Tobii Technology AB

Accuracy and precision Test report

X1 Light Eye Tracker

Date: 2011 12 12
Methodology/Software version: 2.1.1

1. Introduction

This document provides an overview of tests in terms of accuracy and precision regarding the Tobii X1 Light Eye Tracker. The tests were conducted by the Department of Quality Assurance, Hardware Division of Tobii Technology AB, and took place in November 2011.

1.1 Product

Product category: Remote eye trackers
Manufacturer: Tobii Technology AB
Trademark: Tobii Technology
Type designation: X1 Light Eye Tracker
Firmware version: 1.4.2
Serial Number: ISFM1-010101030522

1.2 Method

The tests were performed in accordance with the Accuracy and Precision Test Specification version 2.1.1, developed by Tobii Technology AB. This document can be downloaded from the Tobii site (www.tobii.com).
20 test participants were recruited from Tobii Technology AB's local office in Stockholm. The subjects were selected according to the "ideal population" criteria described in the test specification document. As a consequence, individuals with sight correction, droopy eyelids or poor fixation abilities* were excluded from the tests. All subjects were between 20-50 years old (nine people between 21-30, ten between 31-40, and one person over 40 years of age). Among the subjects, eleven had blue eyes, two had green eyes and seven had brown eyes. There were five people who had the left and fifteen had the right eye as the dominant eye; and all subjects were Caucasian.
All tests were performed in the Department of Quality Assurance test lab, at Tobii Technology AB Headquarters. The lab set-up provides adequate conditions to perform accuracy and precision tests in a controlled environment (figure 1). All tests were conducted by an experienced hardware technician.

* For more information on this criteria please consult the Accuracy and Precision Test Specification.

Figure 1, Test setup in the lab. The measurement setup is based on an XYZ-table (illustration in the upper, right corner in the image), and allows the eye tracker to be transferred to the specific positions in the head position tests. The participant is positioned in front of the eye tracker, using a chinrest in order to fixate the eyes' location. The lamps with soft boxes are positioned around the table to create an even light-spread in the room (for more details on the lab and test setup please contact Tobii Support to receive a copy of the Test Specification document.)

The center of the track box was set to 65 cm from the eye tracker. The following five conditions were tested in successive tests: ideal conditions, large gaze angles, varying head positions, varying illumination and white background (Table 1 displays a summary of the different conditions tested). There was a short break between each test trial for the test leader to change conditions and for the participant to rest her/his eyes. Each test session took on average 45 minutes.

Accuracy and precision values measured on human eyes were based on stimulus points on a TFT screen (1920 x 1200 pixels) mounted with a Tobii X1 Light Mounting Bracket. The test subjects were asked to focus their gaze on each of the points in a test trial. Each point was presented for 2 seconds and the points were presented in random order. The target points were used in order to calculate accuracy, with the center point as a reference point in relation to the measured gaze point. Precision was measured from the same data for each point individually. All tests were performed with the subject in a chinrest. In order to separate human precision errors from system inherent precision, a series of tests were also performed using synthetic eyes.

Table 1, Manipulated variables in each of the accuracy/precision tests. The table describes the different test categories and which variables are manipulated for each of them.

		Ideal conditions	Large gaze angles	Varying illumination	White background	Varying head positions
20 Participants (Same for all tests)	**Eye color**	Mixed	Mixed	Mixed	Mixed	Mixed
	Sight correction	None	None	None	None	None
	Age (years)	20 - 50	20 - 50	20 - 50	20 - 50	20 - 50
Calibration		9-point default	9-point default	9-point default	9-point default	9-point default
Gaze angle		≤20°	**25°, 30°**	≤20°	≤20°	≤20°
Illumination		300 lux	300 lux	**Manipulated**	300 lux	300 lux
Stimulus (Foreground/ background color)		White/Black	White/Black	White/Black	**Black/White**	White/Black
Eye placement in box		Center of box	Center of box	Center of box	Center of box	**Manipulated**

The accuracy and precision calculations are specified in the Accuracy and Precision Test Specification document. The variable "Precision" is as described in the specification calculated via the RMS of successive samples, whereas SDPrecision is the standard deviation measure of the data set. All accuracy and precision results are based on pure raw data, collected directly from the SDK after personal calibration. A filter is only applied to the raw data on the artificial eye precision calculations (Section 2.6.1).

2. Results

2.1 Summary

Average binocular accuracy and precision values for all tests are presented in table 1. For Head positions the best and poorest attained value is specified for each dimension. In addition to accuracy and precision values, (N) is the passing number of participants in each test. The results of these measurements show a large track box with an overall good accuracy and precision. The most extreme position in the track box (head placement over track box center and close edge of track box) was removed as too few participants attained tracking according to the requirements of the method. All other conditions met the requirements. The Tobii X1 Light Eye tracker performed poorer precision wise in the illumination tests and accuracy wise at the far edges of the track box.

Table 1, All results. The table presents the binocular accuracy and precision results for all test conditions. N is the number of participants who met the method requirement, i.e. used for analysis. For the head position tests, where several tests were performed in each direction the best and poorest value is specified. As specified in the test specification, all measurements are without raw data filter. The precision measurements on artificial eyes are also presented with raw data filter (Stampe, level 2).

		N	Accuracy (°)	Precision (°)
Ideal conditions	20°	19	0.5	0.23
Large Gaze angles	25°	19	0.3	0.21
	30°	18	0.3	0.21
Illumination variation	1 lux	17	0.9	0.20
	600 lux	19	0.5	0.77
	1000 lux	18	0.5	0.87
	White background (300 lux)	19	0.5	0.55
Head position variation	Z axis	19 - 20	0.5 - 0.8	0.23 - 0.39
	X axis	18 - 20	0.5 - 1.3	0.23 - 0.38
	Y axis	19 - 20	0.5 - 1.3	0.23 - 0.42
Artificial eyes	Raw data			0.20
	Stampe filter level 2			0.06

2.2 Accuracy and precision at ideal conditions

The binocular and monocular accuracy and precision values under ideal conditions are presented in table 2. Standard deviation precision (SD Precision) is presented as a complement to the regular precision value. 95% of the participants met the track requirements (N=19). The average value for each metric is specified along with the standard deviation (Std). The distribution for all participants is presented in appendix 1.

Table 2, Accuracy and precision under ideal conditions. The average and monocular accuracy and precision are presented along with the standard deviation (Std) for each metric. SD Precision is presented as a reference measure to the regular precision value.

			Accuracy		Precision		SD Precision
		N	Binocular	Monocular	Binocular	Monocular	Binocular
Ideal conditions	Average	19	0.5	0.5	0.23	0.32	0.20
	Std		0.2	0.2	0.06	0.09	0.04

2.3 Accuracy and precision with large gaze angles

The binocular and monocular accuracy and precision results at large gaze angles are presented in table 3, as well as in diagram 1 and 2. The average value for each metric is specified along with the standard deviation (Std). The distribution among the participants is presented in appendix 2.

Table 3, Accuracy and precision at 25 and 30 degrees gaze angle. Binocular and monocular accuracy and precision values are presented for both angles of measurements. The average values are presented along with the standard deviation (Std).

			Accuracy		Precision	
		N	Binocular	Monocular	Binocular	Monocular
25° Gaze angle	Average	19	0.3	0.4	0.21	0.31
	Std		0.2	0.2	0.10	0.15
30° Gaze angle	Average	18	0.3	0.4	0.21	0.30
	Std		0.1	0.1	0.10	0.17

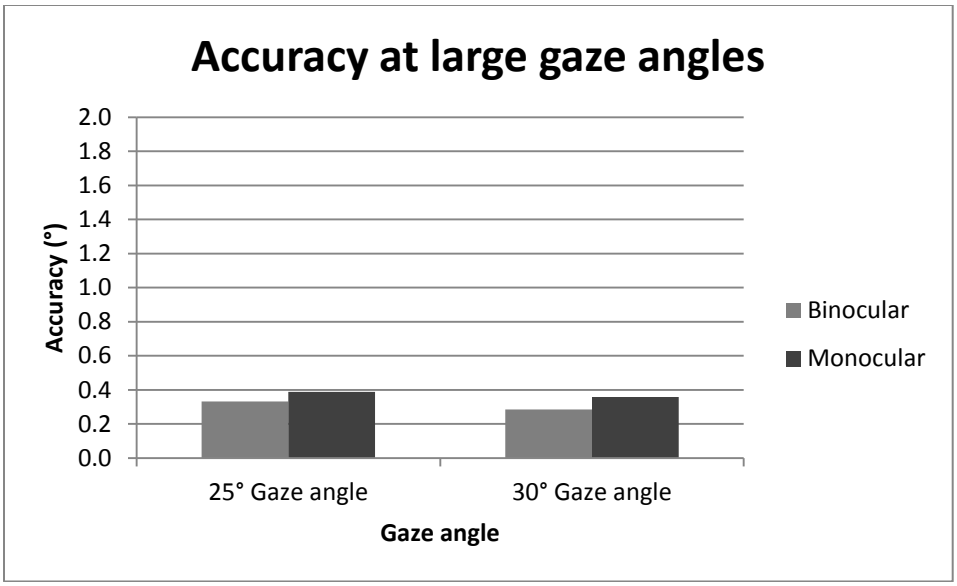


Diagram 1, Accuracy at large gaze angles. The average binocular and monocular accuracy is presented for both measured gaze angles.

