0.1° ± 0.9° for upper, −0.6° ± 1.0° for upper right, −0.2° ± 1.0° for right, −0.8° ± 0.9° for lower right, −0.5° ± 0.7° for lower, −0.5° ± 0.9° for lower left, −0.6° ± 0.5° for left, and −0.6° ± 0.5° for upper left. No significant differences were found among the eight directions, and gaze accuracy was high, at within 1°. The intraclass correlation coefficients were 0.6 or higher in each direction ($P < 0.01$), indicating high repeatability.

Conclusions: In the traditional method for measuring visual field with gaze movements, the fixation point of view needs to be reset for each gaze movement. On the other hand, the system developed in this study has the advantage of not requiring eye movements to return to the

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fixation point. The present findings indicate that our newly developed system is a useful device when standard perimetry is difficult to measure.

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Key words：Visual field, Gaze movement, Eye-tracking device

INTRODUCTION

A steady gaze at a central target and a subjective response are required for standard perimetry, which makes it difficult to quantify the visual field in patients who have difficulty cooperating with examinations, such as infants and patients with intellectual and/or severe disabilities. Therefore, a visual field measurement method that can solve this problem is needed. The use of a visual field test with gaze movements may enable the development of such a method for visual field examinations[1, 2]. A visual field test with gaze movements is a method for evaluating whether the visual field is normal or abnormal based on whether or not the visual target presented in the visual field can be tracked accurately. Mutlukan and Damato measured the visual field in normal child gaze movements[2]. This involved presenting a randomly moving visual target on a monitor and instructing subjects to use a joystick to move a circle on the monitor to always enclose the randomly moving target[2]. As a result, they reported that visual field evaluation including blind spot detection was possible in 75% of cases.

The visual field test with gaze movements does not require a fixed viewpoint. The evaluation of visual field with gaze movements is based on reflexive gaze movements at the peripheral visual target. Such reflexive gaze movements are observed even in infants[3-5] and patients with cognitive impairment[6]. The principle of the visual field test with gaze movements is based on the idea that the visual field with gaze movements must be present at the destination of the reflexive gaze. Therefore, in the visual field test with gaze movements, it is not necessary for subjects to push a button, which is needed in standard perimetry, and thus may be useful in examining visual field with gaze movements in patients who find it difficult to provide a subjective response.

Murray *et al.* developed a display-type equipment for measuring visual field with gaze movements with an eye tracker (Saccadic vector optokinetic perimetry, SVOP) and reported a strong correlation with the Humphrey field analyzer[7-13]. SVOP requires about 6 minutes for one measurement because the fixation point of view needs to be reset for each gaze movement. Therefore, it may be difficult to perform measurements if the patient does not fully understand the test.

In the present study, we developed a visual field-testing system with gaze movements that records gaze movements via a light stimulus search task that does not require eye movements to return to the fixation point. The system also includes analysis software that can quickly quantify the measurement results. This measurement system is designed for screening central visual field measurements of approximately 20 degrees. Therefore, we investigated the reproducibility of the measurements in healthy adult volunteers.

MATERIALS AND METHODS

We examined 30 right eyes of 30 healthy volunteers (16 eyes in 16 women, 14 eyes in 14 men) who provided consent to participate in the study from July 2021 through April 2022. The inclusion criterion was having a best-corrected visual acuity of at least 20/20. Individuals with a history of any of the following disorders were excluded: glaucoma, cataract, age-related macular

