THE EFFECT OF VISUAL ATTENTION FACTORS ON VISUAL FIELD TESTING FOR MAINTENANCE OF GAZE FIXATION

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The maintenance of gaze fixation during visual field testing is needed to accurately measure the functionality of the optic nerve. The present study is intended to analyze the performance of gaze fixation and evaluate five gaze fixation induction methods (GFIM) including black dot (BD; conventional method), changing color dot (CCD), alphanumeric characters (AC), flashing black dot (FBD), and bulls-eye with cross hair (BECH). Recruiting 32 participants (16 in 20s and 16 in 30s), the experiment was conducted in four steps: (1) preparation, (2) exercising the visual field testing, (3) main experiment for five GFIMs, and (4) debriefing. The performance of gaze fixation was analyzed in terms of correct fixation rate (CFR), and subjective satisfaction was evaluated in terms of ease of gaze fixation (EGF), eye fatigue (EF), and overall satisfaction (OS) using a 11-point Likert bipolar scale. The CFRs of the four new GFIMs were all higher than that of BD (BD = 86.7%, CCD = 87.9%, AC = 88.8%, FBD = 91.5%, and BECH = 88.0%). However, there was no statistically significant difference among the CFR averages of the five GFIMs, but the variances of CFR of the newly proposed GFIMs were all lower than that of BD. The subjective satisfaction of BECH (EGF = 2.0, EF = -0.4, OS = 1.6) was highest. Therefore, BECH was recommended for an effective GFIM to maintain the examinee's gaze fixation during a visual field testing in both aspects of the performance and the subjective satisfaction.

INTRODUCTION

Gaze fixation is important for visual field testing which measures the functionality of optic nerve by part. Glaucoma is progressive ophthalmologic disease, leading cause of blindness, triggered by visual field defect that is progressed by optic nerve damage. Visual field testing is one of the tests for measuring the functionality of optic nerve, and is conducted by using the perimetry for an efficient test. For the test, while a subject fixes their eyes on a fixation target, the visual stimulus with brightness control by algorithm is presented, and then the threshold sensitivity value is determined that a subject can recognize are measured (Dersu et al., 2006). If subjects shift their gaze to the other side when the visual field testing target is presented, not only eyes but also the margin of optic nerve is moved, it is therefore most likely to measure the area of optic nerve that is totally different what it is supposed to do.

The gaze-related studies are widely utilized in many fields, such as an advertisement, a web development, and a safety sign, but the research related to medical examination like visual field testing is inadequate. The information of eye tracking can be used in analyzing gaze fixation, trajectories, and distribution. Then, the result can be applied to the field of marketing for investigating the factors holding customer's attention and where the significant information should be placed (Kim & Shin; Lee et al., 2010; Lohse, 1997). However, for the research where gaze fixation is critical factor, analyzing the gaze position has not been actively studied, so it seems to need a further study in terms of this topic.

The existing perimetry cannot fix the gaze of a subject effectively because it uses the simple form of a fixation target. In a medical institution, subjects for visual field testing get instructions to voluntarily fix their eyes by using a fixation target for gaze fixation in the form of a black dot or a light emitting diode colored with orange and green. The simple fixation target for gaze fixation is difficult to effectively fix the subjects' eyes during the visual field testing requiring five to six minutes for each eye. Therefore, it is necessary to research about the factors that induce eyes to be fixed and how these effects influence on visual field testing.

This study developed the method of inducing gaze fixation, evaluated the eye tracking system and subjective satisfaction, and realized the effects of each method on the performance of visual field testing. First, we investigated the critical factors for gaze fixation, and then devised four different methods of inducing it. Second, gaze of subjects were tracked and analyzed by using developed program for visual field testing and eye tracking system for the application of gaze fixation induction method we developed. Lastly, we determined the factors of gaze fixation based on the analyses and the effect of the performance of visual field testing.

MATERIALS AND METHODS

Gaze Fixation Induction Factor and Method

Color, alphanumeric characters, flashing, and shape have the effect of drawing gaze or attention. Sanders and McCormick (1993) stated color and alphanumeric characters are the elements of visual coding for drawing attention. Connors (1975) applied the effect of flashing lights to the project of the development of collision avoidance system (CAS) in NASA in that it helps a pilot to detect early and avoid adjacent planes. Thaler et al. (2013) proved that the gaze fixation performance of a complex shape target is better than that of a simple one.