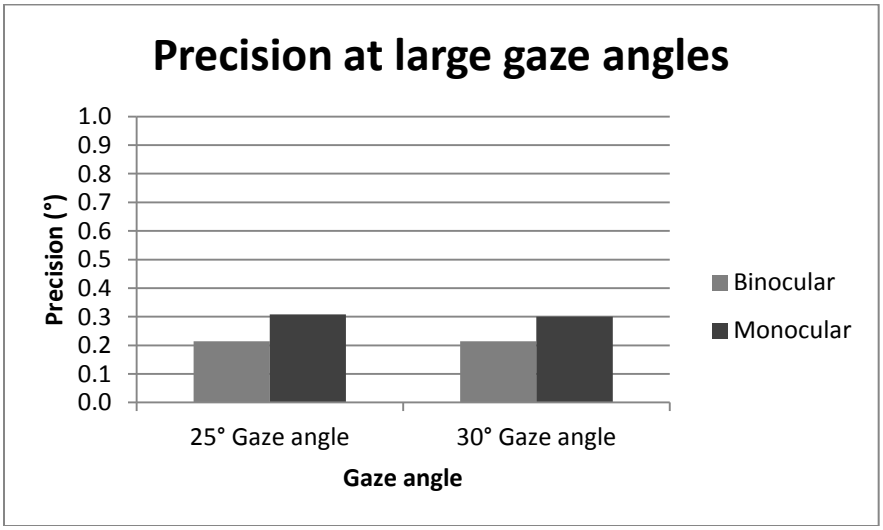


Diagram 2, Precision at large gaze angles. The average binocular and monocular accuracy is presented along with both measured gaze angles.

2.4 Accuracy and precision with varying illumination

Binocular and monocular accuracy and precision results for the illumination test are presented in table 4, as well as in diagram 3 and 4. All tests met the participant requirement with the darkness test the lowest results with 85% of the group passing the test (N=17). The average value for each metric is specified along with the standard deviation (Std). The distribution among the participants is presented in appendix 3. The performance at 300 lux is the same as ideal conditions, but presented here as a baseline to compare to the illumination manipulated tests.

Table 4, Accuracy and precision under varying illumination and stimuli background. The number of participants who met the tracking requirements is presented along with the binocular and monocular accuracy and precision data for each test condition.

			Accuracy		Precision	
		N	Binocular	Monocular	Binocular	Monocular
1 lux (darkness)	Average	17	0.9	1.4	0.20	0.26
	Std		0.7	0.5	0.05	0.07
300 lux	Average	19	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09
600 lux	Average	19	0.5	0.8	0.39	0.54
	Std		0.2	0.3	0.15	0.21
1000 lux	Average	18	0.5	0.9	0.44	0.61
	Std		0.2	0.4	0.13	0.18
White background (300 lux)	Average	19	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09

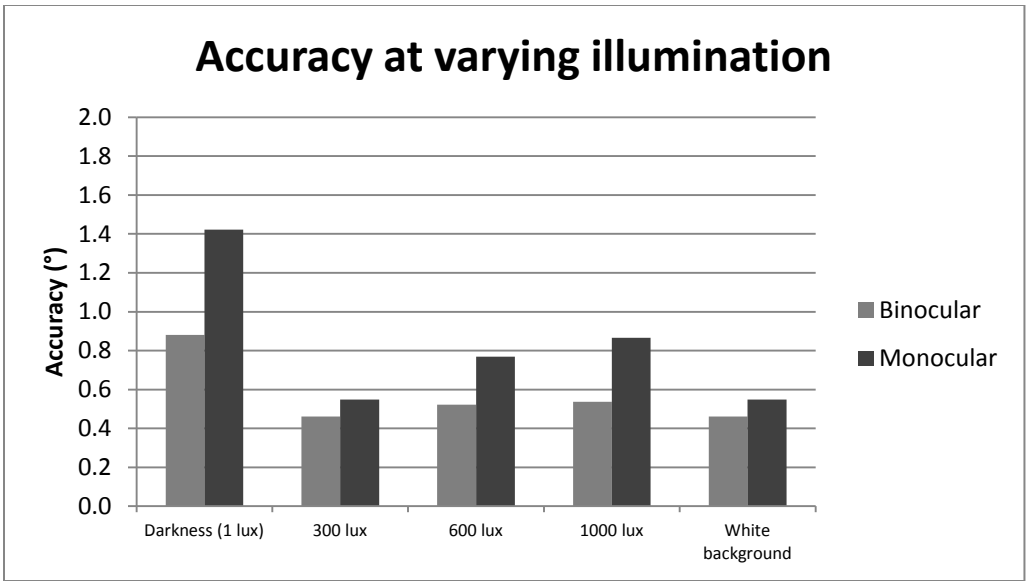


Diagram 3, Accuracy under varying illumination. Binocular and monocular accuracy data is presented for each illumination condition.

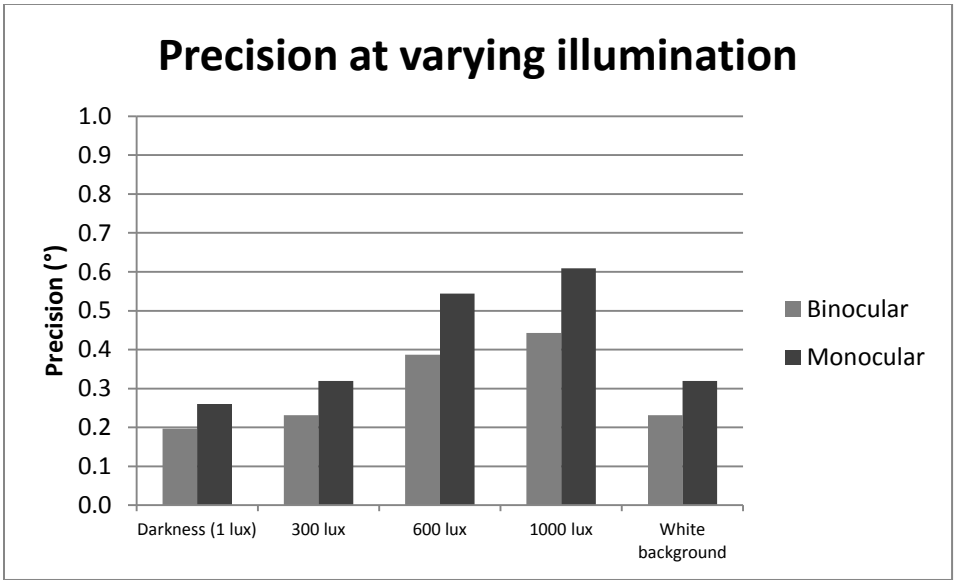


Diagram 4, Precision under varying illumination. Binocular and monocular precision data is presented for each illumination condition.

2.5 Accuracy and precision with varying head positions

The tests with varying head positions are divided into three dimensions, X, Y and Z, and presented individually.

2.5.1 Distance from eye tracker, Z axis

The accuracy and precision measured at varying distances from the eye tracker (X=0, Y=0) are presented in table 5 and diagram 5 and 6. In these diagrams the distribution (max, min and SD from mean) is illustrated with boxes and vertical lines. The average value for each metric is specified along with the standard deviation (Std). No data is specified for 50 cm since too few participants obtained a passing result (N<17).

