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The Use of Glasses during Registration into a Low-Cost Eye Tracking Device Under Different Lighting Conditions

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Abstract—It is known that the use of glasses can hamper the quality and speed of user registration into eye-tracking devices. Studies have been done in which the performances of various eye-tracking devices were compared, typically under ideal viewing angles, with the user sitting behind a display under a fixed lighting condition. Here we investigated the influence of the use of glasses on the quality and time of user registration into a low-cost eye-tracking device under various lighting conditions. Furthermore, we compared the use of glasses on registration within the same group of participants. Participants with prescription glasses were asked to register into the eye-tracking device both with and without their glasses, if possible, and users without prescription glasses or with contact lenses were also asked to register without glasses or with replica, non-prescription glasses. The present results showed indeed that the use of glasses negatively influenced registration quality and time – significantly here, however, only when registration was performed under artificial lighting. Under natural lighting, the difference in registration quality and speed did not reach significance, but bordered on significance. A follow-up measurement confirmed these results, and suggested that calibration with glasses can improve when participants register under ‘ideal’ viewing angles for their particular viewing position.

Keywords—visual passwords; eye tracking; eye gaze; authentication; glasses

I. INTRODUCTION

In order for a participant to register into an eye-tracking device, a calibration needs to be performed so that the eye-tracking software can generate a model to accurately estimate the viewer’s gaze [1]. Calibration is the process by which characteristics of a viewer’s eyes are assessed as the base for an accurate gaze point calculation. The use of glasses can influence calibration quality [2, 3]. This has been investigated by comparing two low-cost eye trackers (the Tobii EyeX[®] and the Eye Tribe[®]) with a medium-cost (Smart Eye Aurora[®]) and two high-cost eye trackers (Seeing Machines faceLAB[®] and Smart Eye Pro[®]) [4]. The performance evaluation of the devices showed that the percentage of viewers that could be calibrated with the Tobii EyeX[®] was just 50% when the participants wore glasses. However, it is unclear whether the calibrations in this study

were performed between participants with prescription glasses and a group with normal eye sight, or among the same participants with and without glasses. Comparison between two different participant groups may not provide valid information; it is conceivable that a group with prescription glasses has more difficulty performing calibration (tracking) tasks because their eyesight is worse than that of participants who do not need glasses [3]. Moreover, in this study the calibration was obtained with participants sitting behind a display under a single room lighting condition [4]. In our previous study, we have conducted measurements on the Tobii EyeX[®] and the Eye Tribe[®] under different lighting conditions. One of the issues that emerged from our findings was that there were some ‘poor’ calibration results, especially for participants who wore glasses when measuring with the Eye Tribe[®].

In the present study, we systematically tested the influence of the use of glasses on the calibration quality and time for a low-cost eye-tracking device (Eye Tribe[®]) under different lighting conditions. In Measurement I, participants with prescription glasses performed the calibration both with and without glasses, if they were able to do so, while participants with uncorrected vision performed the calibration without glasses and with non-prescription, clear replica glasses. The measurements were conducted under three different lighting conditions, at a viewing distance of 40 cm.

In Measurement II, we measured registration quality and time for the same eye tracker under different viewing angles, under two different lighting conditions. For future application, it is conceivable that if eye tracking is going to be used in public settings, users will perform registration under different viewing angles. Users may be standing in front of a device (e.g., ticketing machines or automated teller machines) and register from viewing angles that differ because of differences in their height. Users may be sitting behind a device as well, because they are in a wheelchair or use eye tracking while sitting behind a steering wheel in a vehicle [5, 6]. Furthermore, in public settings lighting will vary depending on weather conditions and artificial lighting. In Measurement II, we therefore investigated the ideal

viewing angle of participants viewing from different heights (standing, sitting), with and without (replica) glasses at different display angles, under two different lighting conditions.

