

Measurement of viewing distances and angles for eye tracking under different lighting conditions

Yesaya Tommy Paulus
Faculty of Design, Kyushu University

Hiramatsu, Chihiro
Faculty of Design, Kyushu University

Yvonne Kam Hwei Syn
Multimedia University Center for Information Security

Remijn, Gerard Bastiaan
Faculty of Design, Kyushu University

<https://hdl.handle.net/2324/7449758>

出版情報 : pp.54-58, 2018-01-11. IEEE

バージョン :

権利関係 : © 2017 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.



Measurement of Viewing Distances and Angles for Eye Tracking Under Different Lighting Conditions

Yesaya Tommy Paulus¹, Chihiro Hiramatsu², Yvonne Kam Hwei Syn³, Gerard B. Remijn⁴

^{1,2,4}Kyushu University

Faculty of Design, Department of Human Science
Fukuoka, Japan

¹STMIK Dipanegara

Department of Information Systems
Makassar, Indonesia

³Multimedia University

Center for Information Security
Cyberjaya, Malaysia

Abstract—Eye tracking can be used for eye-gaze-based authentication in public settings, such as for registration on personal computers and automated teller machines. In this study, we conducted a series of measurements with low-cost eye-tracking devices to assess the feasibility of their use in such settings. We investigated the devices' minimum and maximum viewing distance limits as well as viewing angle range. Both these parameters were tested under three different lighting conditions. The eye-tracking devices used in the measurements were among the most cost-effective devices commercially available today (Tobii EyeX[®] and Eye Tribe[®]). The results showed that the minimum and maximum viewing limit of the Tobii EyeX[®] did not vary significantly with different lighting conditions, and neither did the viewing angle range. The maximum viewing distance of the Eye Tribe[®] was significantly different between two conditions of artificial lighting, although the average difference was just 1 cm. The lowest viewing angle that allowed registration into the Eye Tribe[®] system also differed significantly between the two artificial lighting conditions, but here too the average angle difference was small (0.63°). Taken together, the results show that the performance of the two low-cost eye trackers tested here is robust enough under different conditions of illuminance and luminance for registration into the system.

Keywords—eye tracking; eye gaze; viewing distance; viewing angle; luminance; illuminance

I. INTRODUCTION

Visual passwords based on eye gaze and eye-tracking technology might prove to be good alternatives to conventional alphanumerical passwords. The latter are still used world-wide in public settings for authentication on personal computers or Automated Teller Machines (ATMs), yet are vulnerable to “shoulder surfing” – password theft through close observation of the user’s manual input. Visual passwords might be resistant against shoulder surfing and potentially facilitate easier memorization compared to alphanumeric passwords [1–4], because recognition of images can be easier than recognition of words and numbers [5–7]. Attempts are therefore being made to use eye tracking with eye-gaze-based visual passwords in public settings. One of the first attempts, a system called “EyePassword”, employed only a single alphanumerical password [8]. However, each password key in this system had a focus

point in the center of the on-screen keyboard to help users focus their gaze. This would still make the system vulnerable to shoulder surfing, and later research showed that graphical passwords with (at least) five gaze points were considered to be more resistant to shoulder surfing [9]. In these systems, however, the participants still had to press a keyboard to trigger the gaze input. Furthermore, in this early research, the systems were tested under optimal conditions for users sitting behind a personal computer under a single lighting condition.

Nowadays, we are witnessing a rapid evolution in eye-tracking technology with systems becoming easier to operate at a more affordable price. In order to investigate whether eye tracking can be used for visual password registration in public spaces, such as in settings with personal computers or ATMs, it is necessary to establish whether low-cost eye-trackers perform robustly and efficiently under various lighting conditions. Here we report two measurements on the limits of viewing distance and viewing angle of low-cost eye trackers under different conditions of luminance and illuminance. The measurements were performed with participants standing in front of a display.

II. MEASUREMENT I

Measurement I was designed a) to obtain the maximum and minimum viewing distance at which the participant’s eyes could be registered, and b) to measure the highest and lowest viewing angle at which the eye tracker worked at a viewing distance of 40 cm. Both viewing distance and viewing angle data were obtained under three different lighting conditions. The eye tracker device used in this measurement was the Tobii EyeX[®].

