Binocular vs monocular calibration of video-based eye-tracking system

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As video-based recording becomes more popular for different eye movement experiments and gives comparable results with the scleral search coil technique[1], the question arises – can video-based eye tracking systems be used to evaluate vergence response and its precision. Partly it depends on accurate eye gaze position prediction where calibration is a very important tool[2]. Each research group prefer their own calibration procedure still giving little arguments for their choice. Performing vergence experiments and trying to evaluate precision of vergence movement (so called fixation disparity), calibration procedure – binocular vs monocular – can also influence the eye gaze position prediction. During monocular calibration, the eye could fixate closer to fixation point providing more appropriate eye gaze position coordinates (Figure 1).

The aim of our study is to test the accuracy of binocular and monocular calibration using different types of stimuli: static point and cross and animated point and cross. We used iViewX Hi-Speed binocular video-based tracking system (500 Hz; accuracy: 0.25-0.5°, SMI, Germany) which is usually applied for reading and visual search experiments, not for vergence evaluation.

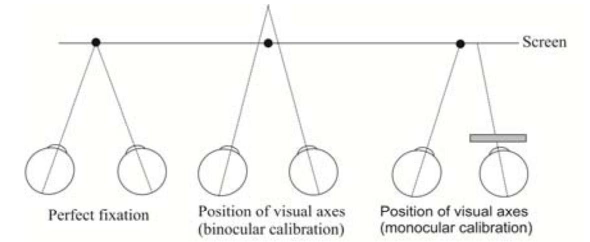

Figure 1: Position of visual axes during calibration. For perfect fixation, we expect both eye fixate on the target. Looking binocularly, the visual axes may not cross on the fixation target because of existing fixation disparity (less than 25 min arc[3-4] measured subjectively, up to 60 min arc[5] measured objectively). Looking monocularly, the eye fixates more closer to the fixation target.

Calibration procedure

Target type and position:

- Screen resolution (size): 1280x1024 px (405x305 mm).
- Target: point and cross (Table 1).

Table 1: Types of calibration targets.

Type	Image	Diameter
Static point		0.5°
Animated point		0.5°, shrank to 0.15°
Static cross		0.5°, line width: 0.06°
Animated cross		0.5°, shrank to 0.15°

- Calibration range: 16° (on a horizontal plane) at 50 cm viewing distance (Figure 2).
- Central target position – in the middle of the screen (640px;512px) and with the midline of the face.
- Color: screen – white; target – black.

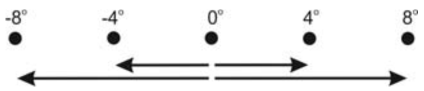

Figure 2: Position of the calibration targets on the screen.

Procedure:

- Created in MS Experiment Center.
- Only one target displayed at a time:
  - ✓ Static target (point or cross) remained visible and unchanged for 1400 ms; calibration data were stored only during last 400 ms.
  - ✓ Animated target (point or cross) shrank during 1000 ms to the smallest target (Table 1) and remained visible for 400 ms during which calibration data were stored.
- Presentation sequence: static point, animated point, static cross, animated cross.
- Calibration sequence: monocular (each eye separately; duration: about 19 s) and binocular (both eyes at a time; duration: about 7 s).
- 3 healthy participants (21-22 y.; VA 1.0); 3 calibration sessions on separate days.

Standard deviation and confidence interval[6]

To evaluate actual position of the eyes and accuracy of our calibration procedure, we calculated standard deviation (SD) and confidence interval (CI(95%)):

Linear regression (between spatially defined calibration points x_i and recorded digital values $\hat{y}_i$:

$$\hat{y}_i = \beta_0 + \beta_1 * x_i$$

Inverse eye position prediction $\hat{x}_{new}$ from any recorded digital data y_{new}:

$$\hat{x}_{new} = \frac{y_{new} - \beta_0}{\beta_1}$$

SD and CI calculations (n = 5):

$$s^2(\hat{x}_{new}) = \frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{(n-2) * \beta_1^2} * [1 + \frac{1}{n} + \frac{(\hat{x}_{new} - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}]$$

$$SD(\hat{x}_{new}) = \sqrt{s^2(\hat{x}_{new})}$$

$$CI(95) = \hat{x}_{new} \pm t(1 - \frac{\alpha}{2}; n-2) * SD(\hat{x}_{new})$$

Reference

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Results

- All participants showed statistically significant linear calibration pattern (Figure 3) with R^2 in between 0.9999 and 0.985.