II. MEASUREMENT I

A. Method

1. Participants

Sixteen participants were invited to participate in this measurement. They were 9 males and 7 females. Their ages ranged from 22 to 34 (mean = 25.38 years, SD $\pm$ 3.16 years). Five participants had uncorrected vision, 4 participants wore contact lenses and 7 participants wore glasses with an average thickness of 1.64 mm, SD $\pm$ 1.25 mm. The height of the participants was between 157 and 182 cm (mean = 168.19 cm, SD $\pm$ 6.91 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

A touch-screen display (Microsoft Surface 4, 12-in) was equipped with the Eye Tribe[®] software. The calibration qualities were measured at a viewing distance of 40 cm 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 (i1 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 10.91 ± 6.59 lux, 199.4 ± 9.96 lux, and 209.29 ± 9.22 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, 0.86 ± 0.25 cd/m², and 6.15 ± 1.5 cd/m² on average, respectively. For the bright display it was 0.21 ± 0.13 cd/m², 4.13 ± 0.36 cd/m², and 30.9 ± 3.12 cd/m² on average, respectively. The participants without glasses were asked to wear replica glasses and the participants with glasses wore their own. The replica glasses were non-prescription, round, and clear glasses with an average thickness of 1.24 mm, SD $\pm$ 0.21 mm. Each calibration process was measured with a stopwatch.

3. Procedures

Written informed consent was obtained from each participant. After a face photo was taken, each participant was asked to follow the movement of a circle by using his/her eye-gaze in order to measure the calibration quality at a viewing distance of 40 cm. First, we measured the calibration qualities for the participants who wore glasses. Depending on their eyesight, if they could see the calibration circle on the display without glasses, the participants were asked to follow the movement of the circle on the display both with and without glasses under the three different

lighting conditions. If they could not see the circle without their prescription glasses, the participants were asked to follow the circle only with their glasses. Second, we measured the calibration qualities for the participants who did not wear glasses, including participants who wore contact lenses. Each participant was asked to follow the movement of a circle on the display by using his/her eye gaze with and without (replica) glasses under the three different lighting conditions. Each participant performed calibration at a viewing angle of 90° without a head-and-chin rest.

Calibrations were obtained with counterbalance in the order of measurement with or without glasses. Thus half of the group with the non-prescription glasses performed the circle-following task first with replica glasses and then without. The other half performed the task first without and then with replica glasses. The order was also counterbalanced for the participants in the prescription-glasses group who were able to follow the circle without glasses. The time for each calibration under each lighting condition was measured, and the calibration was repeated when the result was ‘Poor’, with a maximum of three repetitions for each participant under each lighting condition. The measurements took about 40 minutes for each participant. The procedures of Measurement I and the following Measurement II were approved by the Ethical Committee of the Faculty of Design, Kyushu University.

B. Results

Figure 1 indicates the calibration quality for participants (n=16) with glasses and without glasses under the three lighting conditions. The calibration quality scaling based on the indication by the Eye Tribe[®] software was 4 for ‘Perfect’, 3 for ‘Good’, 2 for ‘Moderate’, and 1 for ‘Poor’ including ‘Redo’ or ‘Uncalibrated’. The average calibration quality for participants with glasses (white bars) in the natural light condition was 2.06 ± 1.06 . In the room light condition it was 1.63 ± 1.03 , and in the full light condition it was 1.75 ± 1.13 . The average calibration quality for participants without glasses (gray bars) was 2.88 ± 1.15 in the natural light condition, 2.5 ± 1.21 in the room light condition, and 2.88 ± 1.15 in the full light condition.

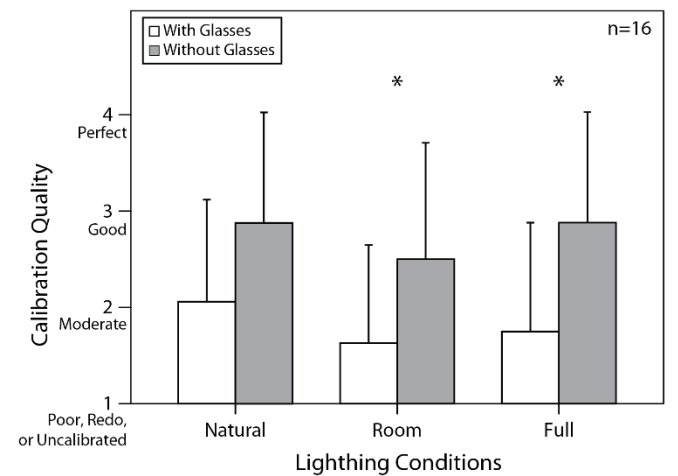


Figure 1. Eye-tracking calibration quality obtained with participants wearing prescription glasses or replica glasses (white bars) and the same participants without glasses (gray bars) under the three lighting conditions in Measurement I. Error bars indicate $\pm$ 1 SD. Asterisks indicate a significant difference between conditions ($p < 0.05$).

