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Relative image size, not eye position, determines eye dominance switches

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Abstract

A recent paper examined eye dominance with the eyes in forward and eccentric gaze [Vision Res. 41 (2001) 1743]. When observers were looking to the left, the left eye tended to dominate and when they were looking to the right, the right eye tended to dominate. The authors attributed the switch in eye dominance to extra-retinal signals associated with horizontal eye position. However, when one looks at a near object on the left, the image in the left eye is larger than the one in the right eye, and when one looks to the right, the opposite occurs. Thus, relative image size could also trigger switches in eye dominance. We used a cue-conflict paradigm to determine whether eye position or relative image size is the determinant of eye-dominance switches with changes in gaze angle. When eye position and relative image size were varied independently, there was no consistent effect of eye position. Relative image size appears to be the sole determinant of the switch.

Keywords: Eye dominance; Ocular dominance; Binocular vision; Binocular disparity; Eye movements; Aniseikonia

1. Introduction

Eye dominance is the tendency to prefer the visual input from one eye over the input from the other. Most adults show a consistent preference for the left or right eye, so it has been assumed that eye dominance is a relatively fixed phenomenon (Porac & Coren, 1976). Khan and Crawford (2001) recently reported that eye dominance is not fixed, but that it switches from one eye to the other with changes in horizontal eye position. They used a visuomotor task (depicted in the left side of Fig. 1) to show that the left eye tends to dominate when the observer looks to the left and that the right eye tends to dominate when the observer looks to the right.

Two mechanisms might have triggered the switch in eye dominance in Khan and Crawford's experiment: (1) extra-retinal, eye-position signals associated with the horizontal position of the eyes (i.e., the horizontal version) and (2) differences in retinal-image size associated with object position relative to the head (Backus, Banks, van Ee, & Crowell, 1999; Ogle, 1938). The first hypothesis is plausible because observers made horizontal eye movements when performing the task (Fig. 1) and the extra-retinal signal associated with that eye movement might have triggered the switch in dominance. The second hypothesis is also plausible because Khan and Crawford used real objects in their experiment; when the object was 15° to the left, the left eye's image was ~3% larger than the right eye's image (Eq. (1)). If the larger of the two retinal images dominated the percept, eye dominance would switch with changes in horizontal object position, much like they observed. Although Khan and Crawford's experiment could not determine the trigger mechanism, they clearly favored the first hypothesis: "In our view, a more robust source of gating information would be direct internal estimates of eye position" (p. 1747). We independently varied eye position and relative image size in order to test the trigger mechanism directly. We were interested in the perceptual effects of dominance switches, rather than possible interactions with visuomotor behavior such as pointing (Khan & Crawford, 2003), so we used a purely perceptual task.

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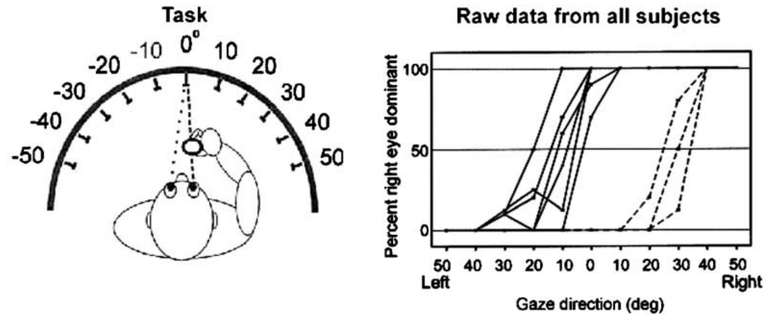

Fig. 1. The task and data in Khan and Crawford (2001). The left panel depicts the task. Observers were asked to fixate a target at one of the azimuths (from −50° to +50°). They then were asked to pull a ring from the target toward themselves such that the target remained perceptually centered in the ring. If they pulled the ring toward the right eye, the right eye was dominant. If they pulled it toward the left eye, the left eye was dominant. The right panel shows some of their data. The abscissa represents the azimuth of the target and the ordinate the percentage of trials in which the observer pulled the ring toward the right eye (indicating right-eye dominance). The solid lines are from seven observers who were right-eye dominant by standard dominance tests and the dashed lines are from three left-eye-dominant observers. The curves show that when the eyes were pointed to the left (e.g., −40°), observers tended to pull the ring toward the left eye (indicating left-eye dominance) and when the eyes were pointed to the right (e.g., +40°), they pulled the ring toward the right eye. The change in response with eye position shows that eye dominance switches.

