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# VISUAL FIELDS FOR FRONTAL PLANE MOTION AND FOR CHANGING SIZE

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**Abstract**—Thresholds were measured in 15 subjects for 2-Hz oscillations of size and for 2-Hz oscillatory motion in the frontal plane using test squares of side lengths 0.5°, 1.0° and 2.0°. Size-oscillation thresholds were lowest (i.e. sensitivity was greatest) for the 2.0° square while thresholds were highest (i.e. sensitivity was least) for the 0.5° square in 28 of 34 tests. Frontal plane motion thresholds, on the other hand, did not generally depend on square size. Equal-threshold contours in the visual field were roughly elliptical in 10 of 13 subjects for both types of oscillation. None of 13 subjects had visual field defects for oscillating-size or frontal plane motion, in contrast with the known incidence of stereo-motion scotomata. One subject was known to be selectively "blind" to stereoscopically-oscillating disparity in some areas of the visual field, but oscillating-size sensitivity was normal in these regions, thus preserving an alternative basis for motion-in-depth judgments.

Vision Visual field Motion Depth Channels

## INTRODUCTION

The visual fields of some normally-sighted subjects contain large areas that are selectively insensitive to changing disparity, though retaining sensitivity to static disparity. In these areas of the visual field subjects are selectively "blind" to stereoscopic motion in depth, though retaining stereoscopic sensitivity to relative position in depth (Richards and Regan, 1973; Richards, 1977). Richards and Regan did not address the questions whether the selective "blindness" was restricted to changing disparity or whether it was, on the other hand, a general inability to see motion in depth *per se* when viewing any of the several stimuli that can cause an impression of motion in depth. One of these several stimuli is changing size: changing an object's retinal image magnification is sufficient to create a compelling impression that the object is moving in depth (Wheatstone, 1852).

The aims of the present study were, first, to find whether the visual fields of normally-sighted subjects contain areas that are specifically insensitive to changing-size stimulation and, second, whether the locations of such changing-size scotomata (if they exist) coincide with areas that are specifically insensitive to changing disparity. In addition, we compared thresholds for frontal plane motion with thresholds for changing size at many points in the visual field, looking for evidence of dissociation between the two thresholds. If found, such a dissociation would provide evidence further to that already available (Regan and Beverley, 1978, 1980) that visual responses to changing size cannot be explained in terms of visual responses to motion. The rationale of this last point is similar to the argument that the occurrence of separate scotomata specific to changing disparity and specific to static disparity is evidence that the neural processing of motion in depth and position in depth are to some extent separate and independent (Regan *et al.*, 1979; Regan, 1982).

## METHODS

Subjects sat 145 cm (57 in.) from an adapting screen subtending 48° × 48°, illuminated with green light to a luminance of $17\,cd/m^{-2}$. The centre of the screen was a circular hole subtending 3.5° dia. behind which was placed a CRT screen (Tektronix model 608 with green phosphor type P31). The CRT screen had a uniform luminance of $17\,cd/m^{-2}$ except at the centre of the screen where a bright stimulus square was located. The side length of the square could be selected as 0.5°, 1.0° or 2.0°, and the mean luminance was $58\,cd/m^{-2}$ (55% contrast). The square was generated by electronics of our own design. Thresholds were measured using a von Bekesy tracking procedure. The stimulus was controlled and results calculated by a microcomputer (Commodore PET). The experimenter first selected whether the stimulus square would oscillate inphase or antiphase. "Inphase oscillations" meant that the square oscillated bodily along a diagonal: opposite edges moved in the same direction at any instant. (In all cases the diagonal was upper left-bottom right.) Inphase oscillation is, in fact, oscillatory motion in the frontal plane. "Antiphase oscillations" means that the size of the square oscillated: opposite edges moved in opposite directions at any instant and the centre of the square remained stationary. The total light flux from the square was held constant throughout. In all cases, the position of any edge oscillated sinusoidally at 2 Hz. Viewing was monocular in all cases.

Subjects were provided with a pushbutton and were instructed to keep it pressed when any oscillation or motion was visible, and to release it when no oscillation was visible. With the button released, the amplitude of oscillation steadily increased at a rate of 2 dB $\sec^{-1}$, and with the button depressed, the amplitude of oscillation steadily decreased at the same rate. The computer ignored the first four button presses and releases, and calculated threshold as equal to the mean of the next six releases and presses. Two measurements were made for each stimulus condition except when these measurements disagreed by more than 3 dB, in which case that measurement was repeated a third time. The visual field was explored by placing a fixation mark at different points on the screen. Especially for eccentric locations it was found necessary to minimize Troxler fading by instructing the subject to continuously move the point of fixation through about $\pm 0.5°$.