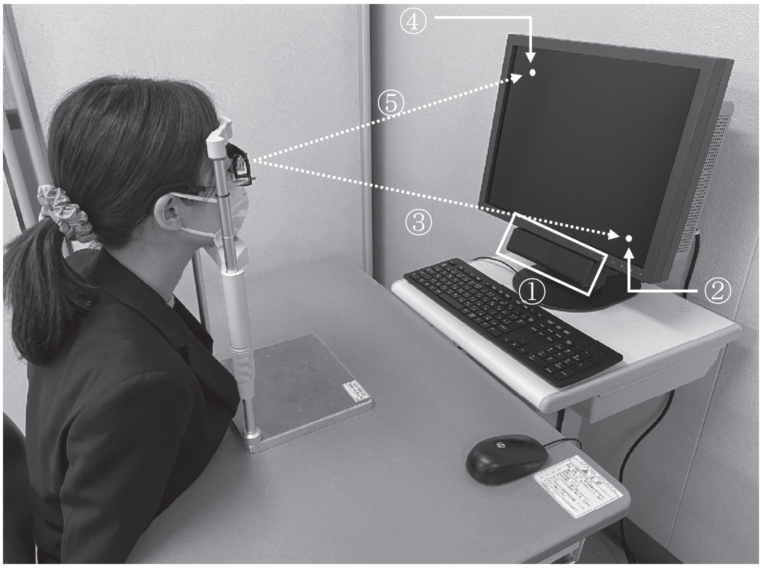

Fig. 1. Experimental setting
This is a device that combines a 19-inch monitor screen with a stimulator. A stereo camera is mounted below the monitor (white square: ①), which makes it possible to record gaze movements in real time by capturing corneal reflection images irradiated by a near-infrared light-emitting diode. The image shows the state of a right eye measurement. A white target was presented on the lower right (②). The gaze moves (③) to the white target (②) if there is a normal response. The white target (②) is presented for 2 seconds before moving to another location (④) at 0.1-second intervals. The gaze moves (⑤) to the white target (④) if there is a normal response. It should be possible to evaluate the visual field with gaze movements 21.5° (theoretical value) to the upper left.

degeneration, or retinal diseases such as diabetic retinopathy.

Gaze movements were measured using Gazefinder (JVCKENWOOD Corporation, Yokohama, Japan) an all-in-one eye-tracking device that captures gaze patterns and presents stimulation targets and does not require goggles or a head restraint (Fig. 1). Gazefinder was run on a personal computer with a 19-inch monitor (1280×1024 pixels). A stereo camera for measuring eye tracking was installed bellow the monitor (Fig. 1). Eye movements were recorded in real time using a stereo camera that captured a corneal reflex image illuminated by a near-infrared light-emitting diode. The sampling rate was 50 Hz, and the distance between the monitor and the face of the subject was approximately 60 cm. The measurement was performed with the chin resting on the chin rest. The participants wore an infrared transmission filter (IR76; Fujifilm Corporation, Tokyo, Japan) in front of their left eye, which was the eye not being measured, and the examination proceeded without the target being visible from the left eye.

The following explanation was given to the participants before the measurements: "A white target will be presented somewhere on the monitor. If you see the target, move your gaze toward it. You will be not told where the target will be presented." A stimulus movie was presented for calibration at five points in the center and four corners on the monitor. Calibration was performed for each measurement. After calibration, a white target (luminance: 80 cd/m^2) for measuring gaze movement was presented on a black background (luminance: 0.08 cd/m^2) in a total of eight directions (horizontal/vertical and oblique). All measurements were performed in a bright room. The size of the white target used corresponds to Goldmann size III with a diameter of 0.43° in the visual angle.

Visual target presentation was performed as follows (Fig. 2). Each screen with a white target (Fig. 2_No.1 to No.9) was presented for 2 seconds. The black (blank) screen was presented for 0.1 seconds between the screens with a white target (Fig. 2_No.1 to No.9). For example, the screen of Fig. 2_No.1 was presented for 2 seconds, and then the black (blank) screen was presented for 0.1 seconds. Then, the black (blank) screen was switched to the next screen (Fig. 2_No.2) which was presented for 2 seconds. After that, the screen switched in the same way up to Fig. 2_No.9. One set of the measurements takes approximately 20 seconds.

If the subject performed correct eye movements to the white target, the examiner judged that the visual field up to the target was "visible". It should be possible to measure visual field with gaze movements in eight directions (horizontal/vertical to 15.3° and oblique to 21.5°). The theoretical value was calculated from the angle (visual angle), formed by the reference target 1 (fixation point) and target 2 (measurement point) at an examination distance of 60 cm. Fig. 1 shows the experimental setup, and Fig. 2 shows the protocol for recording the gaze movements. To evaluate repeatability, gaze conversion measurements were performed three times consecutively on the same day with no time intervals.

The recorded gaze information was saved in Gazefinder. The saved data were output as a comma-separated values (CSV) file. To graph and quantify the data, the CSV files were input into Create Chart analysis software, which was developed in cooperation with CREWT Medical Systems, Inc. (Tokyo, Japan) (Fig. 3).

Before measuring gaze movements using Gazefinder, all participants underwent visual acuity, eye position, and static visual field (using program 30-2 of the Humphrey field analyzer) tests to confirm the absence of visual disturbance or manifest strabismus. If refractive correction was necessary to obtain a corrected visual acuity of 1.0 or better, the data were recorded while the subjects were wearing corrective or contact lenses.