2. Methods

The stimuli were displayed on a custom stereoscope with two mirrors (one for each eye) and two computer displays (one for each eye; Backus et al., 1999). Each mirror and display was attached to an armature that rotated about a vertical axis passing through the eye's center of rotation. With this arrangement, the eye and stereoscope arm rotate on a common axis, so the mapping between the stimulus array and the retina is unaltered with changes in horizontal eye position (specifically, with changes in horizontal version). This arrangement is depicted in Fig. 9 of Backus et al. (1999) and Fig. 7 of Hillis and Banks (2001). In other words, the retinal images were unaffected by a change in the horizontal version of the fixation target, a key feature for the experiments described here. For the stereoscope arrangement to achieve the desired result, the rotation axes of the stereoscope arms and eyes must be co-linear. To assure that they were, we used a sighting technique developed in our lab (Fig. 8; Hillis & Banks, 2001).

The experimental stimuli were dichoptic; each eye's image contained an outline square and a dot near the center of the square (Fig. 2). By a combination of anti-aliasing and spatial calibration, we were able to specify the positions of the dot and the lines composing the square to within 20–30 arcsec (Backus et al., 1999). The square was horizontally displaced relative to the dot by equal amounts but in opposite directions in the two eyes (26.5 minarc of crossed disparity), so the cyclopean directions of the dot and the center of the square were the same. Simulated viewing distance was 57, 171, or 229 cm (the reason for changing viewing distance is explained below). Observers initiated each 1-s stimulus presentation with a button press once they were fixating a central fixation spot accurately. The dot and fixation spot had zero disparity. Because the square had crossed disparity, the dot was displaced to the left relative to the square in the left eye and was displaced to the right in the right eye. During the experiment, the dot and square each had a single perceived direction; that is, the left- and right-eye images were fused or one eye's image was suppressed. If the left eye dominated the percept, the dot would appear to the left of center, and if the right eye dominated, it would appear to the right. At the end of each presentation, the observer indicated whether the dot appeared left or right of the square's center with a button press.

To determine whether retinal-image size or extra-retinal, eye-position signals determined eye dominance, we used a cue-conflict paradigm. Three or five horizontal eye positions (−20° to +20°) and 13 relative image sizes (corresponding to horizontal eye positions of −30° to +30°, in steps of 5°) were presented in all possible combinations. [1] Eye position was varied by rotating the stereoscope's arms and instructing the observers to maintain fixation on the fixation spot. As we noted above, the retinal images are not altered when the arms are rotated (provided that the observer fixates the fixation spot). Relative retinal-image size was manipulated by varying the sizes of the squares presented to the two eyes. The ratio of image sizes for a gaze-normal surface patch is

$$SR = \frac{\sqrt{d^2 + i \cdot d \cdot \sin\gamma + i^2/4}}{\sqrt{d^2 - i \cdot d \cdot \sin\gamma + i^2/4}}, \qquad (1)$$

[1] The reason for different numbers of horizontal positions (five for some observers and three for others) is because some observers were unable to fit their noses in the stereoscope at the greater horizontal positions.

