Dynamic Random-Dot Stereograms Reveal Up-Down Anisotropy and Left-Right Isotropy between Cortical Hemifields

Abstract. *With the use of dynamic random-dot stereograms (which are devoid of all monocular depth cues), the temporal duration for detecting a small, briefly presented test square of different depth than the surround varied as a function of its location in the central portion of the visual field. Test squares presented in the upper hemifield were detectable at consistently shorter durations than those in the lower hemifield when the fixation marker was in front of the surround, and vice versa when the marker was behind. No such anisotropy was found for left and right hemifields. Exploratory studies suggested a similar up-down anisotropy and left-right isotropy in spatial resolution. Thus, the upper hemifield representation at the cortex shows a general superiority over the lower one for binocular detectors tuned to uncrossed disparities, and the lower hemifield shows superiority for those tuned to crossed disparities.*

There are two "schizoid" aspects of visual perception. One is the separate mapping of the left hemiretinas to the left cortical hemisphere and the right hemiretinas to the right cortical hemisphere. The other is the separate mapping of the upper visual hemifields to certain cortical areas with respect to the lower visual hemifields (*1*).

There is much interest in the left-right dichotomy of visual functions, particularly after the "split brain" studies of Sperry and co-workers (*2*). The speech centers in humans usually occupy one hemisphere, usually referred to as the major hemisphere. This results in a strong superiority of the major hemisphere for cognitive tasks, while the other (minor) hemisphere is considered to be better for perceptual tasks, particularly when spatial organization is required (*3*). It has been claimed that stereopsis of static random-dot stereograms, as devised by Julesz (*4*), is superior for the right (usually minor) hemisphere. For instance, Carmon and Bechtoldt (*5*) found that patients with left hemisphere lesions have a shorter perception time for this type of stimulus as compared to those with right hemisphere lesions, and Durnford and Kimura (*6*) reported better performance when the random-dot stereograms were presented to the left of the fixation point.

Interestingly, the neurophysiologically known dichotomy between the upper and lower visual hemifields has not been explored in studies of visual perception. While it is claimed that moving the eye upward changes the alpha rhythm (*7*), there is no evidence in the various visual perimetry studies with classical targets (which appear similar when viewed monocularly or binocularly) for any anisotropy in visual performance between the upper and lower hemifields.

The results reported here show that the stimulus duration threshold, *T*, for dynamic random-dot stereograms provides a sensitive measure for exploring the temporal response variations among binocular disparity units across the visual field. We show evidence that *T* for stereopsis in the upper visual hemifield differs greatly from that in the lower, whereas, contrary to previous reports (*5, 6*), we found no difference, either in magnitude or consistency, between the left and right hemifields. This upper-lower hemifield anisotropy depends on binocular disparity: upper hemifield superiority prevails with uncrossed disparities and the reverse is true for crossed disparities.

The techniques of random-dot stereograms and dynamic random-dot stereograms have been described (*8*). When a dynamic random-dot stereogram is viewed monocularly, both the left and right fields appear as dynamic noise (like the "snow" on a television screen). However, when stereoscopically fused, specified binocularly disparate and correlated areas are seen in vivid depth. In the experiments reported here, the dynamic noise consists of dots illuminated at random on a 50 by 50 array and viewed from a distance at which a dot subtends 6 minutes of arc (6′). The random white dots are generated by a PDP 11/20 computer and are portrayed on the black surface of an *x-y* display scope with a fast P4 phosphor. The stereo images are presented at a 100-hertz frame rate (10-msec duration) with a 12.5 percent dot density for any given frame. The correlated area consists of the background with 0′ disparity and a small square (for example, 24′ by 24′) with a 6′ or 12′ disparity. A steadily luminous fixation marker (slightly brighter than the other dots) is presented in the center of the arrays with a 0′, 6′, or − 6′ disparity.

Subjects fixated at the marker and pressed a button, after which the small square was shown for a specified duration. The subject's response, which consisted of pressing one of two buttons if he detected the square and the other if he did not, automatically decreased or increased the duration by 10 msec. Thus, the subject's responses oscillated around the duration threshold, *T*, and the computer stored and analyzed the data. The square was detected by noticing a change in the fused surround at a particular location, but identification of the depth and shape of the target was not required.

Figure 1A shows the perimetry data

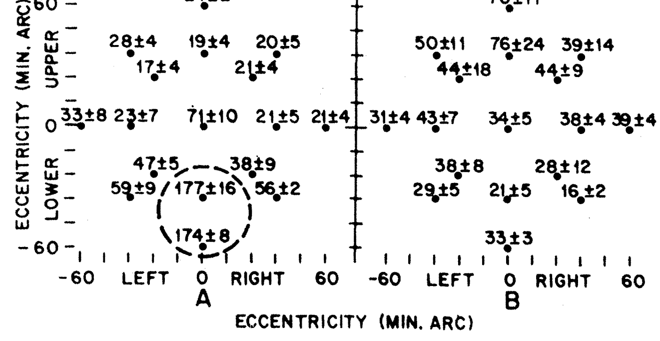

Fig. 1. Mean threshold durations of a typical subject (W.K.) for detecting a 24′ by 24′ stereo test square centered at the points as shown. The fixation marker was always located at the center of gaze (0′, 0′). Numbers above points give the mean threshold durations and standard errors in milliseconds. The abscissa and ordinate designate horizontal and vertical visual field eccentricities and are graduated in units of 12′. Diagrams of the viewing conditions are at top: *B*, background plane; *T*, test plane; *F*, fixation point. (A) The disparity of the fixation marker was 6′ (in front of surround). Dashed lines indicate possible location of stereoscotoma. (B) The disparity of the fixation marker was −6′ (behind the surround).