A. Method

1. Participants

Twenty-five participants were invited to participate in this measurement. They were 14 males and 11 females. Their ages ranged from 20 to 61 (mean = 27.72 years, SD ± 9.26 years). Eight participants wore glasses, 4 participants wore contact lenses, and 13 participants had uncorrected vision. The height of the participants was between 151 and 205 cm (mean = 169.52 cm, SD ± 10.8 cm). Twenty participants were Asian (Japanese, Chinese, Indonesian),

and 5 participants were Caucasian. The participants participated on a voluntary basis and provided written, informed consent as to their participation, after the purpose and procedure of the measurement was explained to them.

2. Apparatus

A touch-screen display (Microsoft Surface 4, 12-in) was used and equipped with Tobii EyeX[®] software. The eye-tracking device was placed just below the display, at a height of 133 cm from the ground. The eye tracker and the display was fixed at a viewing angle of 90°. Viewing distances and angles were measured in a room under three lighting conditions: ‘natural light’ from a window, ‘room light’, and ‘full light’. The ‘full light’ condition combined the ‘natural light’, the ‘room light’, and an additional light spot on the display to which the eye tracker was connected. For these three conditions, illuminance was measured at the point where the participant was viewing the display by a lux meter (il Pro XRITE). Next to illuminance, the display’s luminance was measured under the three lighting conditions as well (TOPCON Luminance Meter BM-9). The display luminance was first measured for a dark display, and then for a bright display (with white paper placed on the display), at seven different points in time during a day in between 9:00 a.m. and 19:00 p.m. The illuminance in the natural, room, and full light conditions was 6.32 ± 5.18 lux, 203.32 ± 9.57 lux, and 210.71 ± 8.63 lux on average, respectively. The display luminance in the natural, room and full light conditions for the dark display was 0.03 ± 0.02 cd/m², 1.08 ± 0.31 cd/m², and 6.72 ± 1.35 cd/m² on average, respectively. For the bright display it was 0.15 ± 0.09 cd/m², 3.95 ± 0.3 cd/m², and 28.11 ± 2.06 cd/m² on average, respectively.

3. Procedures

After receiving informed consent, each participant was asked to stand in front of the display and instructed to focus on a fixation point (a yellow star) in the geometrical middle of the display. From a viewing distance of 40 cm, the participant was registered into the system and his/her face photo was taken with his/her permission. The viewing distance was measured from the tip of the nose of the participant to the middle of the three near-infrared lights of the eye tracker (Figure 1).



Figure 1. Measurement of viewing distances and angles was made from the tip of the participant’s nose to the middle of the three near-infra-red lights of the eye tracker used in Measurement I, or to the midpoint in between the two near-infra-red lights of the eye tracker used in Measurement II.

Following this, the participant was asked to slowly walk forward or backward while focusing on the fixation point in order to measure the minimum and maximum viewing distance at which his/her eyes were registered (Fig. 2a). The Tobii EyeX[®] software indicates successful registration of the viewer’s eyes by means of two white dots on the display. Registration was considered unsuccessful when the dots disappeared from the screen, i.e., when the viewer was standing too close or too far away from the display.

We also measured the lowest and highest viewing angle possible at which the viewer’s eyes were registered at a viewing distance of 40 cm (Fig. 2b). The participant was asked to move upward (by stretching his/her legs) until he/she reached the lowest viewing angle at which the eyes were still registered. Also for this measurement, the participant had to keep looking at the fixation point at the middle of the display at the viewing distance of 40 cm. The angle was measured from the tip of the participant’s nose to the near-infrared light in the middle of the eye tracker. The same procedure was used to measure the highest viewing angle possible at a viewing distance of 40 cm.