To find out whether the use of glasses influenced calibration quality, paired comparisons were performed within each lighting condition for participants with and without glasses using Wilcoxon signed-rank tests. The calibration quality data showed no significant difference for the same participants with glasses and without glasses under natural lighting condition ($Z=-1.94$, $p=0.052$), although this difference bordered on significance. The difference was significant, however, in the room lighting condition ($Z=-2.17$, $p=0.030$) and in the full lighting condition ($Z=-2.47$, $p=0.013$).

Figure 2 indicates the calibration time for participants ($n=16$) with glasses and without glasses under the three lighting conditions. The average calibration time for participants with glasses (white bars) in the natural light condition was 17.64 ± 2.48 sec. In the room light condition it was 18.75 ± 3.26 sec, and in the full light condition it was 19.52 ± 4.36 sec. The average time of calibration for participants without glasses (gray bars) was 16.38 ± 1.45 sec in the natural light condition, 16.75 ± 2.66 sec in the room light condition, and 16.01 ± 1.46 sec in the full light condition. To assess whether the use of glasses influenced the time to calibrate the eye-tracking device, paired comparisons were performed within each lighting condition for participants with and without glasses using Wilcoxon signed-rank tests. The calibration time data showed no significant difference between participants with glasses and without glasses under natural lighting ($Z=-1.704$, $p=0.088$). However, the calibration time difference was significant under room lighting ($Z=-2.99$, $p=0.003$), and under full lighting ($Z=-3.26$, $p=0.001$).

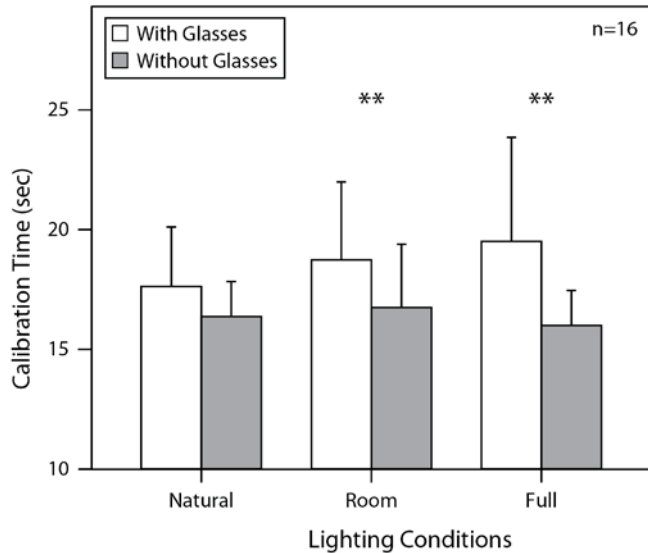


Figure 2. Eye-tracking calibration time for participants wearing prescription glasses or replica glasses (white bars) and the same participants without glasses (gray bars) under the three lighting conditions in Measurement I. Error bars indicate ± 1 SD. Asterisks indicate a significant difference between conditions ($p < 0.01$).

III. MEASUREMENT II

Measurement I indicated that the calibration quality of the Eye Tribe[®] eye-tracking device was poorer and calibration time was longer for participants who wore glasses as compared to the same participants without glasses under the three different lighting conditions. We can assume that the result was not attributable to poor eyesight in the group with corrected vision; the participants with

prescription glasses should have had difficulty performing the calibration task without their glasses, while the participants without glasses (or with contact lenses) should have had no increased difficulty performing the calibration with replica glasses. One obvious problem with the use of (replica) glasses is the reflection or glare from (room) light on the glasses, making calibration difficult. However, our participants noticed another problem when viewing at 90° with glasses. Tracking the calibration circle was especially difficult when the circle was on top of the display, because when viewing the display from a fixed viewing position their eyes were occasionally occluded by the thick frame of the glasses.