All statistical analyses were performed using SPSS version 22.0 (IBM Corporation, Armonk, NY, USA). Multiple comparisons were performed for the three measurements after confirming the normality of the data. The maximum value of DataRateAve, which indicates the rate of gaze acquisition during measurements, is 1.0, with higher values indicating a higher rate of gaze acquisition. To evaluate the accuracy of gaze attainment on the target in each direction (horizontal/vertical to 15.3° and oblique to 21.5°), we averaged the measured values in 8 directions and calculated the difference between the theoretical and measured values. Then repeated measures analysis of variance using a general linear model was performed. In addition, the repeatability of three-time data measured in eight directions was

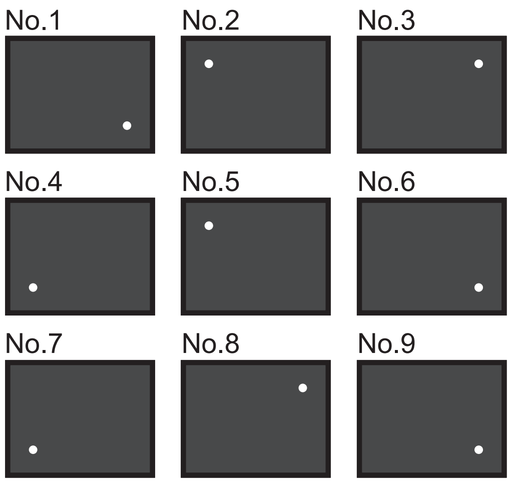

Fig. 2. Stimulus presentation protocol for recording gaze movements
The white target was presented in the order from No. 1 to No. 9, and then eye movements to the presented stimuli were measured. If the participant can perform eye tracking accurately with respect to the white target, it should be possible to measure the visual field with gaze movements in eight directions (horizontal/vertical direction to 15.3 ° and oblique direction to 21.5°).

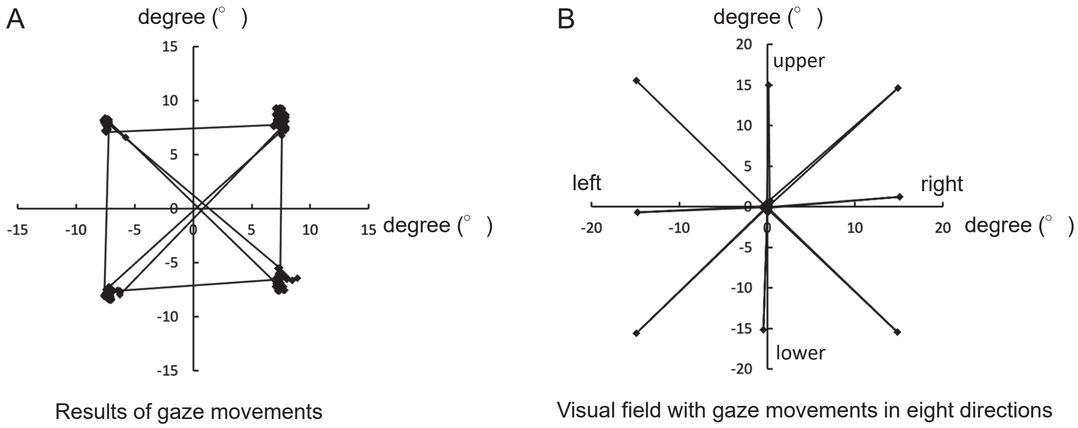

Fig. 3. Typical visual field data with gaze movements using CreateChart analysis software
Results of right eye visual field data with gaze movements in a 21-year-old man. The graph on the left shows gaze movements [A], demonstrating the ability to accurately follow visual targets presented in the visual field. The graph on the right shows the visual field with gaze movements in eight directions in the same subject [B]. The visual field with gaze movements was 15.0° for the upper direction, 20.9° for the upper right, 15.1° for the right, 21.4° for the lower right, 15.2° for the lower, 21.5° for the lower left, 14.9° for the upper left, and 21.5° for the upper left. These data are considered to be normal. CreateChart is analysis software designed to chart data quickly for visualization.

investigated using intraclass correlation coefficients (ICCs). A P-value < 0.05 was considered statistically significant.

All of the investigative procedures conformed to the tenets of the Declaration of Helsinki. This study was approved by the Ethics Committee of Kawasaki University of Medical Welfare (21-014).

RESULTS

The mean age of the participants was 22.7 ± 5.2 years (range, 20-39 years), and the mean spherical equivalent was -3.03 ± 2.76 diopters (D) (-8.50 D to + 0.38 D). Single measurements of target-to-gaze transformation with Gazefinder were completed in approximately 20 seconds, and data were available for all participants in this study.

