Peripheral visual acuity and refractive error: Evidence for "two visual systems"?

CHRIS A. JOHNSON and H. W. LEIBOWITZ
Pennsylvania State University, University Park, Pennsylvania 16802

MICHEL MILLODOT
Department of Ophthalmic Optics, UWIST, Cardiff, Wales

and

ANNE LAMONT
Laboratory of Experimental Optometry, University of Montreal, Montreal, P.Q., Canada

Experiments conducted in two independent laboratories indicate that the correction of refractive errors does not improve peripheral visual acuity. This finding contrasts with previous results for motion detection and other visual functions in the periphery. The "two visual systems" hypothesis provides a heuristic means of interpreting this apparent discrepancy.

A number of recent behavioral and physiological findings suggest the operation of two distinct modes of processing visual information, pertaining to the identification ("what") and localization ("where") of visual stimuli. Anatomically, it appears that resolution and pattern vision are subserved mainly by primary cortical mechanisms, while orientation and localization are chiefly a function of midbrain visual structures (Ingle, 1967, 1973; Schneider, 1967, 1969; Trevarthen, 1968). From a functional viewpoint, Trevarthen (1968) considers an identification mode to be primarily associated with foveal and parafoveal regions ("focal vision"), with a localization mode distributed over the entire visual field ("ambient vision"). Humphrey (1974) reports that the behavioral characteristics of Helen, a destriate rhesus monkey, were consistent with the interpretation of a permanently impaired "focal" system, with the "ambient" system remaining relatively intact.

Much of the current psychophysical evidence of "two visual systems" in humans is represented by the work of Held and his associates (Held, 1968, 1970, 1971). In a number of visual rearrangement experiments, their findings indicate that visual adaptation occurs predominantly with respect to the localization and orientation ("where") aspects of visually guided behavior. Adaptation to contour distortions and related phenomena ("what") was usually either minimal or absent in comparison with the localization adaptation effects. This differential adaptation for visual rearrangement provides dra-

matic support for the "two visual systems" concept. Additional findings consistent with the two modes of visual processing concept include the presence of residual visual function within scotomatous areas in the visual field of patients with cortical lesions (Poppel, Held, & Frost, 1973; Sanders, Warrington, Marshall, & Weiskrantz, 1974). Basically, these results indicate that patients, while unable to "detect" stimuli within areas of field loss, were able to localize (via eye movements) the "nondetectable" stimuli. Thus, differential effects were obtained for visually mediated verbal and motor responses to stimuli presented in scotomatous regions. In this report, we present further psychophysical findings which appear to reflect the presence of two visual systems in humans based upon a differential effect of blur on two separate visual functions in the periphery.

It has been well established that very large refractive errors are normally present in the periphery, with the amount and types of errors exhibiting considerable individual variability (Ferree & Rand, 1933; Lotmar & Lotmar, 1974; Millodot & Lamont, 1974). The poor peripheral dioptrics represent a potential limiting factor for most visual functions, which typically become highly degraded with increasing peripheral eccentricity. In the present study, the effects of refractive error on peripheral visual acuity were examined in two separate laboratories (Penn State and Montreal) employing different methods and test stimuli. The dioptric aspects of this topic have been previously reported (Millodot, Johnson, Lamont, & Leibowitz, 1975); hence, the present report will be concerned primarily with the relationship between these data and the theoretical aspects of "two visual systems."

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METHOD

The apparatus used at Penn State displayed the test and background fields in Maxwellian view. Each trial consisted of a brief (250-msec) exposure of a horizontally oriented sinusoidal grating superimposed on a continuously presented background field (524 cd/m^2). During successive trials, the spatial frequency of the target was varied according to a modified double-staircase method. Acuity thresholds, defined as the point at which the presence of grating lines were reported on 50% of the trials, were determined for each of the four observers at 0° , 20° , 40° , and 60° of eccentricity along the horizontal meridian of the temporal visual field. Refractive error was determined retinoscopically by an experienced optometrist.