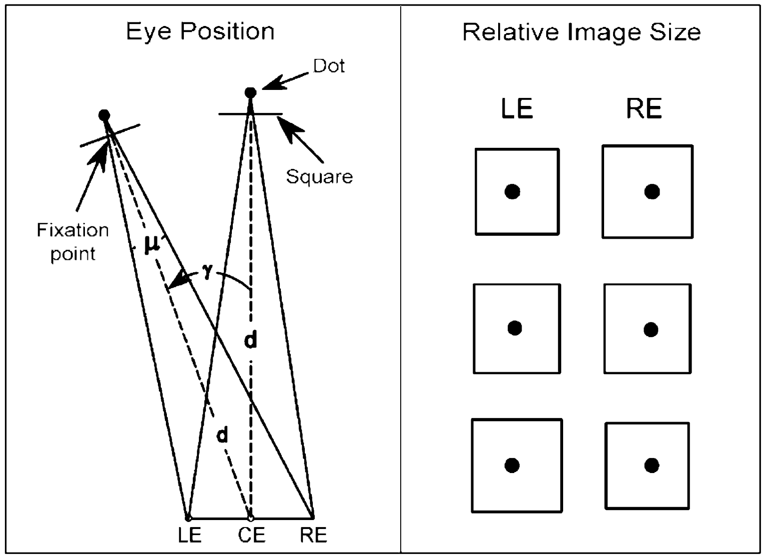

Fig. 2. Eye position and image size manipulations. The left panel is a plan view of the experimental situation. The dot and fixation point were presented in the same plane (i.e., zero disparity) and the square was presented with crossed disparity. Horizontal gaze angle (γ) was varied such that the simulated distance to the fixation point and dot (d) remained the same. Two gaze angles are shown: 0 (straight ahead) and +20 (to the left). The right panel shows examples of the stimuli in the form of a stereogram. Diverge the eyes to fuse. The upper row shows the stimuli for a simulated gaze angle (image-size-specified azimuth) of −20°, the middle row for a simulated angle of 0°, and the bottom panel for a simulated angle of +20°. Notice that the square is larger in the right eye for negative gaze angles and smaller in the right eye for positive gaze angles. The observer's task was to indicate whether the perceived position of the dot was left or right of the perceived center of the square. "Left" responses meant that the left eye was dominant and "right" responses meant that the right eye was.

where d is distance, i is inter-ocular distance, and γ is azimuth (Backus et al., 1999). Note that as distance increases, the size ratio approaches 1 for all azimuths.

Eye position was fixed in a session and one of the 13 retinal-image size ratios was randomly chosen. Each observer was tested at two distances—57 and 171 cm, or 57 and 229 cm—depending on their ability to fuse at long distances. Five experienced observers were tested; three were authors. All had good visual acuity and binocular vision.

3. Results

In the data figures, we plot the percentage of "left" responses for combinations of eye position and relative image size. The predictions are straightforward. If extra-retinal signals were the only signal for switching eye dominance, the observers' responses would be affected by eye position alone. If relative image size were the sole signal, the responses would be predicted from the ratio of image sizes presented to the two eyes. Fig. 3 shows the predictions of the percentage of "left" responses as a function of horizontal eye position (EP) and relative image-size-specified azimuth (IS). Recall that a "left" response means that the left eye was dominant and a "right" response that the right eye was dominant. Thus, the orientation of the data surface is diagnostic of which signal drives the eye dominance. The data would be pitched with respect to the eye-position axis if eye position were the signal and pitched with respect to the image-specified azimuth axis if relative image size were the signal. The data would be pitched with respect to both axes (right panel of Fig. 3) if the two mechanisms contributed equally.

The upper row of Fig. 4 shows the percentage of "left" responses determined from 20 trials for each combination of eye-position- and image-specified azimuth for two observers at 57 cm. Although observers differed in their eye dominance with the eyes straight ahead, all showed a switch in dominance with changes in image-specified azimuth and four of the five showed no switch with eye position (see Fig. 5). For example, when the image was larger in the left eye, more "left" responses were given whether the observer was looking to the left, straight ahead, or to the right. Statistical tests (explained below) confirm that relative image size and not eye position was the primary determinant of the observers' responses.

As viewing distance is increased, the naturally occurring size ratio (Eq. (1)) approaches 1 for all azimuths. Thus, if relative image size is the sole trigger mechanism for dominance switches, we should observe less effect with changes in azimuth at the long distance than at the short distance. If, on the other hand, eye position (i.e., horizontal version) is the sole trigger, the data should be