This study designed the four gaze fixation induction methods, such as the changing color dot (CCD), the alphanumeric characters (AC), the flashing black dot (FBD), and the bull-eye and cross hair (BECH) by using four elements (color, alphanumeric, flashing, and shape) as shown in Table 1. CCD is a method that red, yellow, green, blue, and purple (Munsell five principal hues: red, yellow, green, blue, and purple; Munsell, 1905) dot are randomly presented as each visual field testing stimulus comes up during a visual field examination. AC is a method that alphabet A, B, C and number 1, 2, 3 are

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provided at random as each visual field testing stimulus appears during the examination. FBD is a method that a black dot flashes four times per 1 sec, and BECH is a method that a shape which is a combination of small black dot, large black dot, and crosshair is presented during a visual field testing. We considered a black dot (BD) as a reference compared with the performance of the four gaze fixation methods.

Table 1. Gaze fixation induction factors and methods

Reference	Visual Attention Factor			
	Color	Alphanumeric	Flashing	Shape
Black dot (BD)	Changing color dot (CCD)	B 2 C 1 Alphanumeric Characters (AC)	Flashing black dot (FBD)	Bulls eye & cross hair (BECH)

Participants

32 participants (20s: 16; 30s: 16; range: 29.0 ± 4.4 yr) took a part in this study. Participants were screened by corrected visual acuity (> 0.7) and no visual field defects.

Experiment Environment

Experimental environment consisted of 27” monitor, eye patch, handheld push-button, head positioner, eye tracking system, and visual field testing program as can be shown in Figure 1 and 2. The 27” monitor was used to present visual field test screen, GFIM, and visual field testing stimuli. The eye patch was used to block the opposite eye against testing eye. Handheld push-button (Delcom Products Inc., USA) was used to input the data about whether or not the participants recognize the stimulus when the visual field testing targets was presented on the screen. Head positioner (Arrington Research, USA) was used to minimize the head movement of the participants during eye tracking. The eye tracking system (Arrington Research, USA) was used to track the pupil location of participants’ right eye during the experiment. The visual field testing program was used to present five GFIM and visual field testing stimuli within 24°. The location of the four GFIM and BD and visual field testing stimuli is consisted of 56 locations. The four GFIM and BD are located on the center of visual field area. 54 visual field testing stimuli are located on the 6° grid followed central 24-2 test pattern. A blind spot is located on 16.5° apart from vertical line and 1.5° below from horizontal line as shown in Figure 2.