In Measurement I the participants used the eye tracker at a fixed viewing angle of 90° . In order to obtain good accuracy of the Eye Tribe[®] device, and in order to better mimic the viewing position for the use of an eye tracker in public spaces by users viewing from different angles, the calibration needs to be performed without a fixed viewing position. Because the Eye Tribe[®] is a low-speed system (sampling rate: 30 or 60 Hz), free head movement does not affect the calibration quality [7]. In Measurement II, therefore, we asked participants either to stand at a natural viewing position in front of the eye tracking device - as if they were using an ATM machine, while we also asked some participants to sit behind the eye tracker. The angle of the display and the eye tracker were systematically varied and we investigated the ideal angle for participants of different viewing heights for registration into the system. Furthermore, we performed these measurements for participants with and without (replica) glasses at the different display angles under two different lighting conditions. In order to avoid the reflection of the light spot appearing on the display at certain angles in the full light condition, we only used the natural light and the room light conditions in Measurement II. The measurements were conducted with counterbalance between the with/without glasses conditions and the two lighting conditions.

Table 1. The average of the luminance and illuminance on Measurement II in the two lighting conditions.

Illuminance (lux)						
Display Angles	60	45	30	15	0	-15
Natural	14.19 ± 7.46	13.6 ± 8	13.93 ± 7.57	12.47 ± 4.29	11.83 ± 3.89	15.74 ± 7.78
Room	223.37 ± 18.52	224.1 ± 19.43	224.56 ± 14.67	216.41 ± 14.21	206.67 ± 7.82	209.73 ± 11.26
Luminance (cd/m ²) in Natural Light						
Display Angles	60	45	30	15	0	-15
Dark Display	0.34 ± 0.29	0.37 ± 0.33	0.44 ± 0.39	0.46 ± 0.39	0.3 ± 0.27	0.16 ± 0.18
Bright Display	2.83 ± 2.44	2.42 ± 2.01	2.33 ± 1.98	1.78 ± 1.51	1.69 ± 1.43	1.02 ± 0.95
Luminance (cd/m ²) in Room Light						
Display Angles	60	45	30	15	0	-15
Dark Display	0.38 ± 0.31	0.42 ± 0.41	0.46 ± 0.37	0.57 ± 0.48	0.37 ± 0.29	0.24 ± 0.22
Bright Display	3.39 ± 2.56	2.7 ± 2.07	2.58 ± 2.03	2.13 ± 1.61	1.61 ± 1.28	0.99 ± 0.88

A. Method

1. Participants

Thirty participants were invited to participate in this measurement. They were 16 males and 14 females. Their ages ranged from 21 to 47 (mean = 27.6 years, $SD \pm 6.84$ years). Twelve participants had uncorrected vision, 7 participants wore contact lenses and 11 participants wore glasses with an average thickness of 2.1 mm, $SD \pm 0.6$ mm.

The height of the participants was between 145 and 181 cm (mean = 167.7 cm, SD $\pm$ 9.52 cm). Because we also wanted to obtain data from persons viewing from high positions (>185 cm) and from persons viewing from low positions (<140 cm), i.e., when sitting, some participants' viewing heights were manipulated. To obtain data for persons viewing from below 140 cm, we asked two participants to sit on a chair (with a height of 46 cm from seat to floor). While they sat on the chair we measured their height from the top of their head to the floor. To obtain data from persons taller than 185 cm, and thus viewing from a relatively high position, we asked three participants with a height 170 cm, 178 cm, and 181 cm, respectively, to stand on a stair at a height of 26 cm from the floor. Twenty-four participants were Asian (Japanese, Chinese, Indonesian), 1 participant was Caucasian, and 5 participants were Hispanic/Latinos. After the procedures were explained to the participants, they signed an informed consent form. Each participant was paid for their participation.

2. Apparatus

The Eye Tribe[®] software was installed on a touch-screen display (Microsoft Surface 4, 12-in). The eye tracker was placed below the display and together they were fixed on a tripod at a height of 133 cm from the ground. The tripod was used to facilitate the angle adjustment of the eye tracker and display. The different angles of the eye tracker and the display screen were measured under two lighting conditions: natural lighting and room lighting, as used in Measurement I. The full lighting condition was not used in this measurement because sometimes there was a reflection of spot light on the display when the display angles were changed. Each calibration process was timed with a stopwatch. Illuminance and luminance were measured at every display angle under two different lighting conditions in the same way and with the same equipment as in Measurement I (Table 1).

