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Comparing extra-retinal information about distance and direction

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Abstract

The idea that extra-retinal information about the orientation of the eyes could be used to judge an object's distance has a long history, and has been the issue of considerable debate throughout this century. We here show that the poor performance in comparison with judgements of direction has geometrical rather than physiological reasons, and discuss why previous studies have misled us into believing that information about distance is even poorer than the geometry predicts.

Keywords: Vergence; Version; Spatial vision; Alignment; Human

1. Introduction

When judging where an object is relative to ourselves, we are better at judging its direction than its distance. In a way this is obvious from the geometry of binocular vision. Distance must be determined from the intersection between the object's direction with respect to the two eyes. As the eyes are relatively close to each other, small errors in judging such directions (due either to mislocalizing the object's image on the retina, or to misjudging the orientation of the eyes) give rise to much larger errors in depth than laterally (Fig. 1A). But is this the only reason for us being better at judging direction than distance? To find out we asked subjects to align two vertical lines, both laterally and in depth.

2. Methods

The lines were presented on a computer screen (120 Hz; horizontal size: 39.2 cm, 815 pixels; vertical size: 29.3 cm, 611 pixels; spatial resolution refined with anti-aliasing techniques). Shutter spectacles were used to present different images to the two eyes. Red stimuli were used because the shutter spectacles have least cross-talk at long wavelengths, and because there is relatively little change in sensitivity to red light during dark adaptation. An additional red filter was placed in front of the screen, and the table-top was covered with black cloth, to ensure that subjects never saw anything except the target lines.

The upper line was the reference. Subjects moved the lower line to the left by moving the computer mouse to the left, away from themselves by moving the computer mouse away, and so on. The line's luminance, its angular extent (1.9°), and the vertical separation between the lines (9.1°) remained constant, so that the only variations in depth information were binocular. There were two reference positions; each presented ten times in random order. The first was 2.6° to the left and 8% further than the screen. The second was 2.1° to the right and 8% nearer.

The experiment was performed for three different screen distances: 30, 60 and 150 cm. The subjects (six at each distance) sat with their head in a chin-rest. We chose not to stabilize the head more reliably because we wanted to be sure that the normal relationship between efferent signals and the orientation of the eyes and head are maintained. However, if head movements are not accounted for, and subjects make substantial horizontal

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head movements during the vertical saccades, the accuracy of information about eye orientation may be underestimated, in particular for judgements of direction. We therefore also asked three subjects to perform the experiment for a screen distance of 60 cm while their head was restrained by a dental impression bite-board.

To make sure that subjects had to use extra-retinal information about the orientation of their eyes to perform the task, the lines were presented sequentially (Brenner & van Damme, 1998). Subjects determined which was visible by directing their gaze at it. The switch between the two targets took place during the vertical saccade that shifted their gaze (Fig. 1B). Eye movements were recorded at 550 Hz with an Ober2 (Permobil, Meditech). When the average smoothed vertical eye velocity exceeded a threshold, the target was extinguished. When it exceeded a higher threshold the other target appeared. The thresholds were chosen on the basis of pilot experiments.

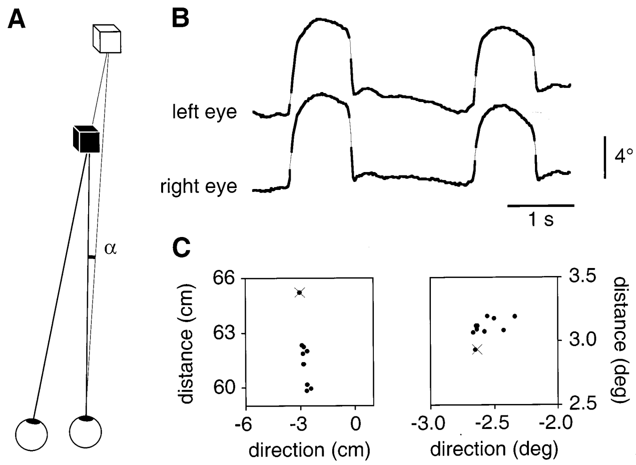

Fig. 1. (A) A small error in judging an object's direction with respect to one eye (α) will generally give rise to a considerably larger misjudgment of distance than of direction. (B) Example of one subject's vertical eye movements during four gaze shifts. The thin sections of the eye movement traces show the intervals during which neither stimulus was visible. (C) The same subject's settings for one reference position, expressed either in centimeters parallel with (*direction*) and orthogonal to (*distance*) the screen (left panel), or as half the sum of (*direction*) and half the difference between (*distance*) the angles relative to the eyes (right panel). The cross indicates the position of the reference.