Table 5, Accuracy and precision at varying distances from the eye tracker. The binocular and monocular accuracy and precision are presented in average values along with the standard deviation (Std) and the number of participants who met the tracking requirements (N) for each distance.

			Accuracy (°)		**Precision (°)**	
Distance		N	Binocular	Monocular	Binocular	Monocular
50 cm	Average	16	NA	NA	NA	NA
	Std		NA	NA	NA	NA
55 cm	Average	20	0.6	0.8	0.27	0.37
	Std		0.2	0.2	0.09	0.12
60 cm	Average	20	0.5	0.7	0.24	0.33
	Std		0.1	0.2	0.07	0.10
65 cm	Average	20	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09
70 cm	Average	20	0.6	0.8	0.30	0.42
	Std		0.2	0.2	0.15	0.21
75 cm	Average	19	0.6	0.8	0.31	0.42
	Std		0.2	0.2	0.15	0.23
80 cm	Average	20	0.8	1.0	0.39	0.52
	Std		0.3	0.3	0.13	0.19

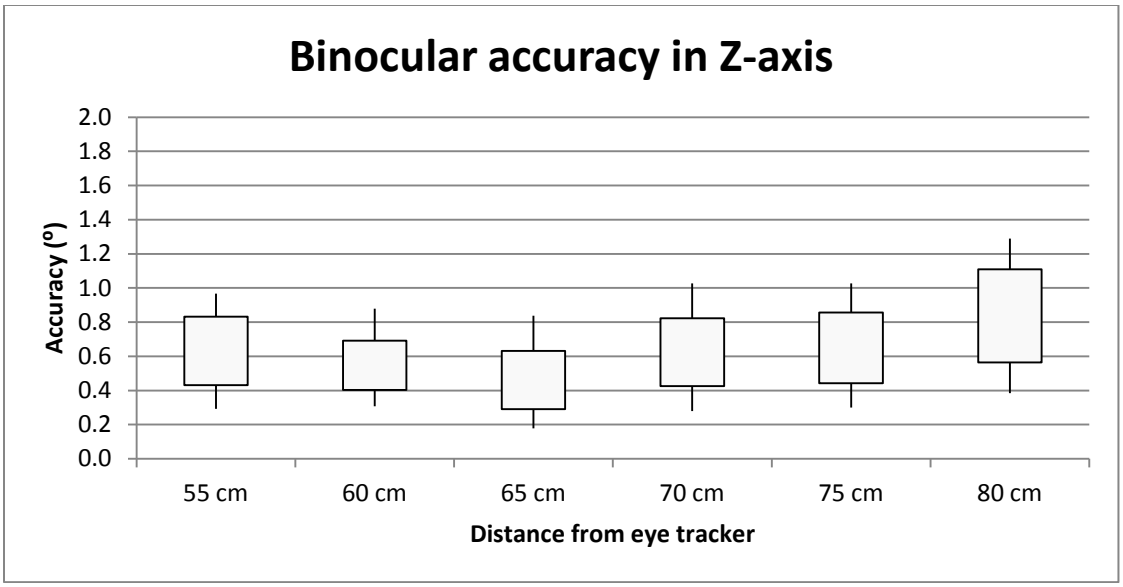


Diagram 5, Binocular accuracy at varying positions in Z axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

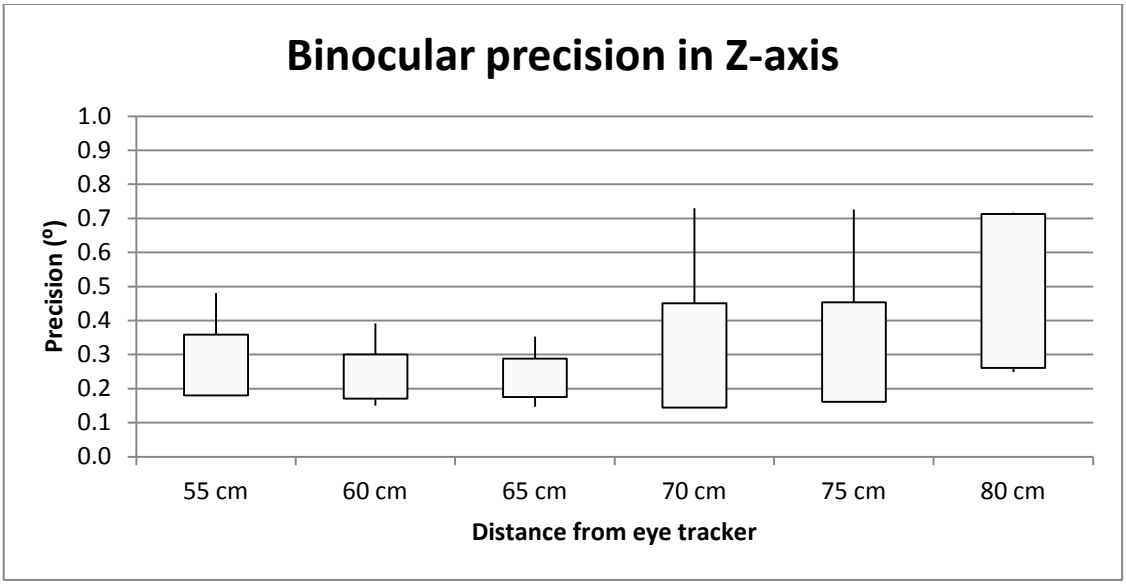


Diagram 6, Binocular precision at varying positions in Z axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

2.5.2 Horizontal, X axis

Binocular accuracy and precision

The binocular and monocular accuracy and precision measured at varying distances from center of track box (Z=65 cm, Y=0) are presented in table 6 and diagram 7 and 8. In these diagrams the average value is presented with a line and the distribution (max, min and SD from mean) is illustrated with boxes and vertical lines.

Table 6, Accuracy and precision at varying positions in X axis. The average value for each metric is specified along with the standard deviation (Std). The number of participants who met the tracking requirements (N) is presented for each test.

			Accuracy (°)		Precision (°)	
Distance		N	Binocular	Monocular	Binocular	Monocular
15 cm	Average	18	1.3	1.4	0.38	0.51
	Std		0.5	0.4	0.17	0.23
10 cm	Average	20	0.9	1.0	0.32	0.43
	Std		0.4	0.4	0.13	0.17
5 cm	Average	20	0.6	0.7	0.27	0.39
	Std		0.2	0.1	0.10	0.15
0 cm	Average	20	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09
-5 cm	Average	19	0.6	0.7	0.25	0.35
	Std		0.2	0.2	0.08	0.12
-10 cm	Average	20	0.8	0.9	0.29	0.40
	Std		0.3	0.4	0.12	0.17
-15 cm	Average	20	1.1	1.2	0.32	0.46
	Std		0.4	0.5	0.13	0.21

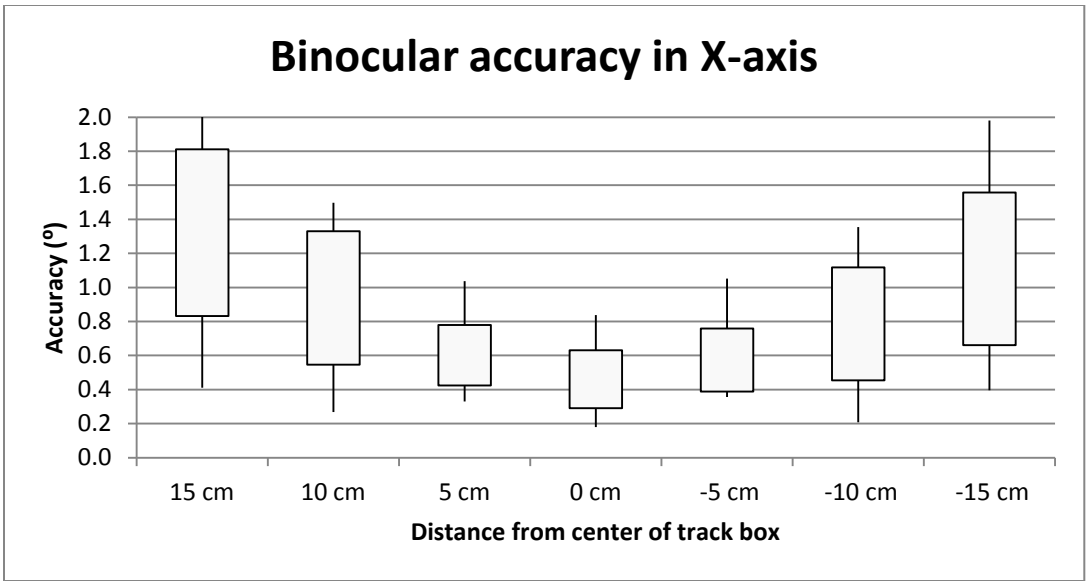


Diagram 7, Binocular accuracy at varying positions in X axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