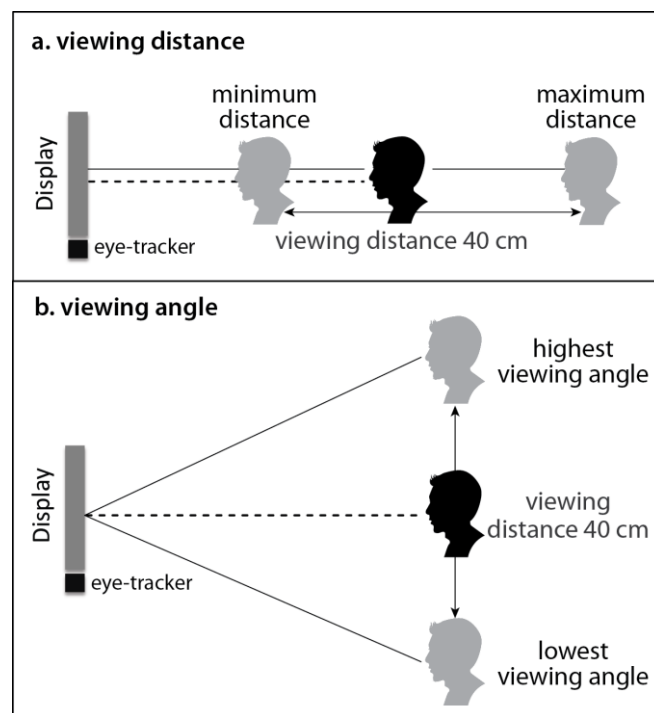


Figure 2. Illustration of measurements performed in Measurements I and II, a. viewing distance, b. viewing angle.

All four parameters (minimum viewing distance, maximum viewing distance, lowest viewing angle, and highest viewing angle) were assessed under the three lighting conditions. This took about 20 minutes for each participant. The procedures for Measurement I and the following Measurement II were approved by the Ethical Committee of the Faculty of Design, Kyushu University.

B. Results

Figure 3 indicates the maximum and minimum viewing distance at which the participant’s eyes ($n=25$) could be registered under the three lighting conditions. The average maximum viewing distance (black bars) in the natural light condition was 71.2 ± 4.61 cm. In the room light condition it was 70.28 ± 5.48 cm, and in the full light condition it was 69.42 ± 4.89 cm. The average minimum viewing distance

(white bars) at which the participant's eyes could be registered was 36.16 ± 1.75 cm in the natural light condition, 36.2 ± 1.55 cm in the room light condition, and 36.28 ± 1.31 cm in the full light condition. Shapiro-Wilk tests for the data obtained at the minimum viewing distances showed that they were not normally distributed ($df=25$, natural lighting: $W=0.87$, $p=0.004$; room lighting: $W=0.86$, $p=0.002$; full lighting: $W=0.90$, $p=0.019$). Statistical analyses were therefore performed using non-parametric Friedman tests. The minimum viewing distance data ($df=2$, $n=25$) showed no significant difference between lighting conditions ($\chi^2 = 0.78$, $p=0.68$). A significant difference between the maximum viewing distances under the three lighting conditions was also not found ($\chi^2 = 2.36$, $p=0.31$).

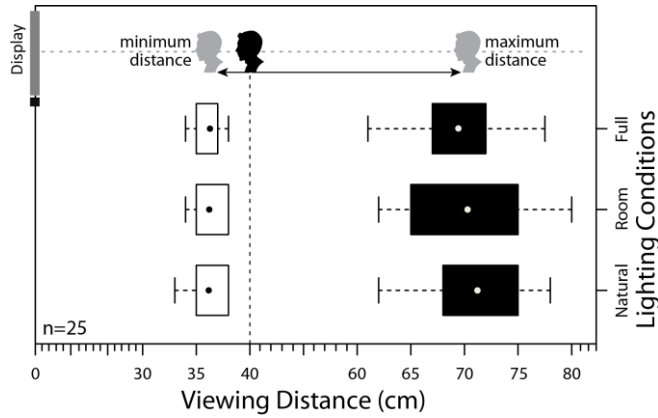


Figure 3. The maximum and minimum viewing distances for which the participant's eyes could be registered under the three lighting conditions in Measurement I. Error bars indicate ± 1 SD.