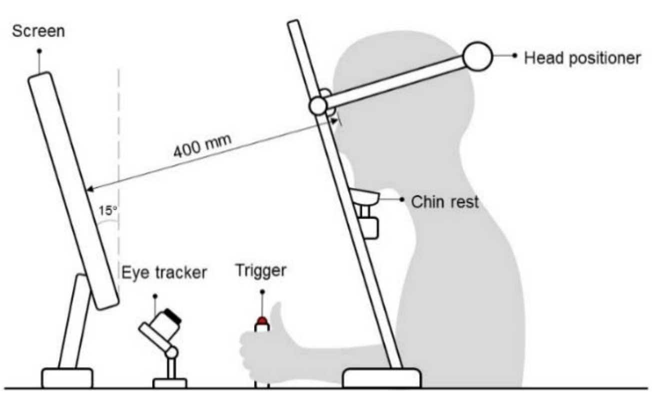

Figure 1. Experimental environment

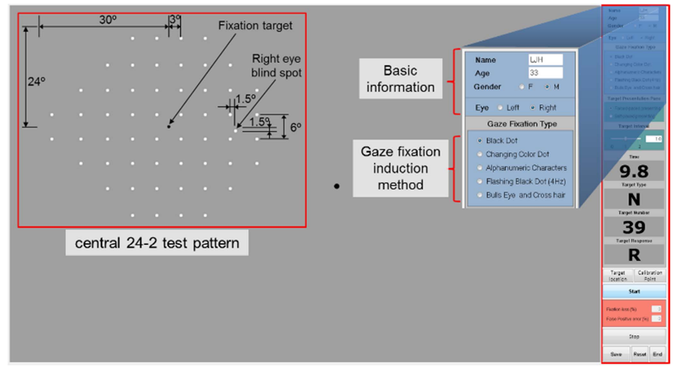

Figure 2. Visual field testing program

Experiment procedure

An experiment was conducted in respect of gaze fixation performance and subjective satisfaction through a four-step protocol, (1) preparation, (2) exercise, (3) experimentation, and (4) debriefing (Figure 3). In preparation step, experiment content was explained and consent was got from the participants. Head positioner set on the desk for anchoring the face of participant. In exercise step, the participant conducted visual field testing for 20 sec for against each GFIM to be accustomed to visual field testing. In experimentation steps, the participant wore eye-patch, positioned its face on head positioner and the direction of eye camera adjusted toward participant’s eye to track the pupil. After each trial was finished, subjective satisfaction was conducted. The experiment was two repetitions. After whole trial was finished, in experimentation step, the preferred GFIM and the reason was collected through debriefing. Total experiment time per one participant took 1h 40 min.

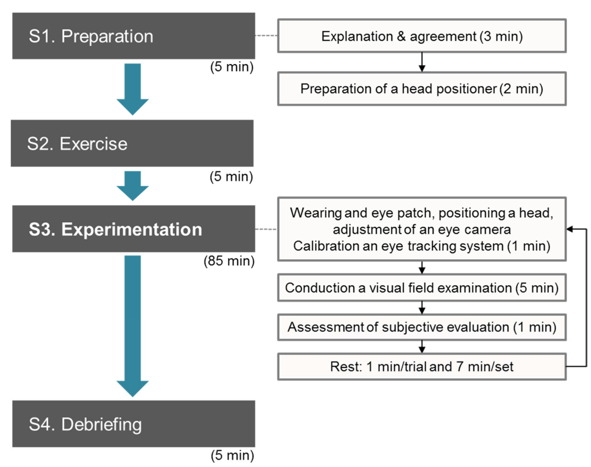

Figure 3. The experimental procedure

Measurements

The performance of GFIM was analyzed in terms of corrected fixation rate (CFR) and the subjective satisfaction was evaluated in terms of ease of gaze fixation (EGF), eye fatigue (EF), and overall satisfaction (OS) using by 11-point Likert bipolar scale.

CFR is the ratio of the total number of measurements of gaze location to the measurements of gaze location within visual angle 1° for presenting visual field stimuli in every 0.2 sec (equation 1). EGF is a criterion which evaluates the degree of easiness to fix and maintain gaze at a gaze fixation target during visual field testing. EF is evaluated the degree of eye fatigue after finishing visual field testing by using each GFIM. OS is evaluated the degree of satisfaction considering overall condition.

$$CFR(\%) = \frac{\sum_{i=1}^{n} F_i}{n} \times 100$$

Where, $F_i = 1$, gaze location $\leq 1°$ during target presentation time by each target (Equation 1)
0, otherwise
$i = 1, 2, 3, \ldots n$
n = *total number of targets*

Statistical analysis

Homogeneity of variances of CFR, EGF, EF, and OS used Bartlett's test. The data with equal variance was analyzed by analysis of variance (ANOVA), but the data with unequal variance was analyzed by Brown and Forsythe's test. Post hoc analysis was used Tukey Kramer test or Dunnett's T3 test.

Analysis of corrected fixation rate

CFR is analyzed the gaze location data measured by using eye tracking system through a five-step procedure (S1. Collect eye tracking data, S2. Remove noise data, S3. Select eye tracking data during target presentation, S4. Analyze gaze trajectories, S5. Determine a gaze fixation). S1, gaze location data was collected by using eye tracking system (sampling rate = 220 Hz). S2, noise data such as non-gaze data and blinking data was removed from raw data. S3, we extracted the gaze data before and after 0.2 sec of the moment the visual stimuli was presented to the participants. S4, according to time-series change, the extracted gaze data was analyzed. S5, if gaze trajectory before and after 0.2 sec of the moment the visual stimuli was presented is located visual angle ≤ 1°, the gaze of participant is fixed to GFIM or BD at the moment.