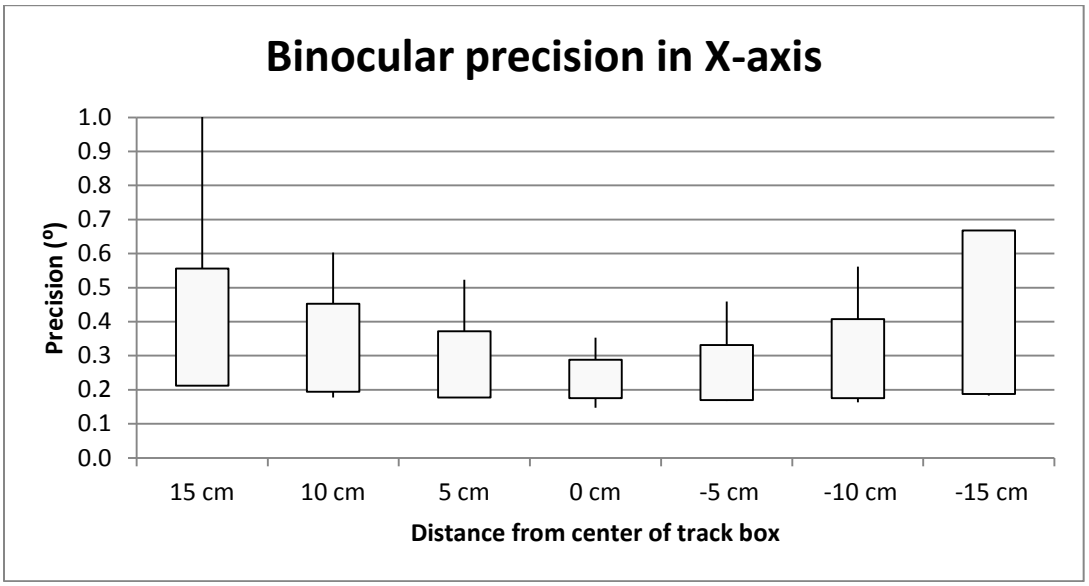


Diagram 8, Binocular precision at varying positions in X axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

Monocular accuracy and precision

The monocular accuracy and precision measured at varying distances from center of track box in X (Z=65 cm, Y=0) are presented in table 7 and diagram 9 and 10. The distribution is presented in diagram 14 and 16. In these diagrams the distribution (max, min and SD from mean) is illustrated with boxes and vertical lines.

Table 7, Monocular accuracy and precision in X axis. The monocular data is based on the dominant eye for each participant in all tests except the most extreme test, where the eye visible in the track box was used for accuracy and precision calculations. The number of participants who met the tracking requirements (N) is presented for each test.

			Accuracy (°)		**Precision (°)**	
Distance		N	Binocular	Monocular	Binocular	Monocular
15 cm	Average	18	1.3	1.4	0.38	0.51
	Std		0.5	0.4	0.17	0.23
10 cm	Average	20	0.9	1.0	0.32	0.43
	Std		0.4	0.4	0.13	0.17
5 cm	Average	20	0.6	0.7	0.27	0.39
	Std		0.2	0.1	0.10	0.15
0 cm	Average	20	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09
5 cm	Average	19	0.6	0.7	0.25	0.35
	Std		0.2	0.2	0.08	0.12
10 cm	Average	20	0.8	0.9	0.29	0.40
	Std		0.3	0.4	0.12	0.17
15 cm	Average	20	1.1	1.2	0.32	0.46
	Std		0.4	0.5	0.13	0.21

* The accuracy and precision values on ± 15 cm are based on the eye within the track box, remaining on the dominant eye as both eyes are placed inside the track box.

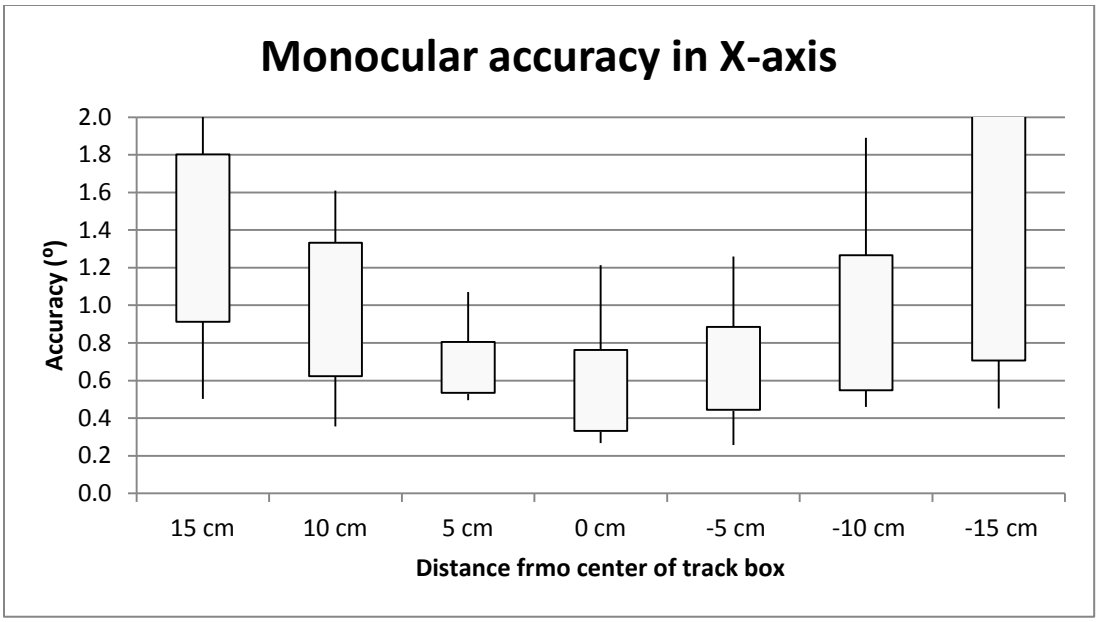


Diagram 9, Monocular accuracy at varying positions in X axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

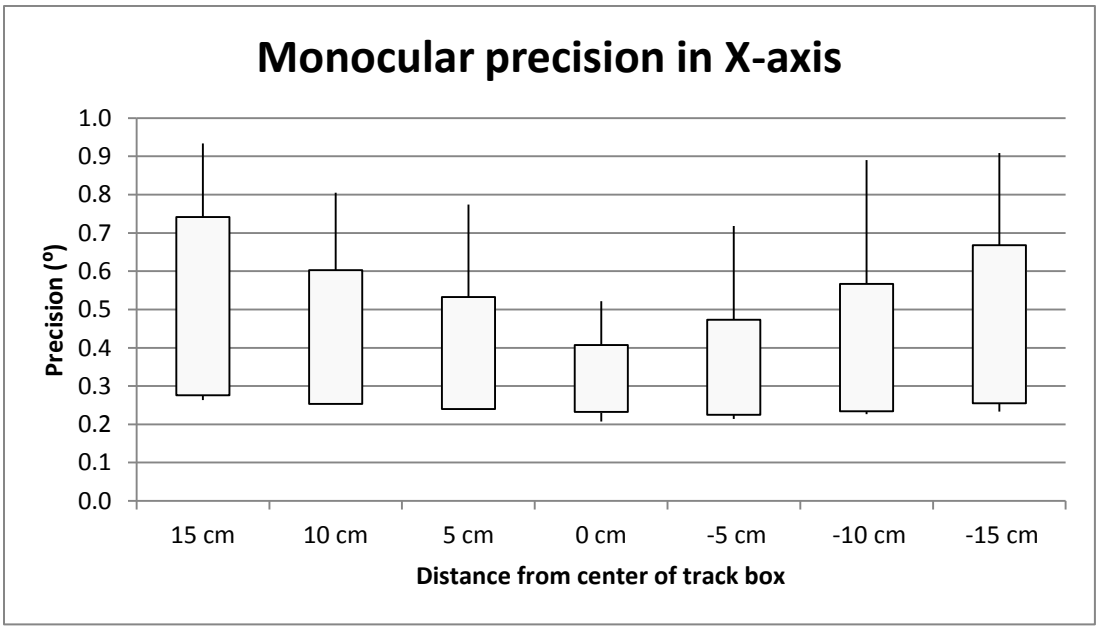


Diagram 10, Monocular precision at varying positions in X axis. The maximum/minimum and standard deviation from mean is presented with boxes and vertical lines.