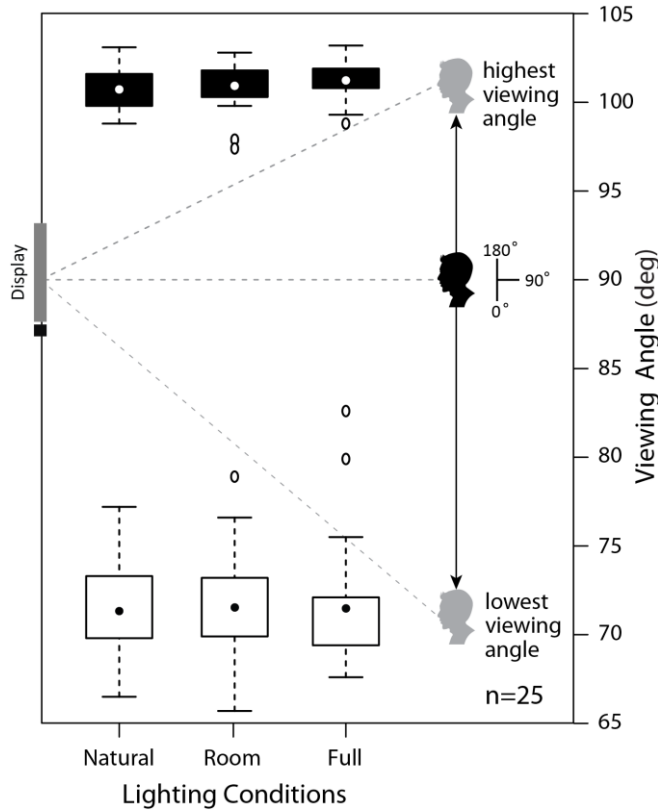


Figure 4. The lowest and highest viewing angles for which the participant's eyes could be registered under the three lighting conditions in Measurement I. Error bars indicate ± 1 SD.

Figure 4 indicates the lowest and highest viewing angle at which the participant's eyes ($n=25$) could be registered under the three lighting conditions. The average lowest viewing angle (white bars) in the natural light condition was $71.33 \pm 2.58^\circ$. In the room light condition it was $71.42 \pm 2.83^\circ$, and in the full light condition it was $71.41 \pm 3.55^\circ$. The average highest viewing angle (black bars) at which the participant's eyes could be registered was $100.73 \pm 1.25^\circ$ in the natural light condition, $100.92 \pm 1.3^\circ$ in the room light condition, and $101.26 \pm 1.04^\circ$ in the full light condition. Shapiro-Wilk tests for the highest viewing-angle data showed that the data obtained under room lighting were not normally distributed ($df=25$, $W=0.90$, $p=0.02$). Similarly, the lowest viewing-angle data obtained under full lighting were also not normally distributed ($df=25$, $W=0.81$, $p<0.01$). Statistical analyses performed using Friedman tests ($df=2$, $n=25$) showed no significant difference between lighting conditions for the highest viewing-angle data ($\chi^2 = 3.08$, $p=0.21$) and for the lowest viewing-angle data ($\chi^2 = 0.06$, $p=0.97$).

III. MEASUREMENT II

In a second measurement, we measured the same parameters (the maximum and minimum viewing distance at which the viewer's eyes were still registered, and the highest and lowest viewing angle) under three different lighting conditions using the eye-tracking device from Eye Tribe[®].

A. Method

1. Participants

Twenty-eight participants were invited to participate in this measurement. They were 18 males and 10 females. Their ages ranged from 22 to 42 (mean = 25.57 years, $SD \pm 4.63$ years). Ten participants wore glasses, 5 participants wore contact lenses, and 13 participants had uncorrected vision. The height of the participants was between 153 and 183 cm (mean = 166.82 cm, $SD \pm 7.82$ cm). All participants were Asian (Chinese, Indonesian, Malaysian and Japanese). The participants participated on a voluntary basis and provided written, informed consent as to their participation after the purpose and procedure of the measurement was explained to them.

2. Apparatus

The Eye Tribe[®] software was installed on a touch-screen display (Microsoft Surface 4, 12-in). Viewing distances and angles were measured in a room under three lighting conditions with the same settings as used during Measurement I. Illuminance and luminance were measured in the same way and with the same equipment as in Measurement I. The average of the illuminance in the natural, room and full light conditions was 6.68 ± 5.63 lux, 202.82 ± 10.19 lux, and 211.86 ± 10.11 lux, respectively. The average of the display luminance in the natural, room and full light conditions for the dark display was 0.03 ± 0.02 cd/m^2 , 0.97 ± 0.32 cd/m^2 , and 6.53 ± 1.44 cd/m^2 , respectively, and for the bright display it was 0.14 ± 0.09 cd/m^2 , 3.88 ± 0.29 cd/m^2 , and 27.46 ± 1.8 cd/m^2 , respectively.