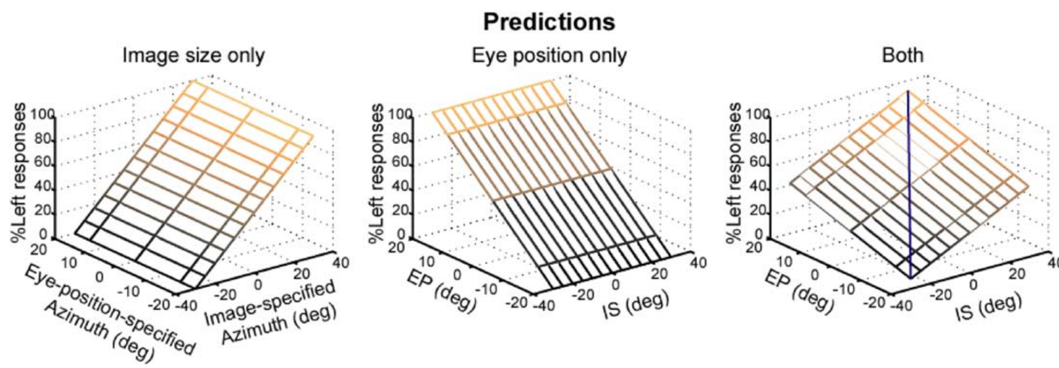

Fig. 3. Predictions. The percentage of "left" responses (indicating left-eye dominance) is plotted as a function of eye-position-specified azimuth (left axis) and image size-specified azimuth (right axis). The left panel shows the predictions if relative-retinal-image size were the only determinant of eye-dominance shifts with eye position. The middle panel shows the predictions if extra-retinal, eye-position signals were the only determinant. The right panel shows the predictions if both cues contributed equally to the shift in dominance.

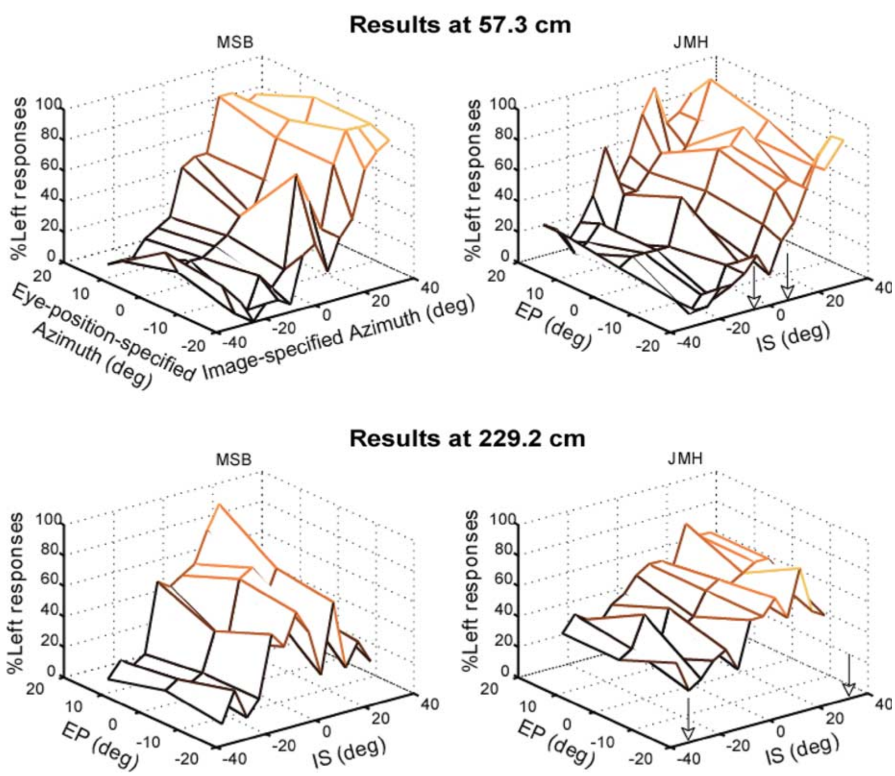

Fig. 4. Results for two observers at 57.3 and 229.2 cm. The data are plotted in the same format as Fig. 3. The upper panels show the data when viewing distance was 57.3 cm and the lower panels the data when distance was 229.2 cm. The arrows in the right panels indicate the azimuths corresponding to size ratios of 1.015 and 0.985 at 57.3 and 229 cm. Notice that much larger azimuths are required at the long distance to produce those size ratios.

unaffected by changes in viewing distance. We tested this prediction by increasing the simulated viewing distance to 229 cm (for observer SSG, it was 171 cm). We presented the same range of image-size and eye-position-specified azimuths at the long viewing distance as we did at the short distance. The results for two observers are shown in the lower row of Fig. 4. Now there was a less consistent effect of relative image size and again no effect of eye position. Because the image-size ratio associated with a given azimuth decreases with distance, the range of ratios was much smaller at the far than at the near distance. To illustrate this, the arrows in Fig. 4 indicate