RESULTS

Performance of gaze fixation

The gaze fixation performance and stability of four GFIM were higher than that of BD in terms of CFR. The CFR of four GFIM (CCD: 87.9%; AC: 88.8%; FBD: 91.5%; BECH: 88.0%) was better than that of BD (86.7%) but was not shown statistically different (Figure 4). The CFR variance of four GFIM (CCD: 11.6%; AC: 10.9%; FBD: 8.3%; BECH: 9.7%) was statistically lower than that of BD (13.3%) by Bartlett's test (B = 14.54, p = .006).

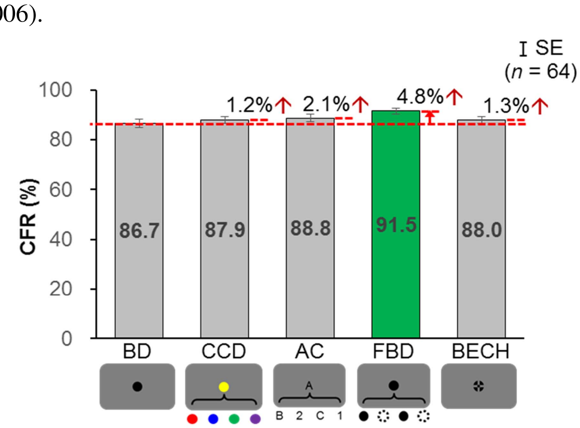

Figure 4. Correct fixation rate (mean ± SE)

Subjective satisfaction

The subjective satisfaction of BECH was evaluated higher than that of BD with respect to EGF, EF, and OS. EGF of BECH was the highest rating of 2.0 points, AC was 1.1 points, FBD was 0.8 points, and CCD was 0.5 points (Figure 5a). EF of BECH was the highest rating of -0.4 points, and when using BECH, it was analyzed to feel less eye fatigue than when using BD. When using AC (0.3 points), FBD (0.9 points), and CCD (1.0 points), participants felt more eye fatigue than when using BD (Figure 5b). Finally, OS of BECH was the highest rating of 1.6 points, next AC was 0.5 points. OS of BECH and AC was higher than that of BD. However OS of CCD and FBD was lower than that of BD. There was no statistical difference among BD, CCD, and FBD (Figure 5c).

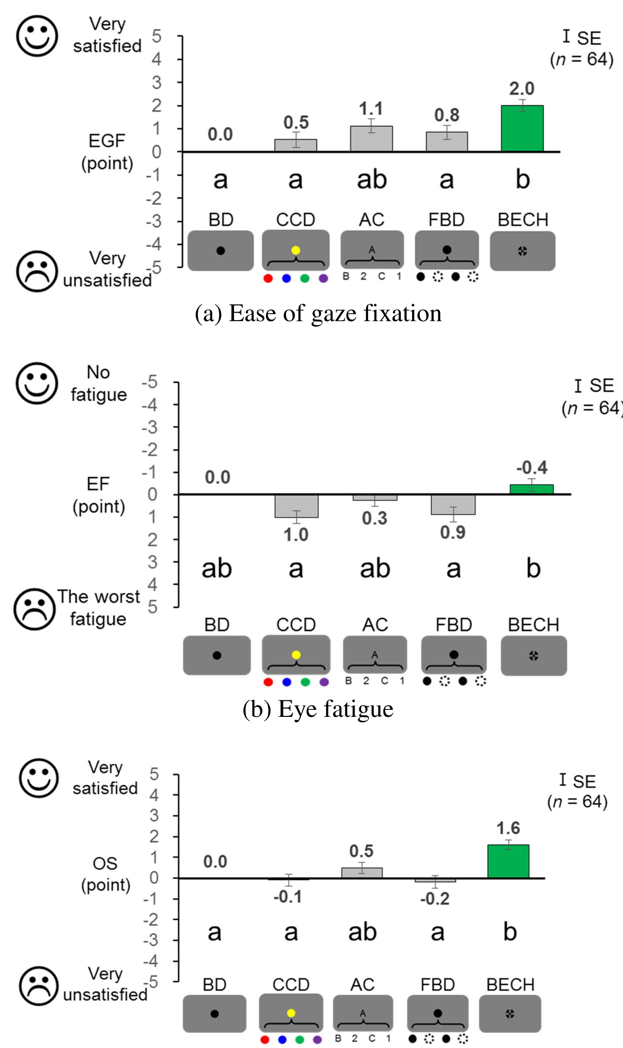

Figure 5. Subjective satisfaction (mean ± SE)