3. Procedures

All procedures in this measurement were the same as in Measurement I, except for the procedure to measure the calibration quality. In the default procedure used in the Eye Tribe[®] software, the participant was asked to follow the

movement of a circle by using his/her eye gaze in order to measure the calibration quality at which his/her eyes were registered. The Eye Tribe[®] software indicates acceptable results when the result is one of the following: 'Perfect', 'Good' or 'Moderate'. Calibration was not acceptable when the result was 'Poor' or 'Redo'. The calibration measurement was repeated when the result was not acceptable, with a maximum of three repetitions for each participant. The limit of three repetitions was set in order to avoid eye fatigue. The Eye Tribe[®] has two near-infra-red lights.

B. Results

Figure 5 indicates the maximum and minimum viewing distance at which the participant's eyes (n=28) could be registered under the three lighting conditions. The average maximum viewing distance (black bars) in the natural light condition was 77.93 ± 5.11 cm. In the room light condition it was 76.86 ± 5.05 cm, and in the full light condition it was 77.86 ± 4.77 cm. The average minimum viewing distance (white bars) at which the participant's eyes could be registered was 28.89 ± 1.64 cm in the natural light condition, 28.96 ± 1.69 cm in the room light condition, and 29.25 ± 1.67 cm in the full light condition.

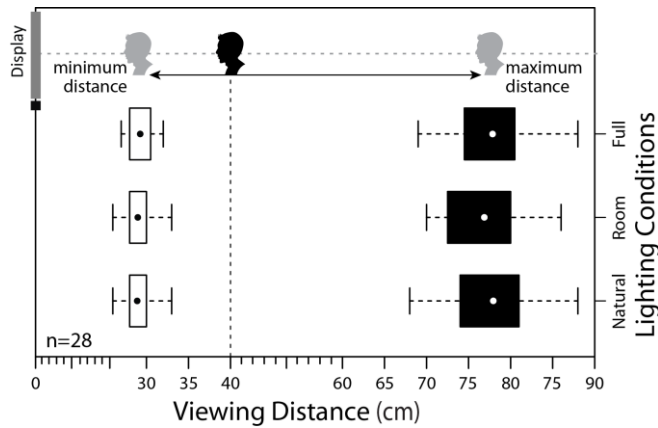


Figure 5. The maximum and minimum viewing distances for which the participant's eyes could be registered under the three lighting conditions in Measurement II. Error bars indicate ± 1 SD.

Shapiro-Wilk tests for the data obtained at the minimum viewing distances showed that data obtained in the full light condition were not normally distributed ($df=28$, $W=0.92$, $p=0.026$). Statistical analyses were therefore performed using non-parametric Friedman tests. The minimum viewing distance data ($df=2$, $n=28$) showed no significant difference between lighting conditions ($\chi^2 = 2.58$, $p=0.28$). The Friedman test for the maximum viewing distances under the three lighting conditions, however, showed a significant difference ($\chi^2 = 9.41$, $p=0.009$). Paired comparisons were performed with Wilcoxon signed-rank tests to see which pair(s) showed the significant difference. Because of multiple comparisons, the alpha level was Bonferroni-adjusted to $0.05/3 = 0.0167$. The maximum viewing distance obtained under the natural lighting condition neither differed from that obtained under the room lighting condition ($Z=-1.92$, $p=0.06$), nor from that obtained under the full lighting condition ($Z=-0.38$, $p=0.71$). The maximum viewing distance under the full lighting condition, however, was significantly larger than that measured under the room lighting condition ($Z=-2.82$, $p=0.005$).

Figure 6 indicates the highest and lowest viewing angle at which the participant's eyes (n=28) could be registered

under the three lighting conditions. The average lowest viewing angle (white bars) in the natural light condition was $81.74 \pm 1.28^\circ$. In the room light condition it was $81.26 \pm 1.6^\circ$, and in the full light condition it was $81.89 \pm 1.57^\circ$. The average highest viewing angle (black bars) at which the participant's eyes could be registered was $113.85 \pm 3.43^\circ$ in the natural light condition, $113.73 \pm 3.23^\circ$ in the room light condition, and $113.4 \pm 4.17^\circ$ in the full light condition.