from a typical subject (W.K.) when the marker and the test square had a 6′ disparity (in front of the surround). Figure 1B shows perimetry data for the same subject when the marker had a − 6′ disparity (behind the surround) and the test square had a 6′ disparity (in front of the surround). Several unexpected results are indicated in Fig. 1A: (i) the center of the visual field has much poorer temporal resolution (longer *T*) than the rest (there are two atypical points directly below the center of gaze which, for this subject, are even poorer); (ii) the upper hemifield has a much better temporal resolution than the lower hemifield; and (iii) the left hemifield has about the same temporal resolution as the right hemifield. Similar trends are seen in Fig. 1B except the upper-lower hemifield anisotropy is reversed.

To obtain the data in Fig. 2 we presented the test square in four positions with the following *x* and *y* coordinates from the center fixation point: (36′, 36′), (36′, − 36′), (− 36′, 36′), and (− 36′, − 36′). Besides the viewing conditions described above, two others were used: a fixation marker with 6′ disparity and a test square with 12′ disparity (both in front of the surround); and a fixation marker with 0′ disparity (in the plane of the surround) and a square with 6′ disparity (in front of fixation marker and surround). At each of the four positions, *T* was the mean of ten threshold reversals. The relative difference (in percentage) between values of *T* for upper and lower positions was computed by subtracting the average of the two upper positions from the average of the two lower positions and dividing the remainder by the average of the four positions. The left versus right relative difference was similarly computed. Figure 2 shows the results obtained for three subjects under each of the four viewing conditions. Except for the viewing condition in which the fixation marker fell in the depth plane of the surround, all three subjects showed consistent and substantial anisotropies between upper and lower hemifields, whereas none were found between left and right hemifields.

This strong anisotropy between the center of the fovea and the rest and between the upper and lower hemifields can be demonstrated only with dynamic random-dot stereograms that are devoid of all monocular cues. The slightest monocular cue leads to much improved perception times and abolishes any

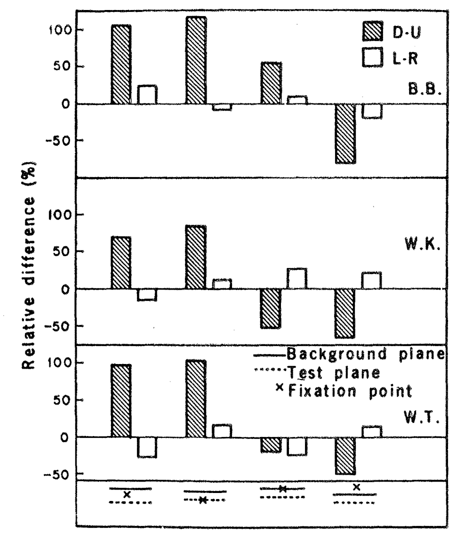

Fig. 2. Percentage relative differences between mean duration thresholds for down and up (*D-U*) and left and right (*L-R*) for test squares presented to three subjects. The four viewing conditions are illustrated at the bottom.

anisotropy (*9*). Thus the anisotropy is the property of the corical units sensitive to binocular disparity, similar to those in area 18 of the monkey (*10*) and area 17 of the cat (*11*). These units are selectively stimulated with dynamic random-dot stereograms, which are not detected at earlier processing stages (*8*). Subject W.K. showed a "stereoscotoma" under the center of his visual field (Fig. 1A); the duration threshold for stereopsis in this area was much (more than 100 msec) longer than elsewhere. Except for this "scotoma," his stereopsis is excellent. For all subjects, the duration threshold for uncrossed disparities was higher at the center of gaze than to the left and right of it.

We could not confirm the left-right difference reported by others (*5, 6*). We think the reason lies primarily in the way subjects in these studies were required to identify on each trial one of several cyclopean figures portrayed by the static random-dot stereogram. This added the task of geometric pattern recognition or categorization to the task of perceiving depth, and the results may have been confounded by the left-field superiority in recognition of geometric patterns (*12*).

Our exploratory investigations indicate that the presently reported differences in temporal resolution of the upper visual hemifield relative to the lower hemifield are paralleled by similar differences in the spatial resolution or acuity between the upper and lower hemifields (*13*). Thus spatial resolution for uncrossed disparities is superior in the upper hemifield, and that for crossed disparities is superior in the lower hemifield.

This general anisotropy between the upper and lower hemifield representations reveals itself only during stereopsis without monocular cues. This suggests that processing stages before stereopsis (in the retina, lateral geniculate nucleus, area 17 of the cortex, and so forth) are isotropic. The large anisotropies and particularly the striking reversals associated with changes in binocular disparities within a 1° eccentricity suggest large differences in the spatiotemporal response properties of binocular disparity detectors tuned to different disparities. Since stereoscopic acuity is an order of magnitude finer than visual acuity, it is not surprising that such large sensitivity differences can exist within such a narrow region of central vision.

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9. When the same stimuli were viewed under static random-dot stereogram conditions, which introduce strong monocular cues such as stroboscopic motion or an abrupt positional shift of a cluster of dots relative to the static surround, all stimuli at all locations were detectable at the shortest duration (10 msec).
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13. The parallelism between temporal and spatial resolution holds even for the left and right hemifields, since they are isotropic for spatial resolution as well. The spatial resolution is measured by determining the largest eccentricity at which a depth target of specified size (width), presented for a constant suprathreshold duration (500 msec), can just be seen.

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