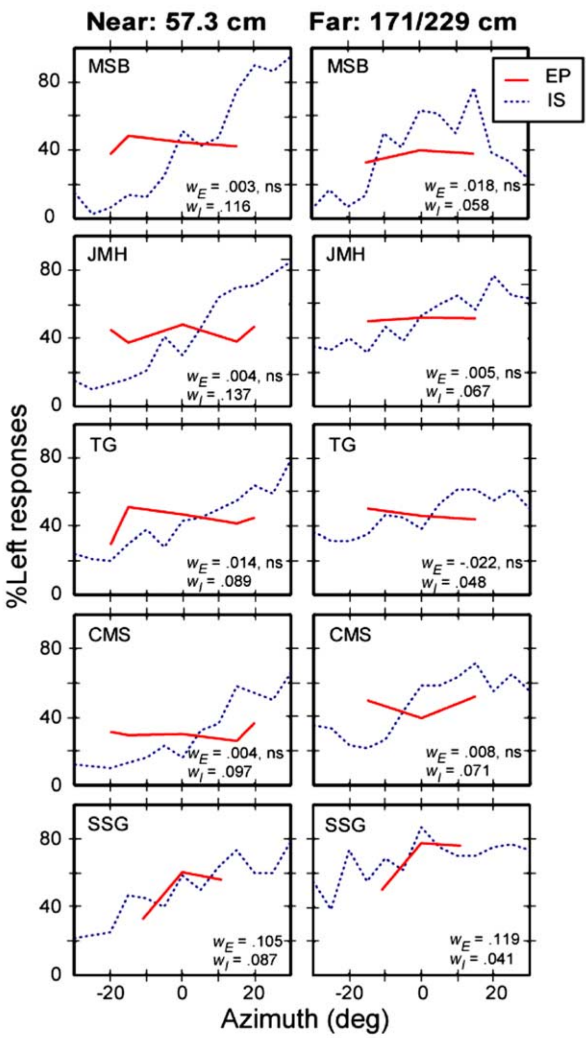

Fig. 5. Results for all five observers at near and far distances. The left column shows the data for a viewing distance of 57 cm and the right column for either 171 or 229 cm (SSG could not fuse the fixation target at 229 cm, so he was tested at 171 cm). Each panel plots the percentage of "left" responses as a function of azimuth. The dashed lines show the data when averaged across eye-position-specified azimuths; they show the effect of image-size-specified azimuth. The solid lines show the data when averaged across image-size-specified azimuth in order to show the effect of eye-position-specified azimuth. The weights w_E and w_I (see text) derived from the regression analysis are given in each panel. If the weight was not significantly greater than 0, it is indicated by *ns*.

the azimuths that correspond to ratios of 1.015 and 0.985 at 57 and 229 cm. The arrows are much farther from 0° at the long viewing distance.

Fig. 5 summarizes the results for all observers and distances. The data are plotted in two ways: averaged across eye position to show the effect of image size (dashed lines) and averaged across relative image sizes to show the effect of eye position (solid lines). The data from the short viewing distance (left column) exhibit a consistent effect of image size and not eye position. In contrast, the data from the long distances (right column) show a less consistent effect of image size and no consistent effect of eye position. We also used linear regression to analyze the data. Observer's responses (L) were modeled as a linear combination of eye position (E) and retinal-image size (I) and a bias (k):

$$L(E, I) = w_E E + w_I I + k.$$

Each panel shows the regression weights, w_E and w_I, and indicates whether they were significantly greater than 0. The weight w_E for eye position was not significantly different from 0 (95% confidence limits) at any distance for four of the five observers; for observer SSG, it was significantly greater than 0 at both distances. The weight w_I for image size was significantly greater than 0 for all observers at both distances. The weights, however, were consistently larger at 57.3 cm, which indicates a greater effect of image-size-specified azimuth at the near distance. The smaller effect of image-size-specified azimuth at the long viewing distance is probably a consequence of the geometry expressed by Eq. (1). In natural vision, the image-size ratio at a given azimuth approaches 1 with increasing distance, so the signal that apparently causes eye-dominance switches becomes smaller. Perhaps the dominance switch occurs when the image-size ratio reaches a critical value greater or less than 1. Thus, an unnaturally large size ratio presented at a long viewing distance (specified by the eyes' vergence) might cause eye-dominance switches as consistently as we observed at 57.3 cm.

4. Conclusion

Eye dominance can switch with a change in horizontal eye position (Khan & Crawford, 2001). We found that the determinant of the switch is the change in relative retinal-image size in the two eyes and not extra-retinal, eye-position signals. Because the switch is driven by relative image size, it is less likely to occur with natural viewing at long viewing distances.

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