DISCUSSION

This study compared the proposed methods with the existing ones through quantitative performance measure and subjective satisfaction evaluation using the eye tracking system in order to examine the effects of the gaze fixation induction method on visual field testing. For the testing, subjects' eyes are absolutely required to be fixed for measuring the correct area of optic nerve. In a clinical test, subjects continue to receive instructions during the test to keep their gaze to be controlled. However, the fixation target embedded in the existing perimetry provides subjects with only simple and meaningless light or shape, so its effect on the test is not clear. Also, with respect to the gaze fixation induction method embedded in perimetry, there were just few quantitative analyses like assessment of performance for gaze fixation and research about evaluating the subjects' subjective preferences, such as ease of gaze fixation and eye fatigue. This study quantitatively evaluated the performance for gaze fixation induction method based on CFR calculated based on the data from eye tracking system. It also investigated the effects of four different gaze fixation induction methods on the result of visual field testing based on the subjects' preferences evaluated by their satisfaction scores.

It is recommended to customize the gaze fixation induction methods for visual field testing based on subjects' preferences. The four gaze fixation induction method we proposed in this study showed the statistically significant lower variance, but not better performance with respect to gaze fixation compared to the existing methods. In particular, FBD method showed the highest value of CFR, but lower preference than BECH method in terms of satisfaction evaluation. Not only performance but also subject's preference is a critical factor in the aspect of usability, so it is encouraged to allow subjects to select the gaze fixation induction method based on their personal preferences in order to improve the usability of perimetry.

An individual preference for gaze fixation induction method is affected by complexity and symmetry. BECH method showed the most complexity and the best overall effectiveness for gaze fixation (Thaler et al., 2013). Also, it was reported that the form with symmetry has the greatest effect of drawing subjects' attention (Park, 2010). As can be seen from Table 1, BECH method is the form that overlaps the shape of cross with the black circle of 0.6 degree viewing angle and places a small black circle of 0.2 degree viewing angle in the center of the cross. BECH method is more complex than the previous ones, but it earned favorable evaluation in terms of ease of fixation due to its symmetry.

This study was conducted on healthy people between ages of 20 and 40 without visual field defect, the evaluation by normal and glaucoma patients between ages of 40 and 70, main target of the visual field testing, is needed in a further study. The subjects in this study are 32 male and female in their 20s and 30s, younger than those over 40s who account for high proportion of glaucoma diagnosis. Furthermore, the performances of gaze fixation among the different methods are unlikely to show clear distinction because the young tend to be involved in the experiment with sustained attention compared to the old. In the clinical test, visual field testing is usually performed aiming at people over 40s, so it is necessary to conduct an experiment of people between ages of 40 and 70 about the influence of gaze fixation induction method on visual field testing.

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REFERENCES

Connors, M. M. (1975), Conspicuity of target lights; the influence of color, NASA TN D-7960, 1-14.

Dersu, I., Wiggins, M. N., Luther, A. Harper, R., and Chacko, J. (2006). Understanding visual fields, Part I; Goldmann perimetry. *Journal of Ophthalmic Medical Technology, 2*(2).

Kim, T., and Shin, D. (2014). User Experience (UX) of Facebook: Focusing on users' eye movement pattern and advertising contents. *The Korea Contents Associantion*, *14*(7), 45-57.

Lee, H. and Kim, Y. (2010). Analyses of users' responses and eye-movement patterns according to internet advertising purposes and forms. *Journal of Korean Society of Design Science*, *23*(4), 195-206.

Lohse, G. L. (1997). Consumer eye movement patterns on yellow pages advertising. *Journal of Advertising*, *26*(1), 61-73.

Munsell, A. H. (1905), "A Color Notation", G. H. Ellis Co., Boston, USA.

Park, J. (2010). The influence of shape elements on visual attention in stereoscopic images. *Journal of Digital Design*, *10*(2), 499-510.

Sanders, M. and McCormick, E. J. (1993), Human factors in engineering and design, 7th (Ed.) : McGraw-Hill, Columbus, USA.

Thaler L., Schütz, A. C., Goodale, M. A., and Gegenfurtner, K. R. (2013). What is the best fixation target? The effect of target shape on stability of fixational eye movements. *Vision Research*, *76*(1), 31-42.