DataRateAve, which indicates the rate of gaze acquisition during measurements, showed high values, at 0.99 ± 0.01, for the first measurement, 0.99 ± 0.01 for the second, and 0.99 ± 0.01 for the third. No significant differences were found between measurements (P = 0.640).

Measurement values in the eight directions were 15.1° ± 0.9° for the upper, 20.9° ± 1.0° for the upper right, 15.1° ± 1.0° for the right, 20.7° ± 0.9° for the lower right, 14.8° ± 0.7° for the lower, 20.9° ± 0.9° for the lower left, 14.7° ± 0.5° for the upper left, and 21.0° ± 0.7° for the upper left. Fig. 3 shows the results of the typical measurements.

The differences between the theoretical and actual measurement values were -0.1° ± 0.9° for the upper, -0.6° ± 1.0° for the upper right, -0.2° ± 1.0° for the right, -0.8° ± 0.9° for the lower right, -0.5° ± 0.7° for the lower, -0.5° ± 0.9° for the lower left, -0.6° ± 0.5° for the left, and -0.6° ± 0.5° for the upper left, respectively. No significant differences were found among the eight directions, and the gaze to the intended location were within less than within 1° for both horizontal/vertical and oblique (Fig. 4).

The ICCs in the eight directions were 0.620 (P = 0.008) for the upper, 0.613 (P = 0.001) for the upper right, 0.757 (P < 0.001) for the right, 0.635 (P < 0.001) for the lower right, 0.810 (P < 0.001) for the lower, 0.684 (P = 0.002) for the lower left, 0.731 (P < 0.001) for the left, and 0.653 (P = 0.004) for the upper left. In each direction, the ICC was 0.6

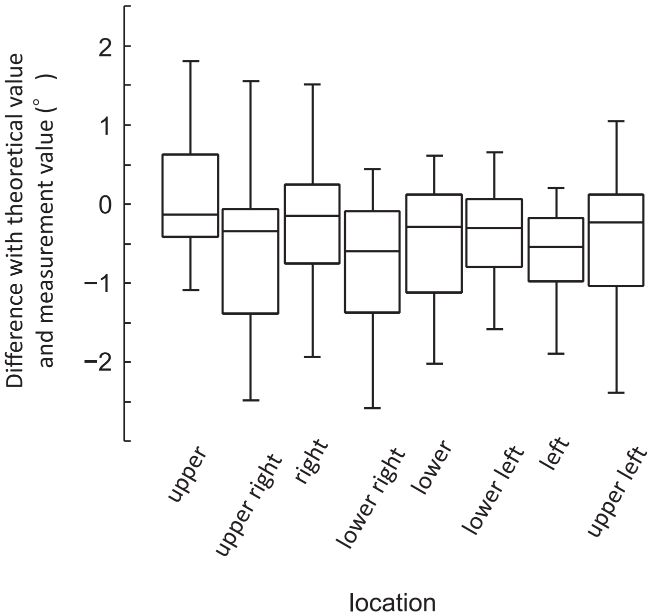

Fig. 4. Difference between theoretical and actual measurement values
No significant differences were found among the eight directions, and the gaze to the intended location was within less than 1° in both the horizontal/vertical and oblique directions.

or higher, and the data were considered to be highly reproducible.

DISCUSSION

In the present study, we developed a visual field-testing system with gaze movements to perform central visual screening of approximately 20 degrees within the visual field based on eye tracking using a commercially available device. The system developed in this study has the advantage of not requiring eye movements to return to the fixation point. Therefore, the present findings indicate that our newly developed system is a useful device when standard perimetry is difficult to measure.

A major problem with visual field-testing systems with gaze movements is that brightness of the target cannot be changed, so threshold evaluation cannot be performed for each measurement point. Also, with the present system, the measurement range is limited to about 20 degrees. Therefore, it is difficult to compare our measurement system to standard perimeters such as the Goldmann perimeter or the Humphrey Field Analyzer perimeter, which are capable of precise visual field measurements. However, visual field-testing systems that use gaze movements for screening purposes have two advantages over standard perimeters. One advantage is that it reduces the amount of stress inflicted on the patient. Even experienced patients feel apprehensive about visual field examinations[14]. Therefore, examination conditions for visual field tests, which are far removed from daily conditions, place a heavy burden on the patient and affect the examination results[15, 16]. Jones *et al.*[17] investigated the usability of visual field test with gaze movements and standard automated perimetry in the same patients using a Likert scale-based questionnaire. As a result, they reported that the visual field test with gaze movements was significantly better than standard automated perimetry for all question items, such as ease of examination, ease of understanding, and amount of fatigue. Although we did not evaluate usability in the present study, it is conceivable that our system can perform gaze measurements with less burden compared with the device used by Jones *et al.*[17] because in our system, measurements can be completed quickly, in about 20 seconds.