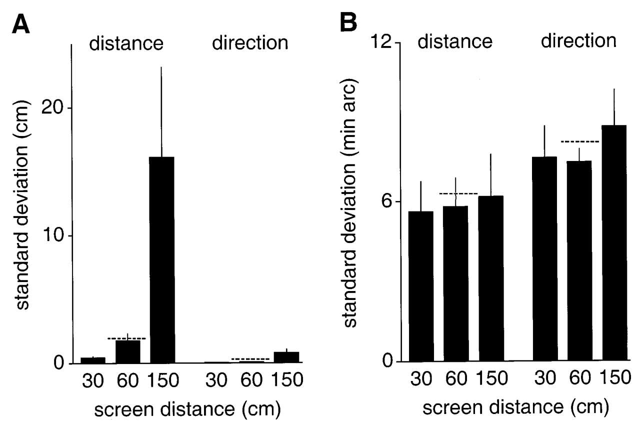

Fig. 2. The standard deviations in the six subjects' settings were clearly larger for distance than for direction when expressed in centimeters (A). This was certainly not so when expressed as angles (B). Using bite-boards rather than the chin-rest made little difference (thin, dashed, horizontal lines; average of three subjects).

3. Results

Subjects made both systematic and variable errors. Fig. 1C shows one subject's settings for one reference target. When expressed in centimeters, both the bias and the variability were predominantly in distance. This asymmetry disappeared when the settings were expressed as angles.

The systematic errors were not consistent across subjects. Fig. 2 shows the variable errors for each screen distance. First, the standard deviation of the ten settings for each reference position was determined. Next, the values for the two reference distances were averaged (after ascertaining that there were no systematic differences). Finally, the mean and standard error were calculated across subjects.

In centimeters, the variable errors were much larger for distance than for direction, and this asymmetry increased with screen distance (Fig. 2A). When expressed as angles, however, the standard deviations were not larger for distance than for direction, and were similar at all screen distances (Fig. 2B). Restraining the head did not change this result (thin dashed lines in Fig. 2).

4. Conclusion and discussion

We conclude that the resolution of extra-retinal information about the orientation of our eyes is *no* worse for distance (vergence) than for direction (version). One reason for judgements of distance appearing to be worse than the geometry predicts is that other sources of information about distance interfere with the subjects' judgements. For instance, the demonstration that subjects can make large tracking vergence eye movements without seeing any target motion in depth (Erkelens & Collewijn, 1985) is frequently cited as evidence against our ability to use extra-retinal information about distance. This demonstration works best if the target is large (Regan, Erkelens & Collewijn, 1986), and only works if the image does not expand in the manner that a real object's would when it approaches (Brenner, van den Berg & van Damme, 1996). Perceived motion in depth is largely determined by the expansion of the retinal image. Thus, what this demonstration shows is that when there is strong retinal evidence that the target is not moving in depth (no retinal expansion), extra-retinal information about ocular convergence fails to give an impression of motion in depth. This does not necessarily mean that extra-retinal information is absent, or even that perceived distance is also unaffected under these very conditions (see Brenner et al., 1996).

Many investigators have tried to force subjects to rely exclusively on extra-retinal information by having them localize a single dot of light in the dark (Crannel & Peters, 1970; Foley, 1976; Foley & Held, 1972; Morrison & Whiteside, 1984). Under such conditions, totally ungrounded assumptions about distance (Gogel, 1972) and size (Wallach & Floor, 1971) can dominate subjects' judgements. Although this indicates that extra-retinal information about distance is very unreliable under such conditions, the same can be said for extra-retinal information about direction. Without additional visual information, the correspondence between the extra-retinal signal that is used for visual localization and the orientation of the eyes is disrupted as the subjects' eyes slowly drift away without the subject noticing it (Matin, Pearce, Matin & Kibler, 1966; Foley, 1976). The present results are unlikely to have been influenced by such drifts, because such drifts influence both targets in the same manner, while saccadic eye movements do not go by unregistered (Findlay, 1974; Brenner & van Damme, 1998).

The ability to accurately align targets in depth has previously been attributed to a special trick: comparing retinal disparity across isovergent saccades (e.g. Enright, 1991). Since saccades are not always isovergent, subjects would have to know which saccades involve changes in vergence and which do not, which in itself is a form of extra-retinal information about ocular convergence. Moreover we have previously shown that performance is almost as good when the task is to halve or double the distance, in which case subjects do not make isovergent saccades. The fact that performance was only almost as good (standard deviations of about 20 rather than 10 minarc) is not surprising considering that these tasks depend on the accuracy with which subjects judge the actual distance to the reference, while equal distance judgements do not (see Brenner & van Damme, 1998 for a more thorough discussion). Thus we are convinced that the results of the present study do represent the resolution of extra-retinal information about ocular convergence.

Finally, we emphasize that the finding that extra-retinal information is just as good for distance as for direction does not mean that it is as frequently used. Both the geometry of binocular vision and the presence of alternative sources of information about distance may normally make us rely much less on extra-retinal information about ocular convergence than about our direction of gaze.

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