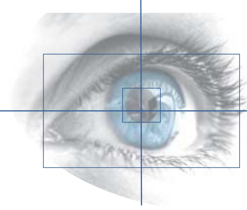

Monocular and binocular calibrations in evaluating fixation disparity with video-based eye-trackers

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Introduction

Fixation disparity is a small vergence error – typically less than 25 arcmin when measured subjectively with nonius lines[1-2], and up to 60 arcmin or more when measured objectively with eye-trackers[3-4]. This application demands an extremely precise and accurate eye gaze position prediction, making calibration quality a crucial issue[5]. In studying fixation disparity, researchers prefer to apply a monocular calibration[4,6-14]. Only two relevant studies applied a binocular calibration[15-16]. Still debates exist – is there really a difference between monocularly calibrated and binocularly calibrated fixation disparities? The theoretical background shows that both monocular and binocular calibration procedures may affect the binocular eye gaze position prediction (Figure 1).

The aim of our study was to evaluate the effect of the calibration procedure on fixation disparity measurement. We predict a difference in the objective fixation disparity measurement obtained after the monocular calibration (the monocularly calibrated fixation disparity) compared with the binocular calibration (the binocularly calibrated fixation disparity); in most cases, we expect the monocularly calibrated fixation disparity to be larger than the binocularly calibrated fixation disparity.

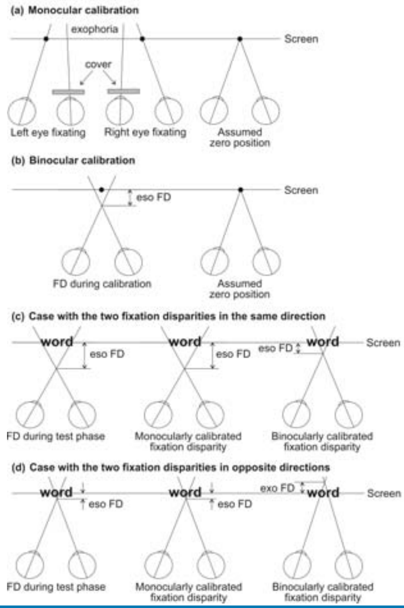

Figure 1. (a) Monocular calibration: looking with one eye, there is no fixation disparity. It is assumed that the opened eye fixates exactly onto the calibration target, while the occluded eye is in the resting position (e.g., exophoria). The condition of zero fixation disparity is defined by the two monocular fixations of, first, the left and, subsequently, the right eye, recorded separately.

(b) Binocular calibration: the real vergence position may be a fixation disparity (e.g., eso fixation disparity), but this will not be detected, since the calibration assumes a state of zero fixation disparity—as if the two lines of sight will intersect or cross directly on the fixation target.

(c) Reading a word binocularly, fixation disparity (e.g., eso fixation disparity, based on the monocular calibration) may exist, that is detected while applying the monocular calibration and is underestimated (less eso) while applying the binocular calibration; both fixation disparities are in the same direction (the monocularly calibrated fixation disparity is more eso than the binocularly calibrated fixation disparity). The binocularly calibrated fixation disparity – measured during the test phase – represents the difference between the binocular calibration phase and the test phase vergence angles. Therefore, the binocularly calibrated fixation disparity is not zero.

(d) If smaller fixation disparity exists during the test phase compared with calibration phase, the monocularly calibrated and the binocularly calibrated fixation disparities may have different directions. It can be an effect of the measuring noise that may superimpose the measurement and give the small degree of fixation disparity.

Method

The position of both eyes was recorded in 19 participants (a median age of 23 y.; 20 – 39 y.) with the iViewX Hi-Speed binocular video-based eye tracking system (500 Hz; SMI, Germany). We created a monocular calibration procedure (Figure 2) and applied inverse prediction[17] to calculate the eye gaze position (Figure 3). Precision of calibration was evaluated by calculating standard deviation (SD_{cal}) of the predicted eye gaze position[18]; the precision is greater when the standard deviation is smaller:

$$s^2(\hat{x}) = \frac{\sum_{i=1}^{n}(y_i-\hat{y})^2}{(n-2)*\beta_1^2} * \left[1+\frac{1}{n}+\frac{(\hat{x}-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] \qquad SD_{cal}(\hat{x}) = \sqrt{s^2(\hat{x})}$$

were: $\hat{x}$ – predicted eye gaze position during the calibration procedure; $\bar{x}$ – the position of the middle calibration target in the center of the screen; x_i – the position of the calibration targets; y_i – the recorded digital values of the dark pupil centre in the eye image; $\hat{y}$ – the calculated digital values of the dark pupil centre; n – number of calibration targets; β_1 – the slope of the linear regression line.