3. Procedures

After written informed consent was obtained and a face photo was taken at a viewing distance of 40 cm, the participants were asked to follow the instructions. First, the participants were asked to stand in the middle in front of the screen without crossing a floor mark set at a viewing distance of 40 cm. While standing, the participants were asked to relax and to take a natural viewing position. They were asked to maintain this natural viewing position during calibration, as if they were using an ATM machine. Two participants were instructed to sit and to maintain a natural viewing position throughout the calibration. All participants were instructed to make no head movements even when the angle of the display was changed. Second, the participants were asked to perform calibration under different display and eye tracker angles, in order to assess their ideal viewing angle. The following 9 display angles were used: 60°, 45°, 30°, 15°, 0°, -15°, -30°, -45°, and -60° (Figure 3).

Third, with regard to the participants' eyesight (with or without glasses), we performed the same procedure as in Measurement I. The participants performed the calibration both with and without glasses under the 9 display angles, under the two different lighting conditions. We did not measure the calibration time when the eyes of the participants did not appear on the calibration display, indicating that the eye tracker could not detect the participant's eyes (invalid tracking). Each participant performed the calibration with randomized display angles.

The order of wearing glasses and lighting conditions was counterbalanced among participants. We did not repeat the measurement when the calibration result was 'Poor', 'Redo' or 'Uncalibrated'. The measurements took about 60 minutes for each participant.

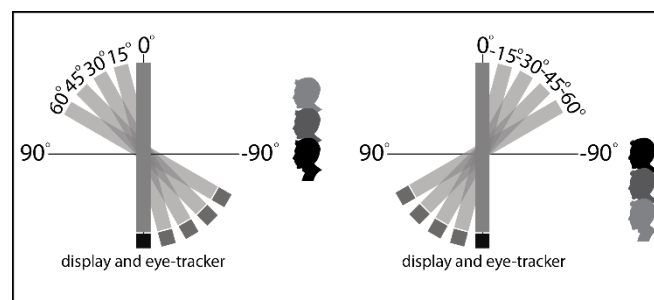


Figure 3. The angles of the display and eye tracker used in Measurement II. Participants were asked to maintain a natural viewing position while they tried to register into the eye-tracking system under various display and eye tracker angles in random order.

B. Results

The data show that 16 participants could register into the eye-tracking device at two display angles, and 14 participants could register at one display angle. The display angles depended on the participant's viewing height. We will call the display angles "first angle" (n=30) and "second angle" (n=16). A Pearson's correlation analysis was performed to determine the relationship between the viewing height of the participants and the angles of the eye tracker and the display that allowed registration. There was a significant correlation between the viewing height of the participants and the first angle of the display they could register themselves with ($r = 0.94$, $n=30$, $p<0.001$), as well as a significant correlation between the viewing height of the participants and the second angle of the display they could register with ($r = 0.97$, $n=16$, $p<0.001$).

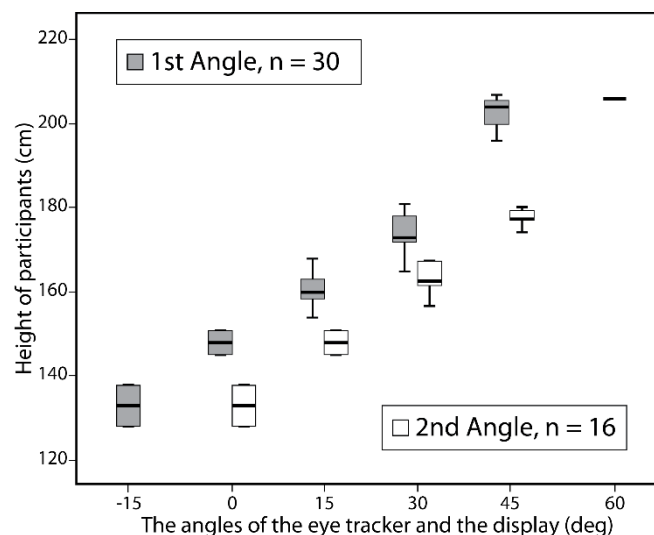


Figure 4. The gray boxes and white boxes show the first and second angles, respectively, of the eye tracker and the display under which participants could register into the eye tracking device. The angles are plotted against the participant's (viewing) heights. Error bars indicate $\pm$ 1 SD.