In the Montreal experiment, the apparatus and procedure were somewhat different from those employed at Penn State. During each trial, a dark Landolt ring, in one of four possible orientations, was briefly (220 msec) projected onto a white screen (adapting luminance, 86 cd/m^2) in the observer's visual field. Visual acuity thresholds (50% correct) were determined by the method of constant stimuli. Measurements were obtained between 0° and 60° of eccentricity, in successive 10° intervals, along the horizontal meridian of the temporal visual field of three observers. Refractive error was determined with an Arnulf retinofocometer. Details of both the Penn State and Montreal experiments are described elsewhere (Millodot et al., 1975).

RESULTS

Figure 1 presents the mean visual acuity (semi-logarithmic coordinates) for the four Penn State and the three Montreal observers as a function of stimulus eccentricity with and without correction of

Figure 1. Mean visual acuity (logarithmic scale on ordinate) as a function of stimulus eccentricity with and without correction of peripheral refractive error for four Penn State (circles) and three Montreal observers (triangles). The test object for the Penn State experiment was a sinusoidal grating, while a Landolt C was used for the Montreal experiment. (After Millodot et al., 1975.)

refractive error. All curves display the characteristic decline in visual acuity with increasing eccentricity. However, there is little or no difference between the data obtained with and without correction of refractive error in the periphery. This contrasts with the marked effect of blur on visual acuity in central vision (Borish, 1970). It should be noted that, in both experiments, the refractive error at 60° of eccentricity averaged more than 4 diopters for all observers, while some exhibited as much as 6 or 7 diopters of oblique ray astigmatism.

To validate the results of both experiments, two of the Penn State observers were subsequently tested in the Montreal laboratory. Their results were similar to the data obtained with the three original Montreal observers. Again, no differences in peripheral visual acuity with and without correction of refractive error were found. In view of these similar results, obtained under different experimental conditions, we are reasonably certain that visual acuity in the periphery is not limited by dioptics. The results of the Penn State observers in the validation experiment also suggest that differences in the absolute values of visual acuity obtained at Penn State and Montreal can be attributed to the different test objects employed.

DISCUSSION

The present findings contrast with previous studies which have examined the effects of blur on absolute detection, increment, and motion thresholds in the periphery (Enoch, Sunga, & Bachman, 1970; Fankhauser & Enoch, 1962; Johnson & Leibowitz, 1974; Leibowitz, Johnson, & Isabelle, 1972; Ronchi, 1971). These functions are quite sensitive to blur in the periphery, exhibiting considerable improvement following the correction of refractive error. It is difficult to interpret this apparent discrepancy, although the concept of "two visual systems" may be of some assistance.

The primary function of the visual periphery is the apprehension of stimuli to direct eye movements for detailed foveal inspection. Thus, motion and abrupt luminance changes produced by motion are particularly appropriate stimuli for peripheral vision, which is mainly characterized by the "where" or "ambient vision" mode of processing. It might be assumed, therefore, that subcortical mechanisms responsive to motion and abrupt stimulus changes would be sensitive to image quality over most of the visual field. On the other hand, the discrimination of detail, primarily associated with the "what" or "focal vision" mode of processing, might be expected to be sensitive to blur in the central visual field, but not necessarily in the periphery. Such an interpretation, based on the two visual systems hypothesis, is consistent with the results of this and previous psychophysical investigations.

It is important to consider the implications of the two modes of processing visual information concept. From the point of view of the functional performance of the visual system, individual differences in the ability to detect moving stimuli in the periphery are of adaptive significance. Indeed, considering the role of motion detection in adjustment, the superior ability to appreciate moving stimuli off-axis must be considered to be a distinct competitive advantage. This would also hold for the role of peripheral stimuli in relation to the mobility of the organism in which the ability of the moving eye to localize objects in space peripherally without foveal fixation would increase the organism's efficiency. In this context, it is paradoxical that peripheral motion detection is degraded by poor peripheral dioptrics, while peripheral resolution, which plays a minor role in adjustment, remains immune.

SUMMARY

A dissociation of the effects of blur on various functions in central and peripheral vision has been demonstrated psychophysically. The nature of the dissociation is compatible with previous psychophysical dissociations of function, all of which suggest the operation of two modes of visual processing ("two visual systems"). A more extensive analysis of functional visual properties within the context of "two visual systems" may provide a fruitful approach to the general understanding of visual function.

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