Each participant had three calibration sessions on separate days with 4 monocular and 4 binocular trials. Calibration was performed twice – before and after the dot scanning task (11 black points, size 0.5°, presented for 1 s, one point at a time, from left to right in 16° area; the sixth point was presented in the middle of the screen).

Figure 2. Five calibrations targets (0.5°, black on white background) were presented (only one point at a time in a randomized sequence) in the middle of the screen, 240 and 480 minarc to the left and to the right of the central target. The calibration range was 16° (on a horizontal plane) at 50 cm viewing distance.

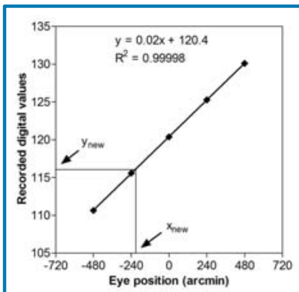

Figure 3. Linear regression allows to link the known coordinates of calibration targets to the recorded digital values of the dark pupil center in the eye image. All participants exhibited linear calibration patterns (R^2: median = 0.9989; IQR = 0.9995 – 0.9976, n = 1,792). The regression coefficients did not vary significantly between the first and the second calibrations, and between the binocular and monocular calibrations (Wilcoxon sign-rank test: p > .05). However, lower regression coefficients (below 0.99) were more frequent (p < .001) during monocular calibrations (6.7 ± 0.8%) than during binocular calibrations (3.1 ± 0.6%).

Results

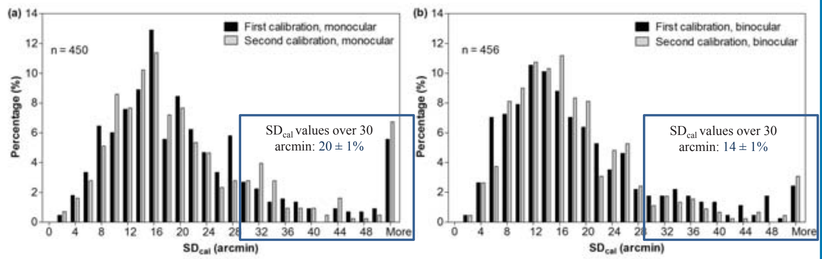

Figure 4. The SD_{cal} values did not vary significantly between the first and the second calibration, and between the monocular (a) and binocular (b) calibrations (Wilcoxon sign-rank test: p > .05). However, higher SD_{cal} values (over 30 arcmin) appeared more frequently (p < .001) during monocular calibrations, rather than during binocular calibrations.

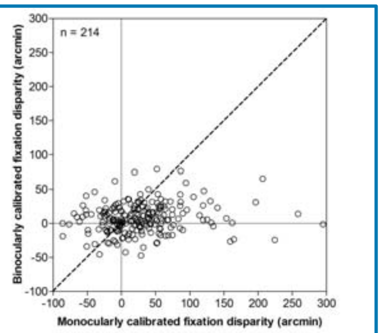

Figure 5. Fixation disparity from all experimental trials without any data selection (averaged from the first and the second calibration; the last 400 ms of data from the sixth point's fixation). The monocularly calibrated fixation disparity varied significantly more than the binocularly calibrated fixation disparity. The dashed line represents the identity line, if the monocularly calibrated fixation disparity were equal to the binocularly calibrated fixation disparity.

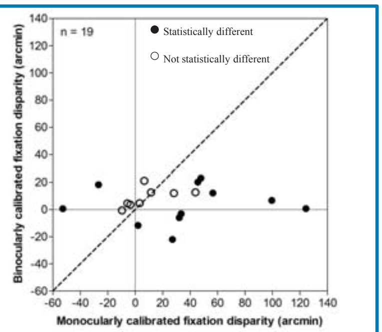

Figure 6. After excluding data with large SD_{cal} (over 25 arcmin) and calculating the median value for each participant, the data reveal a significantly wider range of the monocularly calibrated fixation disparities, compared with the binocularly calibrated fixation disparities. Eleven participants (filled circles) demonstrate statistically significant differences between the monocularly calibrated and the binocularly calibrated fixation disparities (Mann–Whitney U test, two-tailed, p < .05).

Conclusions

The objective fixation disparity differs depending on whether the calibration is performed monocularly or binocularly, and this difference depends on the individual's fixation disparity. Both types of calibration have advantages and drawbacks. Binocular calibrations are easier to perform, since they require less time and do not require a dichoptic presentation of calibration targets. Monocular calibration is more difficult to perform resulting in less precise calibration results than binocular calibration. However, binocular calibrations will typically underestimate the magnitude of the fixation disparity and only monocular calibrations are physiologically valid in the sense that the resulting fixation disparity is determined relative to the assumed center of visual direction.

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