2.5.3 Vertical, Y axis

The accuracy and precision measured at varying distances from center of track box (Z=65 cm. X=0) are presented in table 8 and diagram 11 and 12. In these diagrams the distribution (max. min and SD from mean) is illustrated with boxes and vertical lines. As can be seen the eye tracker allows more movement when moving head down in box than moving the head up which is related to the configuration.

Table 8, Accuracy and precision at varying positions in Y axis. The binocular and monocular accuracy and precision are presented as the average values along with the standard deviation (Std) and the number of participants who met the requirements (N) for each test trial.

			Accuracy (°)		**Precision (°)**	
Distance		N	Binocular	Monocular	Binocular	Monocular
15 cm	Average	1	NA	NA	NA	NA
	Std		NA	NA	NA	NA
10 cm	Average	19	1.0	1.1	0.32	0.43
	Std		0.3	0.3	0.14	0.18
5 cm	Average	19	0.6	0.7	0.24	0.33
	Std		0.3	0.3	0.08	0.09
0 cm	Average	19	0.5	0.5	0.23	0.32
	Std		0.2	0.2	0.06	0.09
5 cm	Average	20	0.6	0.7	0.31	0.41
	Std		0.2	0.2	0.16	0.21
10 cm	Average	20	0.9	1.0	0.31	0.43
	Std		0.3	0.3	0.14	0.17
15 cm	Average	20	1.3	1.4	0.42	0.57
	Std		0.5	0.5	0.20	0.25

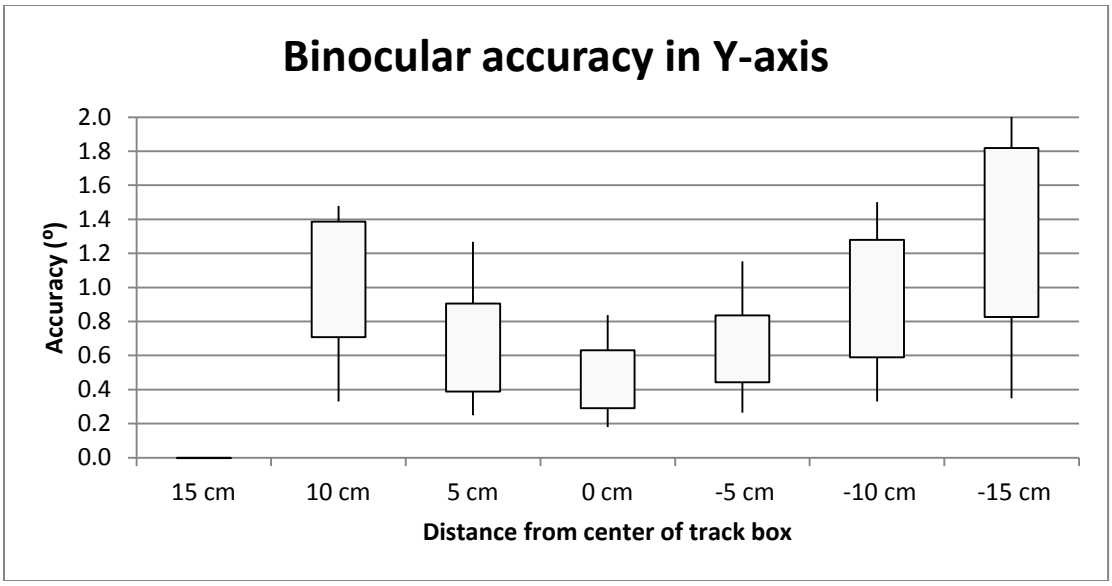


Diagram 11, Binocular accuracy at varying positions in Y axis. The average accuracy is illustrated with a line, and the max/min and standard deviation from mean is presented with boxes and vertical lines.

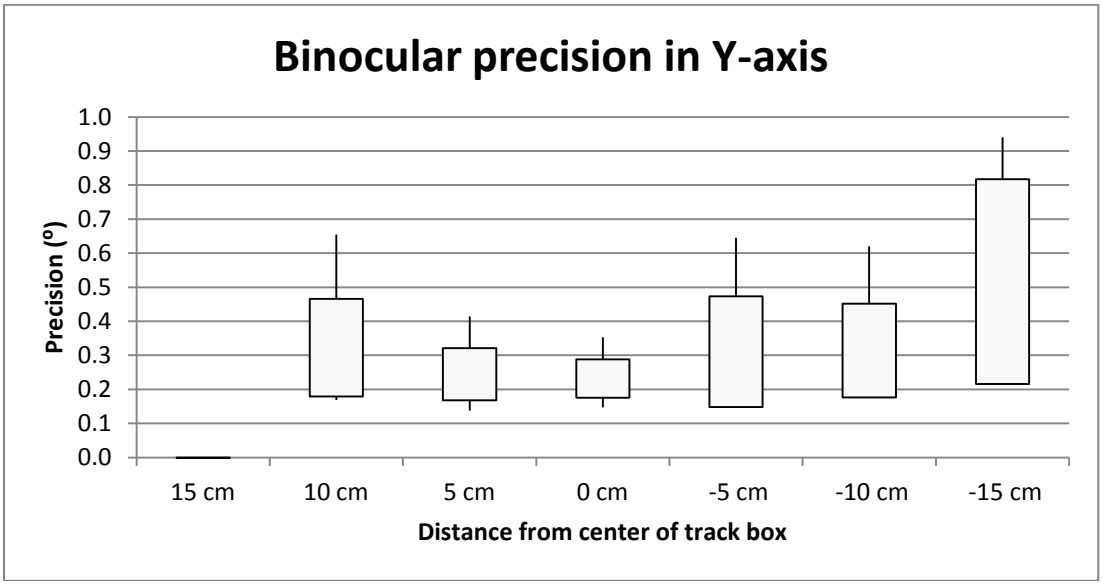


Diagram 12, Binocular precision at varying positions in Y axis. The average accuracy is illustrated with a line, and the max/min and standard deviation from mean is presented with boxes and vertical lines.

2.6 Artificial eye precision

2.6.1 Ideal artificial precision

Artificial eye precision is presented with and without added filter (Table 9). Since the Tobii X1 Light tracks with both dark and bright pupils, precision is to be measured using eyes of each property. Currently, there is no bright pupil data as no such artificial eyes are yet developed.

Table 9, Artificial eye precision. Binocular and monocular artificial precision is presented with and without added filter. The stampe filter level 2 is a filter commonly used with eye tracking data (Stampe. 1993).

	Dark pupil		**Bright pupil**	
n = 9*	Binocular	Monocular	Binocular	Monocular
Raw data	0.20	0.27	NA	NA
Stampe filter 2	0.06	0.08	NA	NA

* n, in the case of artificial eyes, is the number of data sets (each one second of data) the precision value is based upon.

2.6.2 Artificial precision at varying distances

Binocular and monocular artificial eye precision at varying distances from the eye tracker is presented in table 10 as well as diagram 13.