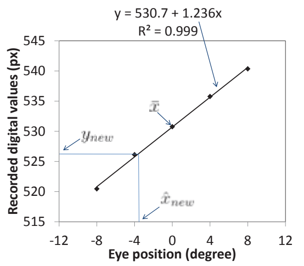

Figure 3: Example of linear regression analyses for participant 1 (binocular calibration, right eye, day 1).

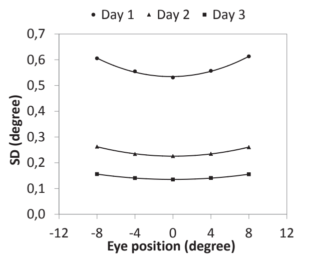

Figure 4: SD values for participant 2 at separate sessions using static point (monocular calibration for the right eye).

Table 2: Predicted position (CI(95%)) for the right eye from monocular and binocular calibration (participant 1).

Position of the calibration targets (degrees)	Monocular (degree)	Binocular (degree)
-8	-8.02 (-8.50 to -7.54)	-8.56 (-10.79 to -6.33)
-4	-4.04 (-4.49 to -3.59)	-3.29 (-5.23 to -1.35)
0	0.03 (-0.38 to 0.44)	0.16 (-1.75 to 2.07)
4	4.46 (401 to 4.91)	3.83 (1.86 to 5.80)
8	7.88 (7.40 to 8.36)	7.88 (5.68 to 10.08)

Table 3: SD values for central target at different sessions (participant 3). Target – static cross.

	Monocular (degree)		Binocular (degree)	
	Right eye	Left eye	Right eye	Left eye
Day 1	0.46	0.60	1.04	1.11
Day 2	0.33	0.55	0.34	0.65
Day 3	0.11	0.14	0.12	0.48

Table 4: SD values for central target for different targets (participant 3) at Day 1.

	Monocular (degree)		Binocular (degree)	
	Right eye	Left eye	Right eye	Left eye
Static point	0.53	0.58	1.00	0.81
Animated point	0.46	0.59	1.04	1.11
Static cross	0.46	0.60	1.04	1.11
Animated cross	0.46	0.60	1.04	1.11

- Predicted eye position could be somewhere in the CI(95%) defined by the SD. We observed difference (not significant) between predicted eye position and position of the calibration target (Table 2).
- We observed higher calibration accuracy (smallest SD) in the center of the screen (Figure 4) at Day 1. There were no statistically significant difference between central and peripheral calibration targets at Day 2 and Day 3.
- SD decreased significantly with repeated calibration (Figure 4) – participants showed training effect both for binocular and monocular calibration (Table 3).
- Using static targets (points and crosses), we observed significantly smaller SD for monocular calibration compared with binocular calibration (Table 4).
- Using animated targets (points and crosses), SD changes for binocular and monocular calibration differ individually for each participant (Table 4).

Conclusions

Our data show that we have to repeat calibration procedure for better eye position prediction if we take naive participants. This training improves not only central field calibration, but also peripheral precision so important for reading and visual search experiments. It seems also reasonable to use monocular calibration to afford better fixation on the target and more accurate prediction of eye gaze position. But the type of the target should be considered.

Achieved SD is still too large to allow usage of iViewX Hi-Speed eye tracking system for evaluation of some vergence response parameters such as fixation disparity. We still work on improving accuracy by increasing the number of calibrations and testing repeatability of vergence response parameters.

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