There were 15 subjects in all, 10 females and 5 males, whose ages ranged from 20 to 64 years. For 8 subjects inphase and antiphase thresholds were measured along 2–8 half-meridians for all three sizes. For 13 subjects inphase and antiphase thresholds were measured along 8 half-meridians (vertical, horizontal and two 45° obliques) using the 1° test square at eccentricities of 4°, 8° and 12°. These field plots were repeated using the 0.5° and 2.0° squares additionally for two of these subjects, out to an eccentricity of at least 20°.

It is known that the eyes of some (but not all) subjects have refractive errors in peripheral vision, even when foveal vision is corrected (Ferree and Rand, 1933; Frisén and Glausholm, 1975), and that motion sensitivity can be improved in the periphery by correcting this refractive error (Johnson and Leibowitz, 1974; Liebowitz *et al.*, 1972). Because we wished to investigate visual fields for everyday vision we used the appropriate refractive correction for best foveal acuity rather than correcting separately for every eccentricity.

## RESULTS AND DISCUSSION

Visual fields are most commonly recorded using a circular disc as stimulus (Scott, 1957; Aulhorn and Harms, 1972; Tate and Lynn, 1977). The disc is commonly somewhat brighter than the adapting background, and may be presented as a moving target whose eccentricity is varied until the disc is just visible (kinetic perimetry) or as a static target whose luminance is adjusted until it is just visible (static perimetry). The subject's task is to detect the presence of the just-visible target in both kinetic and static perimetry. Perimetry is not, however, restricted to testing gross visual sensitivity to the presence or absence of an object: visual fields can be plotted for more subtle aspects of visual function such as visual acuity and spatial frequency contrast sensitivity (Rijsdijk *et al.*, 1980; Blondeau and Phelps, 1981; Regan and Beverley, 1983), colour vision (Aulhorn and Harms, 1972), depth perception (Richards and Regan, 1973), motion perception (McColgin, 1960) and temporal aspects of visual function such as perceptual delay (Regan *et al.*, 1976), critical flicker fusion frequency (Aulhorn and Harms, 1972) and double-flash resolution (Galvin *et al.*, 1976). In this paper we add changing size sensitivity to the list, and report on visual fields for changing-size measured in 13 control subjects.

Figure 1 shows antiphase and inphase thresholds for 0.5°, 1.0° and 2.0° square sizes. Data are shown for one half-meridian, along the upper right 45° oblique. In this, and in all other measurements, foveal thresholds could not be measured because of technical limitations of the apparatus.

Inphase thresholds in Fig. 1 grew progressively higher (i.e. less sensitive) as eccentricity increased in all 34 half-meridian tests in the 13 subjects. This confirms previous reports (Johnson and Leibowitz, 1974; Leibowitz *et al.*, 1972; McColgin, 1960; Tyler and Torres, 1972; Warden *et al.*, 1945). Antiphase

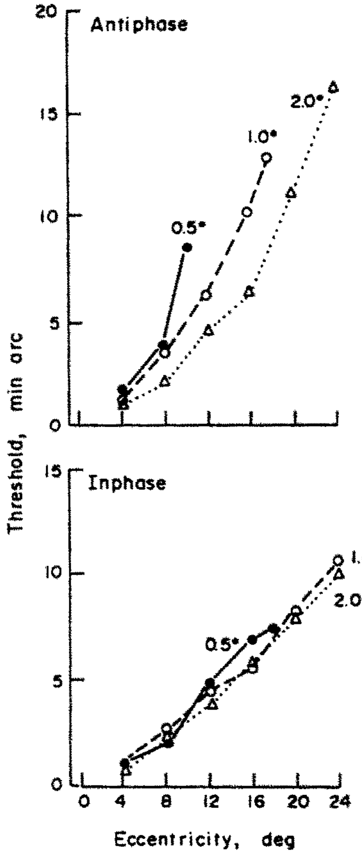

Fig. 1. Oscillation thresholds in min arc peak-to-peak versus eccentricity for three square targets of mean side lengths 0.5°, 1.0° and 2.0° respectively. For changing-size (antiphase) thresholds, opposite edges moved in opposite directions at any instant, while for frontal plane motion (inphase) thresholds opposite edges moved in the same direction at any instant. Plots are for the upper right oblique half-meridian. Oscillation frequency 2.0 Hz. Subject D.R.

thresholds also grew progressively higher with eccentricity in all 34 tests.