Table 10, Artificial eye precision at varying distances from the eye tracker. Binocular and monocular data is presented for each distance position. As for the human measurements, the number of data sets is nine (nine points of data collection).

n=9*	**Artificial eye precision**	
Distance	Binocular	Monocular
45 cm	0.22	0.31
50 cm	0.18	0.23
55 cm	0.14	0.18
60 cm	0.16	0.19
65 cm	0.20	0.27
70 cm	0.21	0.25
75 cm	0.29	0.38
80 cm	0.48	0.48
85 cm	0.52	0.70

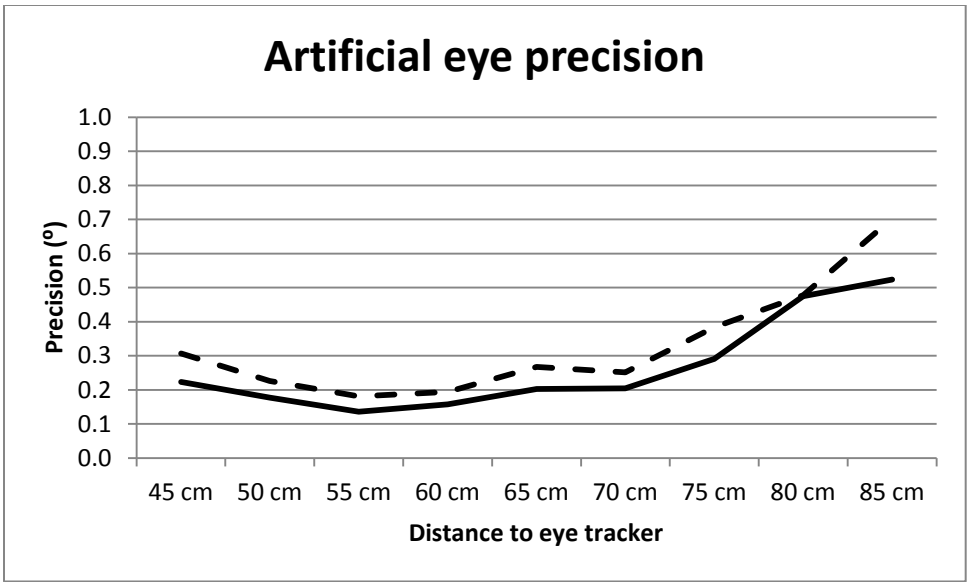


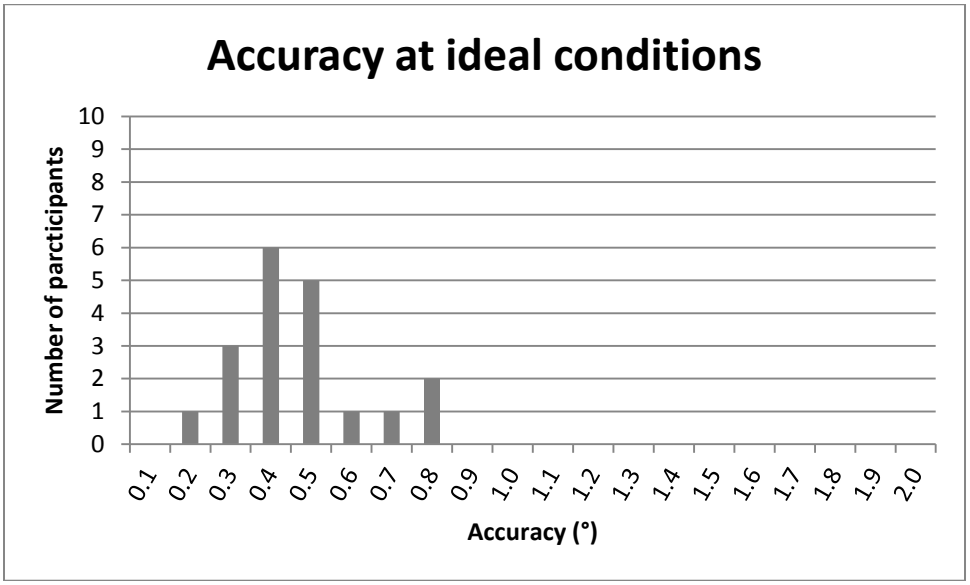
Diagram 13, Artificial eye precision at varying distances from the eye tracker. Both monocular and binocular data are presented for each distance.

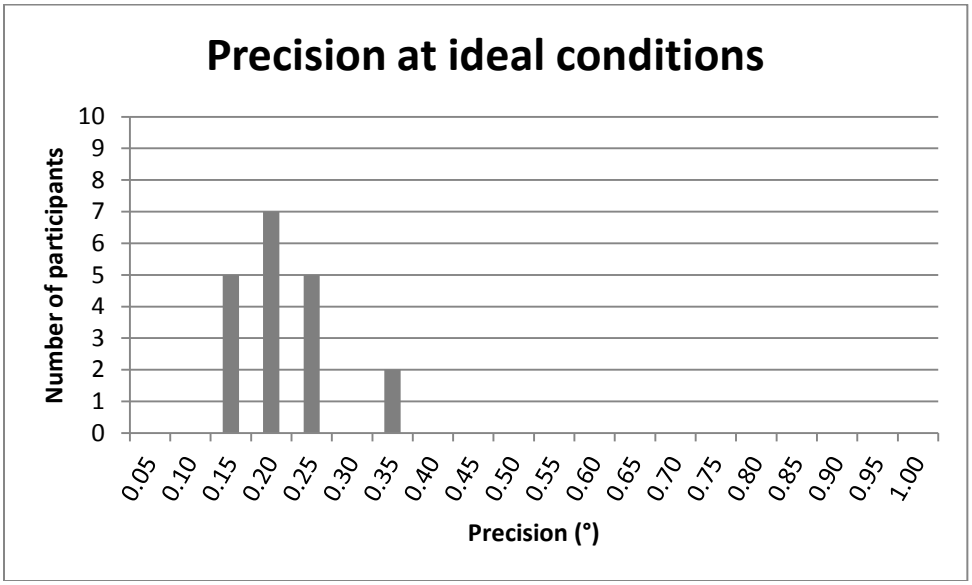
3. References

Stampe, D. M., (1993) Heuristic filtering and reliable calibration methods for video-based pupil-tracking systems. *Behavioural research methods, Instruments and computers, 25 (2), 137-142.*

Appendix 1 Accuracy and precision under ideal conditions

The diagrams below show the data for each subject in the test. The accuracy/precision value is on the x axis, whereas the number of participants who obtain the specific value is presented on the y axis.