Figure 4 shows the box plot of the data, showing a linear relation between the angles of the display and the height of the participants under which they could register themselves into the eye-tracking system. Roughly summarized over the data of both angles combined, the participants with a height

of 200-220 cm could register into the eye-tracking device at a display angle of 60° or 45°. The participants of 180-200 cm could register at 45° and 30°, while those of 160-180 cm could register at display angles of 15° and 0°. The participants who were sitting and viewing from below 140 cm could register at 0° and -15°. The results convincingly show that in order to use eye trackers in a public setting, e.g., for ATM machines, users need to be able to adjust the display angle according to their height. Especially people viewing from below 140 cm, such as wheel-chair users, require a very different angle than people standing up.

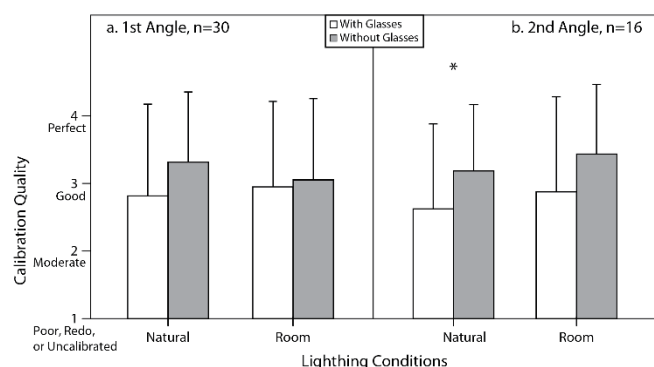


Figure 5. Eye-tracking calibration quality obtained at the first and second angle with participants wearing prescription glasses or replica glasses (white bars) and the same participants without glasses (gray bars) obtained under two lighting conditions in Measurement II. Error bars indicate ± 1 SD. Asterisks indicate a significant difference between conditions ($p < 0.05$).

Figure 5 shows that, similar to the results of Measurement I, the quality of the registration into the eye-tracking device is better without glasses than with glasses. The calibration quality for participants with glasses (white bars) at the first angle was 2.8 ± 1.35 under natural lighting, and 2.93 ± 1.26 under room lighting. At the second angle it was 2.63 ± 1.26 and 2.88 ± 1.41 for natural and room lighting, respectively. The calibration quality for the same participants without glasses (gray bars) at both angles was higher; at the first angle it was 3.3 ± 1.03 under natural lighting and 3.04 ± 1.2 under room lighting. At the second angle it was 3.2 ± 0.98 under natural lighting and 3.44 ± 1.03 under room lighting.

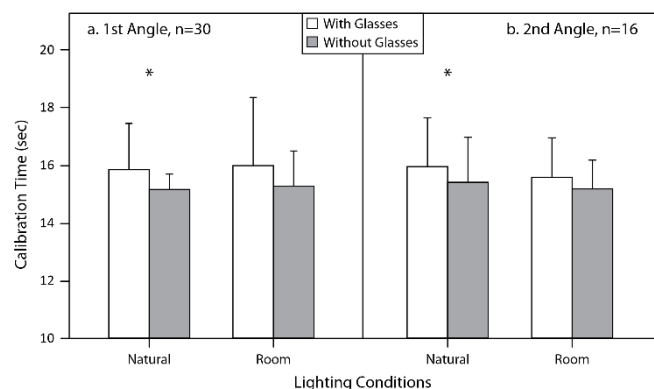


Figure 6. Eye-tracking calibration time obtained at the first and second angle for participants wearing prescription glasses or replica glasses (white bars) and the same participants without glasses (gray bars) obtained under two lighting conditions in Measurement II. Error bars indicate ± 1 SD. Asterisks indicate a significant difference between conditions ($p < 0.05$).

Figure 6 shows that the registration time was also shorter overall without glasses. The calibration time needed by participants without glasses (gray bars) at the first angle

(natural lighting: 15.16 ± 0.53 sec; room lighting: 15.27 ± 1.21 sec) and at the second angle (natural lighting: 15.43 ± 1.57 sec; room lighting: 15.19 ± 1.00 sec) was shorter than the calibration time needed by the same participants with glasses (white bars) at the first angle (natural lighting: 15.85 ± 1.6 sec; room lighting: 15.98 ± 2.36 sec) and at the second angle (natural lighting: 15.97 ± 1.7 sec; room lighting: 15.6 ± 1.37 sec).