The second advantage is that our method does not require large-scale equipment or complex tasks. In addition to a large space and a dark environment, standard perimetry requires expensive testing equipment. Moreover, standard perimetry involves a complicated task in which the subject fixates their gaze at a central point while their chin and forehead is fixed, and responds by pressing a button when a peripheral light stimulus is visible. Therefore, it is difficult to measure gaze in patients who have difficulty responding subjectively, such as infants. On the other hand, the visual field test system with gaze movements developed in the present study has a simple structure in which the monitor and stimulator are integrated into a single unit, enabling measurements in a small space. Furthermore, measurements are performed under natural conditions similar to daily life because they are based on the observation of reflexive gaze movements. It may also be possible to examine difficult subjects, such as infants. A previously reported method for evaluating the visual field in infants involved manually manipulating peripheral stimuli and observing their responses[4, 18−21]. However, manual stimulus presentation is influenced by the experience of the examiner and requires time for measurements. Furthermore, this method lacks reliability because it relies on the subjective judgment of the examiner. As the purpose of the present study was to evaluate the validity and reproducibility of the visual field test results with gaze movements in healthy adult volunteers, we did not conduct measurements in infants. This remains a task for the future. A previous study using SVOP, which requires the resetting of a fixation point each time gaze movement is measured, showed a high success rate of 92.3% for testing healthy infants aged 3.5-15 months[13]. On the other hand, our visual field-testing system with gaze movements is based on a light stimulus search task that does not require eye movements to return to the fixation point. Therefore, we speculate that our system may improve the ease of measurements compared with SVOP, and may therefore be applicable to infants from whom obtaining a subjective response is difficult. These findings, including the two advantages stated above and the reproducibility of the measurement results, suggest the usefulness of our newly developed system.

One visual field measurement that does not require a subjective response is pupil perimetry, which is a measurement method for evaluating the visual field objectively using the reaction amount and pupillary light reflex threshold[22, 23]. Pupil perimetry enables objective evaluations to be carried out noninvasively, as well as the detection of early nerve fiber layer defects due to glaucoma[24]. However, the accuracy of this method is limited because the pupillary light reflex varies considerably between individuals[24]. Furthermore, a fixation point is needed for each measurement and a stimulus for each pupillary light reflex. Strictly speaking, the responses obtained in the present experiments are not simple reflexes based on retinal stimulation. However, we think that visual field test with gaze movements is an appropriate method to evaluate the visual field easily.

This study had three limitations. First, our device does not perform threshold evaluation at each measurement point. In addition, the present system has a limited measurement range of about 20 degrees due to the structure of the device. In this study, visual field assessment was based on the ability to accurately orient the gaze to a target presented in the visual field. As threshold measurements are important for visual field measurements, we consider that it is a big problem that the threshold measurement cannot be evaluated with this system. In the future, we plan to add the ability to measure thresholds to the program. We also consider expanding the measurement range. Second, patients with visual field abnormalities should be evaluated. In order to examine the reproducibility of the measurements, it is necessary to compare them with standard perimetry in patients with visual field defects. The purpose of this study is to investigate reproducibility in healthy adult volunteers. This is because we have developed a new type of visual field-testing system that involves eye movements. Therefore, we did not evaluate patients with visual field defects. Murray *et al.* performed visual field tests using gaze movements in patients with glaucomatous visual field defects[10). In addition, it was reported that the patient did not lose sight of the visual target during the measurement, and the visual field abnormality could be detected with a high reproducibility. In the future, we plan to compare the results of a visual field test system with gaze movement and a standard visual field test for patients with visual field defects to examine the reliability of this system. Third, as the purpose of this study was to evaluate investigated of the validity and reproducibility in healthy adult volunteers of our visual field test system with gaze movements, we did not test infants with a subjective response difficulty or patients with a visual disturbance. Based on the high accuracy of the measurement system clarified in this study, we plan to carry out measurements on infants and patients with a visual disturbance in the future.

In conclusion, we designed a visual field test system with gaze movements that does not require subjective responses. Our system requires only about 20 seconds for one measurement. Moreover, the present findings indicate that our newly developed system is a useful device when standard perimetry is difficult to measure.

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CONFLICT OF INTEREST

No conflicting relationship exists for any author.

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