For the subject of Fig. 1 (upper panel) antiphase threshold was lowest (most sensitive) for the 2.0° square, intermediate for the 1.0° square and highest for the 0.5° square at any given eccentricity. This finding held in at least one half-meridian for all subjects tested and in 28 of the 34 half-meridian tests carried out. Inphase thresholds, on the other hand, generally did not depend on square size at any given retinal location, as illustrated in Fig. 1. No subject showed any gross local elevation of the inphase threshold, i.e. we found no "frontal plane motion scotomata". Three of the subjects were aged 57 years or more. These older subjects showed no appreciable elevation of absolute thresholds compared with the younger subjects.

Plots like that of Fig. 1 were recorded for all 8 half-meridia using the 1.0° target in 13 subjects. Visual fields were derived from each set of 8 plots by calculating loci of equal thresholds. Figure 2 shows visual fields for antiphase and inphase oscillation for one subject (author D.R.). Of the 13 subjects tested, 10 subjects had equal-threshold contours that formed horizontal ellipses that were approximately symmetrical at the fovea in accord with the only previous report (McColgin, 1960) that we have found on motion fields. [It is of interest to note that visual field isopters recorded by conventional kinetic perimetry are also of elliptical shape, though not symmetrical about the fovea (Frisén and Frisén, 1975).] Equal-threshold contours were more nearly circular for two subjects and one subject showed a region of enhanced sensitivity in the lower left quadrant. Our inphase (oscillatory frontal plane motion) fields are difficult to compare quantitatively with McColgin's, since his data were not expressed either as displacements or as velocities. No subject showed any gross local elevation of an absolute antiphase threshold, i.e. we found no changing-size scotomata.

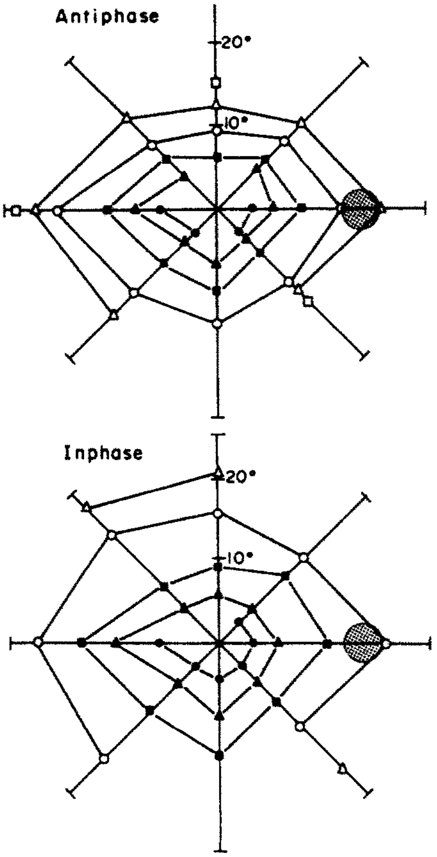

Fig. 2. Visual fields for changing size (antiphase oscillations) and for oscillatory frontal plane motion (inphase). Lines connect points of equal thresholds namely 1 min (solid circles), 2 min (solid triangles), 4 min (solid squares), 8 min (open circles), 12 min (open triangles) and 16 min (open squares). Mean square size 1.0°. Other details as in Fig. 1.

In previous studies we reported evidence that the visual system contains functional subunits for changing-size that are functionally independent of inphase motion (Regan and Beverley, 1978, 1980; Regan, 1982). With this in mind, we plotted the ratio of antiphase to inphase thresholds at each eccentricity along each meridian. Our aim here was to sensitively detect any local changes in antiphase threshold that were not associated with a corresponding local change of inphase thresholds. We found no such evidence.

One implication of the present findings for skilled eye–hand coordination (as in car driving, cricket and baseball) is as follows. Richards and Regan's (1973) finding that some control subjects with normal vision have extensive areas of the visual field that are "blind" to stereoscopic motion in depth might suggest that such subjects would tend to misjudge motion in depth when an object such as a ball or a motorcyclist enters the affected area of the visual field. We report here that, although scotomata for stereo motion in depth seem to be fairly common in control subjects, we found no such scotomata for changing size in any of the 15 subjects tested in the present study: changing-size sensitivity seems to be physiologically more robust than sensitivity to changing disparity. Since both changing-disparity or changing-size are effective stimuli for motion-in-depth sensation (Regan and Beverley, 1979), our present findings may imply that some subjects with stereo motion scotomata may experience less disruption of eye-hand coordination than might be expected, since they are sensitive to changing-size stimulation. For instance, the very patchy stereo motion fields shown in Richards and Regan (1973) and the scotomata-free changing-size fields shown in the present report are for the same control subject (author D.R.). A comparison of Fig. 2 in this article with Figs 1 and 2 in Richards and Regan (1973) shows that, for this subject, changing-size sensitivity was normal in the areas of the visual field that were "blind" to changing-disparity, so that motion in depth could be seen in this part of the visual field in everyday viewing conditions.

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