Shapiro-Wilk tests showed that the highest viewing angle data measured under the natural lighting condition were not normally distributed ($df=28$, $W=0.91$, $p=0.025$). The Friedman test ($df=2$, $n=28$) showed that there were no significant differences between the highest viewing angles obtained under the three lighting conditions ($\chi^2 = 0.49$, $p=0.78$). The Friedman test for the lowest viewing angles, however, showed significance ($\chi^2 = 9.14$, $p=0.01$). Paired comparisons performed with Wilcoxon signed-rank tests and a Bonferroni-adjusted alpha level ($0.05/3 = 0.0167$), taking multiple comparisons into account, showed that the lowest viewing angle obtained under the natural lighting conditions did not differ from that obtained under the room lighting ($Z=-1.66$, $p=0.10$) and the full lighting conditions ($Z=-0.79$, $p=0.43$). The lowest viewing angle under full lighting, however, was significantly higher than the lowest viewing angle under room lighting ($Z=-2.82$, $p=0.005$).

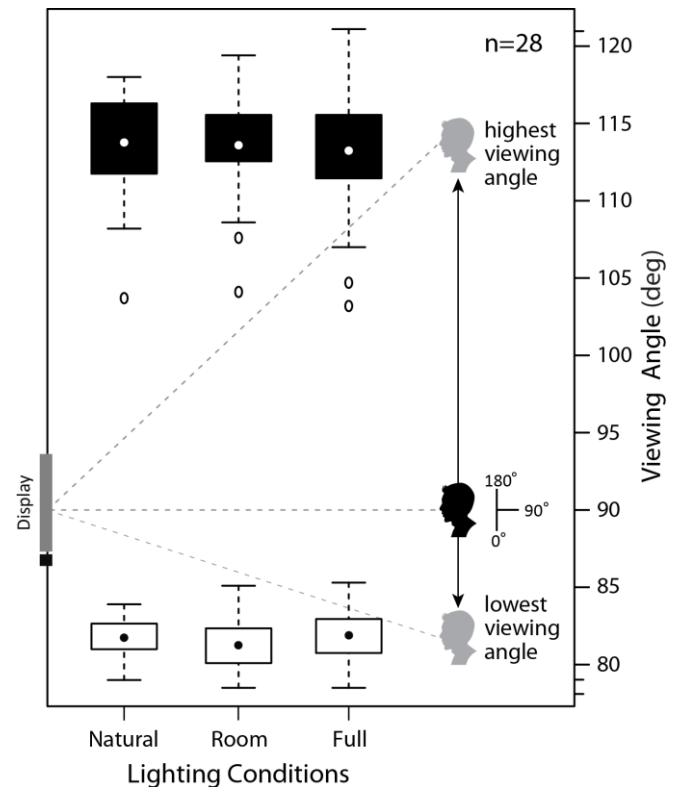


Figure 6. The lowest and highest viewing angles for which the participant's eyes could be registered under the three lighting conditions in Measurement II. Error bars indicate ± 1 SD.

There are obvious differences between the average lowest viewing angle and the average highest viewing angle obtained with the Tobii EyeX[®] (Measurement I; Figure 4) and the Eye Tribe[®] (Measurement II; Figure 6). This is most likely caused by the eyes' position on the Eye Tribe[®] device as used in Measurement II, which was slightly above the middle of the display. When the participants were standing in front of the display and looked at the fixation point at a

viewing angle of 90° during the measurements, the Eye Tribe® system placed the participant's eye slightly upwards from the midline of the display. Therefore, the highest viewing angle for the Eye Tribe® was wider than for the Tobii EyeX®, while the lowest viewing angle for the Eye Tribe® was narrower than that for the Tobii EyeX®.