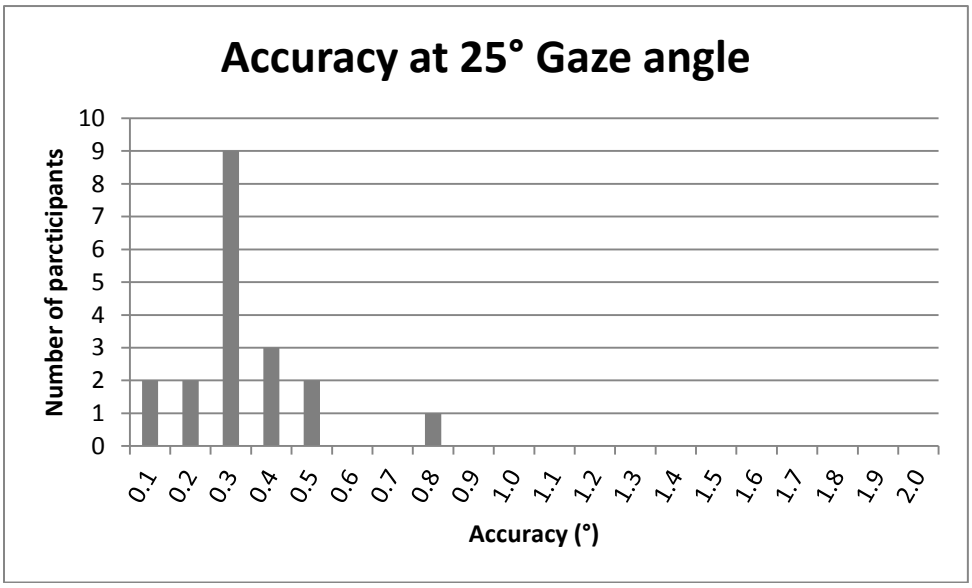


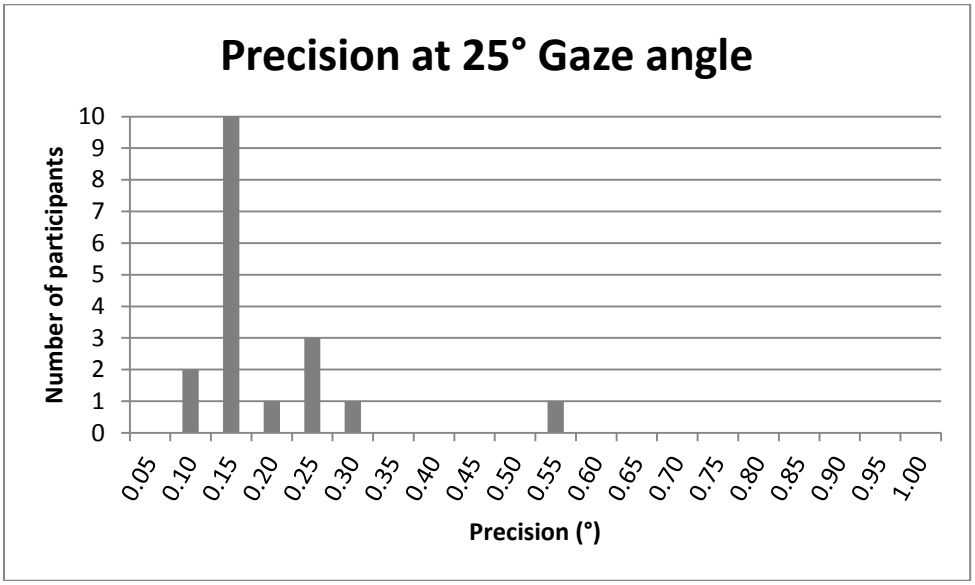


Appendix 2 Accuracy and precision at large gaze angles

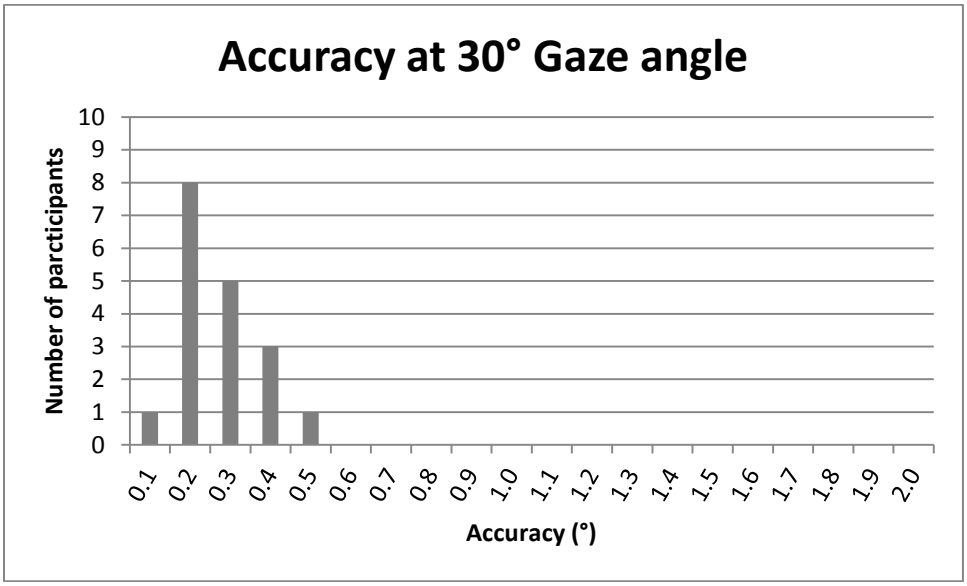
The diagrams below show the data for each subject in the test. The accuracy/precision value is on the x axis, whereas the number of participants who obtain the specific value is presented on the y axis.