Paired comparisons were performed to determine whether the use of glasses influenced calibration quality and calibration time within each lighting condition for participants with and without glasses using Wilcoxon signed-rank tests. Three participants with prescription glasses were not able to perform the calibration without glasses at their first angle. Their data were excluded from the tests. The difference in the first-angle calibration quality between participants with and without glasses under natural lighting ($Z = -1.915$, $p = 0.056$) and room lighting ($Z = -0.32$, $p = 0.975$) was not significant, although the difference under natural lighting bordered on significance. Similarly, the second-angle calibration quality was not significantly different between participants with glasses and without glasses under room lighting ($Z = -1.709$, $p = 0.088$). However, calibration quality at the second angle was significant under natural lighting ($Z = -2.124$, $p = 0.034$).

As regards calibration time, a significant difference was found for the first angle data ($Z = -2.423$, $p = 0.015$) and the second angle data ($Z = -2.435$, $p = 0.015$) between participants with glasses and without glasses under natural lighting. No significant difference at the first angle ($Z = -1.83$, $p = 0.068$) and at the second angle ($Z = -0.683$, $p = 0.495$) was found under room lighting.

IV. DISCUSSION & CONCLUSION

Measurement I with the Eye Tribe® eye-tracking device showed that the calibration quality of participants who wore prescription glasses or replica glasses was 'Moderate' (average 2.06 on a scale of 4) under natural lighting. The calibration under natural lighting with the same participants without glasses, though, was closer to 'Good' (average 2.88 on a scale of 4). In the room lighting and the full lighting conditions, the calibration quality for participants with glasses was similarly 'Moderate' (room lighting: 1.63; full lighting: 1.75), and almost 'Good' without glasses (room lighting: 2.5; full lighting: 2.88). Measurement I also showed that the calibration time required by participants was about 1-3 seconds longer on average when they wore (replica or prescription) glasses than when they did not. The negative effect of glasses on the calibration quality and time as found here could be due to the presence of light reflection and glare, or due to the fact that when tracking an object high in the visual field, the participants' eyes were occluded by the frame of the glasses.

Measurement II with the Eye Tribe® eye-tracking device showed a significant correlation between the height of the participants and the angles of the eye tracker and the display under which they could register themselves. In short, if the participant was tall or viewing from a high position looking down on the display, the display should be angled upwards in a more horizontal position for registration to occur. By contrast, people sitting down on chairs or in wheelchairs would benefit from a vertical display position or a downward angle.

Overall, the results of the calibration quality and the calibration time obtained in Measurement II were better as in Measurement I. Although no statistics were performed due to differences in group sizes, the average quality for participants with glasses under natural and room lighting in Measurement I, from a 90° viewing angle, was 2.06 and 1.63, respectively. In measurement II the average quality markedly improved: 2.8 and 2.93 at the first angle, respectively, and 2.63 and 2.88 at the second angle, respectively. The calibration time obtained for participants with glasses in Measurement II under natural and room lighting (at the first angle 15.85 sec and 15.98 sec, and at the second angle 15.97 sec and 15.6 sec, respectively) was also faster than that obtained in Measurement I (17.64 sec and 18.75 sec, respectively). Measurement II thus strongly suggests that in order to achieve good and fast calibration, the eye-tracking device and the display need to be set at a certain angle, depending on viewing height.

In conclusion, both measurements show that a low-cost eye-tracking device can be consistently effective under different lighting conditions. This device thus can be used for visual password registration in public spaces for registration into ATMs or personal computers, and other devices that require authentication. Both measurements, however, show that the use of glasses indeed can influence the registration into the system. Our measurements convincingly show this in direct comparisons of participants wearing replica or prescription glasses and the same participants without glasses. Nevertheless, when the display angle is adjusted to the participant's (viewing) height, participants should be able to perform the calibration and authentication without problems even with glasses. Future studies on eye tracking for visual password registration should explore different visual password formats and preferences from people of all ages and different ethnicities.

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