IV. DISCUSSION & CONCLUSION

Measurement I with the Tobii EyeX® eye-tracking device showed no significant differences between the three lighting conditions for the four parameters investigated here (maximum and minimum viewing distance and highest and lowest viewing angle). Measurement II with the Eye Tribe® eye-tracking device, however, showed that the maximum viewing distance under room lighting was smaller than that under full lighting. The average difference was small - only 1 cm, but nevertheless significant. Also when measuring with Eye Tribe®, the lowest viewing angle was significantly higher when viewing under full light as compared to viewing under room light. Here too the average difference was small, just 0.63°. However, when measuring with the Eye Tribe®, there were 'poor' calibration results, especially for participants who wore glasses. Research has shown that the calibration quality for eye-tracking devices was indeed poorer for participants with glasses as compared to those without glasses [10]. Further investigation should be undertaken to investigate the effect of wearing glasses on calibration accuracy. Taken together, the results strongly suggest that even low-cost eye trackers can be considered for implementation into systems that may require eye-gaze-based authentication, such as visual passwords, under various lighting conditions in public spaces (e.g., personal computer use or ATMs) or semi-public spaces (e.g., vehicles).

In conclusion, this study shows that the average of the minimum and maximum viewing distances and the lowest and highest viewing angles for the eye-tracking devices used here do not change under various lighting conditions. In other words, both measurements show that these eye trackers performed effectively and consistently under the three lighting conditions, which is of importance for both fundamental research on eye tracking as well as for practical applications of eye tracking in society.

ACKNOWLEDGMENTS

The procedures described here have been approved by the Ethical Committee of the Faculty of Design, Kyushu University, Japan. We would also like to thank the participants for their time and efforts. This study was supported by the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance of Indonesia, and Directorate General of Higher Education (DIKTI), Ministry of Education of Indonesia.

REFERENCES

- [1] L. Standing, J. Conezio, and R. N. Haber, "Perception and memory for pictures: Single-trial learning of 2500 visual stimuli", *Psychon. Sci.*, vol. 19, no. 2, pp. 73–74, 1970.
- [2] R. Weiss, and A. De Luca, "Passshapes: Utilizing stroke based authentication to increase password memorability", In *Proceedings of the 5th Nordic Conference on Human-computer Interaction: Building Bridges, NordiCHI '08*, pp. 383–392, 2008.
- [3] N. Wright, A. S. Patrick, and R. Biddle, "Do You See Your Password? Applying Recognition to Textual Passwords", In: *Proceedings of the 8th symposium on usable privacy and security, SOUPS'12*, pp. 1-14, 2012.

- [4] F. Tari, A. A. Ozok, and S. H. Holden, "A Comparison of Perceived and Real Shoulder-surfing Risks between Alphanumeric and Graphical Passwords", In: *Proceedings of the 2nd symposium on usable privacy and security, SOUPS'06*, pp. 56–66, 2006.
- [5] A. G. Goldstein, and J. E. Chance, "Visual recognition memory for complex configurations", *Percept. Psychophys.*, vol. 9, no. 2, pp. 237–241, 1970.
- [6] A. E. Dirik, N. Memon, and J. C. Birget, "Modeling user choice in the PassPoints graphical password scheme", In: *Proceedings of the 3rd symposium on usable privacy and security, SOUPS'07*, pp. 20–28, 2007.
- [7] X. Suo, Y. Zhu, and G. S. Owen, "Graphical Passwords: a survey", In: *Proceedings of the 21st Annual Computer Security Applications Conference, ACSAC'05*, pp. 463–472, 2005.
- [8] M. Kumar, T. Garfinkel, D. Boneh, and T. Winograd, "Reducing shoulder-surfing by using gaze-based password entry", In: *Proceedings of the 3rd symposium on usable privacy and security, SOUPS'07*, pp. 13–19, 2007.
- [9] A. Forget, S. Chiasson, and R. Biddle, "Shoulder-surfing resistance with eye-gaze entry in cued-recall graphical passwords", In: *Proceedings of the Conference on Human Factors in Computing Systems, CHI'10*, pp. 1–4, 2010.
- [10] G. Funke, E. Greenlee, M. Carter, A. Dukes, R. Brown, and L. Menke, "Which Eye Tracker Is Right for Your Research? Performance Evaluation of Several Cost Variant Eye Trackers", In: *Proceedings of the Human Factors and Ergonomics Society 2016 Annual Meeting, HFES'16*, pp. 1240–1244, 2016.