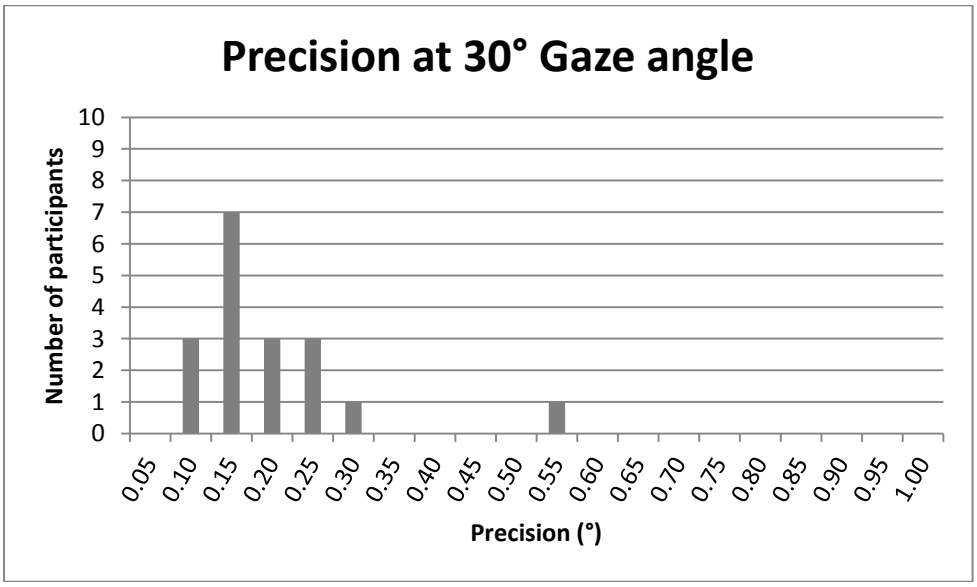
25 Degrees





30 Degrees

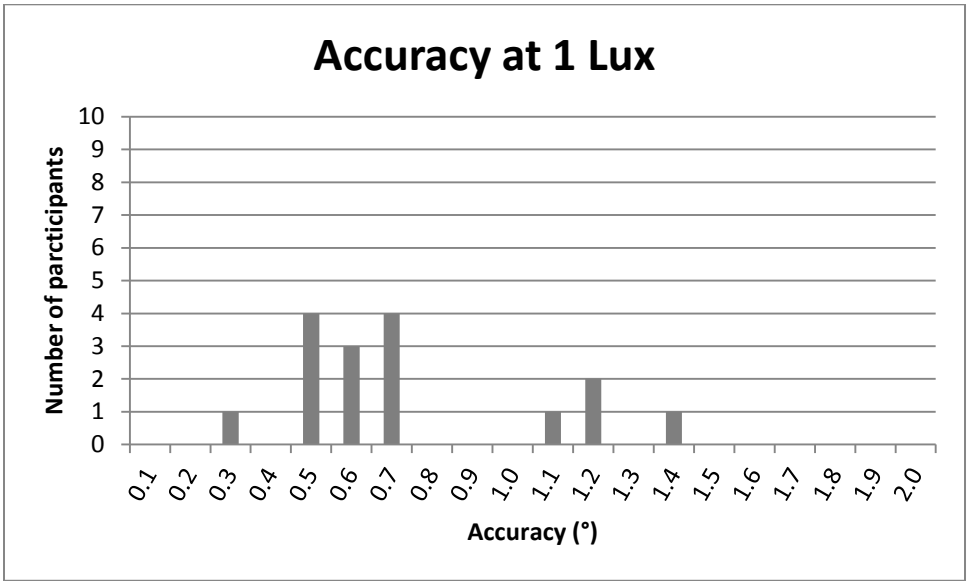


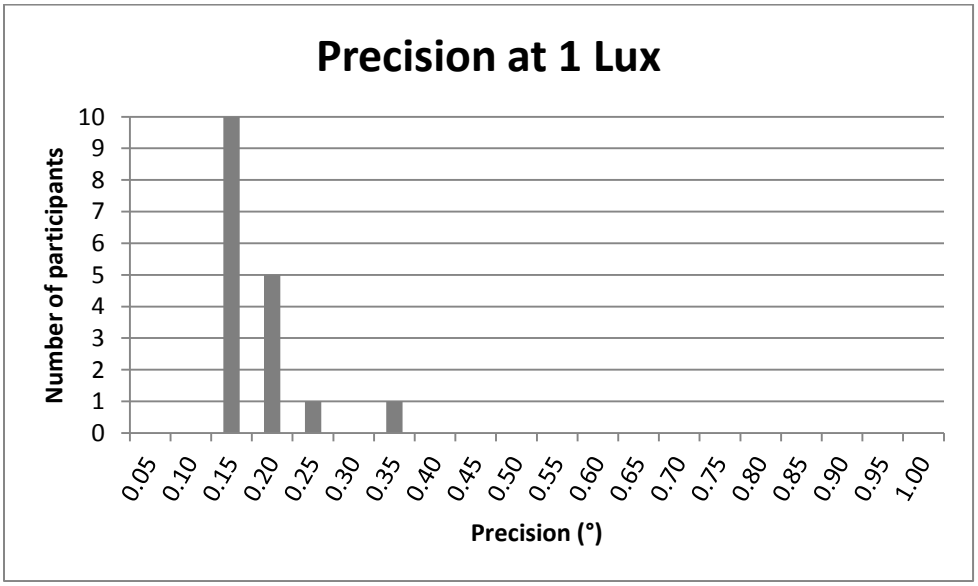


Appendix 3 Accuracy and precision under varying illumination

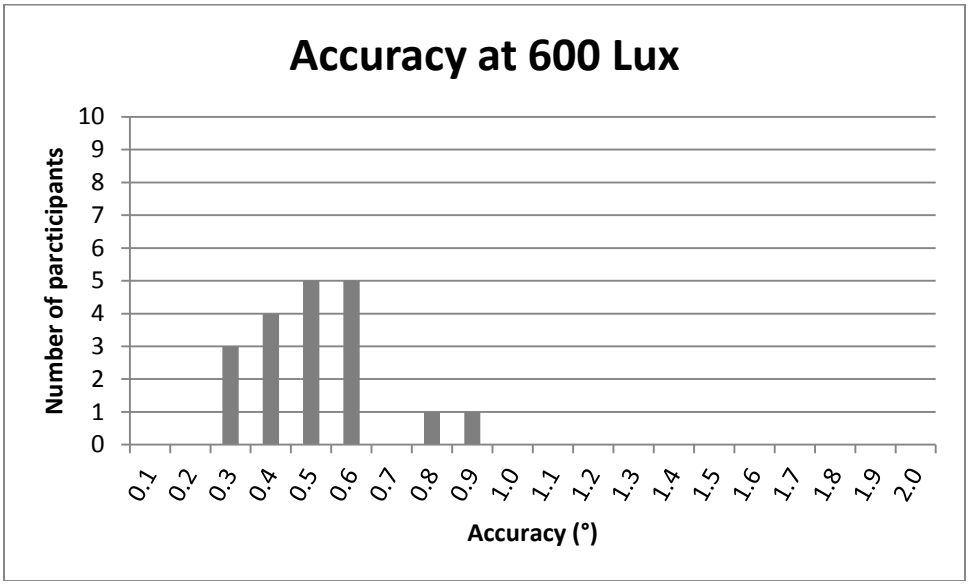
The diagrams below show the data for each subject in the test. The accuracy/precision value is on the x axis, whereas the number of participants who obtain the specific value is presented on the y axis.

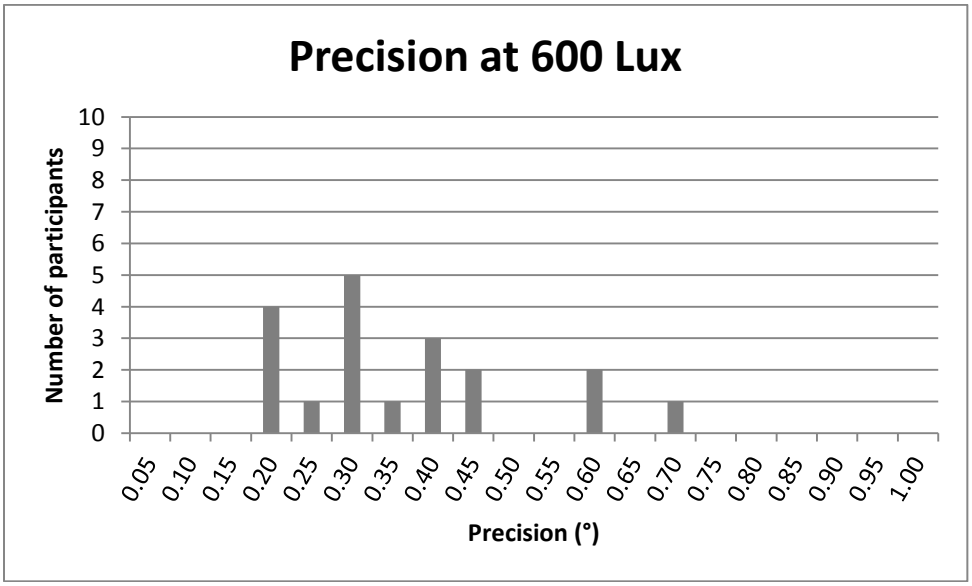
1 lux (darkness)



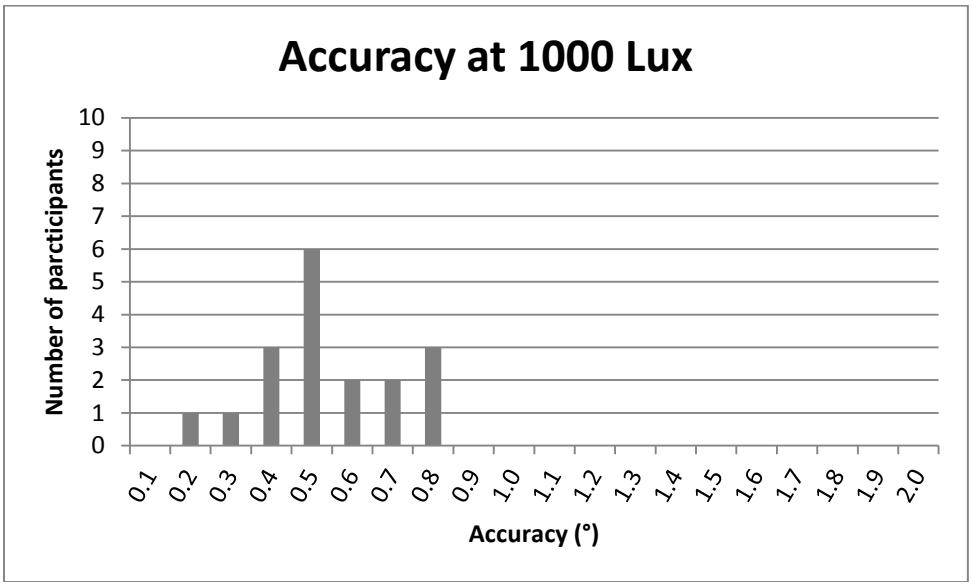


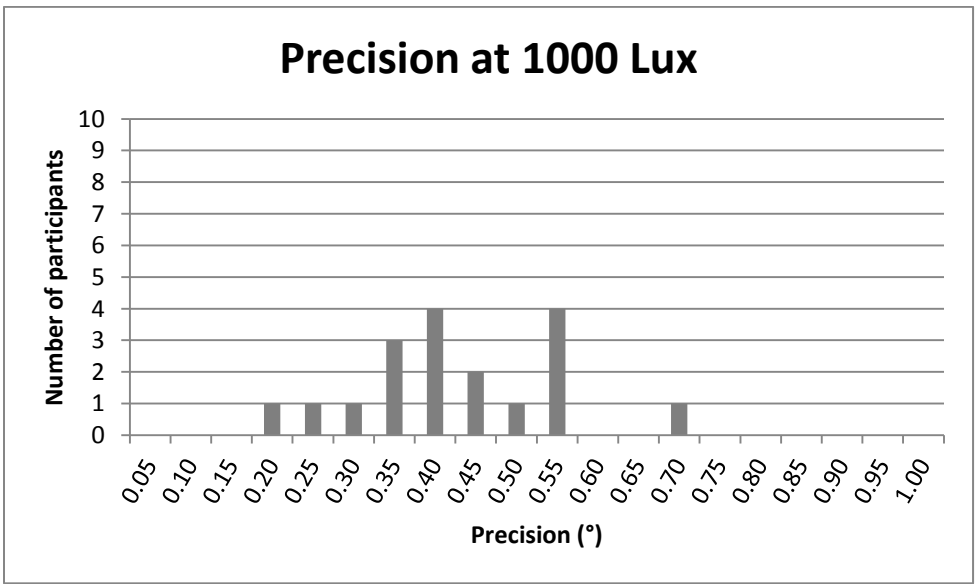
600 lux





1000 lux





White background