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SHORT COMMUNICATION

Contrast-dependent Dissociation of Visual Recognition and Detection Fields

Hans Strasburger and Ingo Rentschler
Institut für Medizinische Psychologie, Universität München, Goethestrasse 31, D-80336 München, Germany

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Abstract

Seeing an object 'as something' is different from simply seeing it (see Watanabe, S., 1985, *Pattern Recognition: Human and Mechanical*, John Wiley). This distinction between recognition and detection often goes unnoticed in physiology and clinical practice, where visual performance is characterized in terms of acuity, visual field and contrast sensitivity. The corresponding functions of stimulus *detection* are consistent with the neural projection properties from the retina to the striate cortex, i.e. the 'cortical magnification theory'. Yet *recognition* performance for characters (Strasburger, H. *et al.*, 1994, *Eur. J. Neurosci.*, **6**, 1583–1588) and grey-level patterns (Jüttner, M. and Reutschler, I., 1996, *Vision Res.*, **36**, 1007–1022) does not fit into this scheme. Here we show that this discrepancy results in the dissociation of visual recognition and detection fields, which is dramatic at low pattern contrast. Form proper can be appreciated exclusively within the much narrower field of recognition, the *window of visual intelligence*. Its function is, at low contrast, probably mediated by the magnocellular pathway and at all contrasts is determined by the processing characteristics of higher stages of the ventral visual pathway.

We determined, on the one hand, visual fields of recognition by psychophysically measuring contrast thresholds for the identification of (isolated) numeric characters [for an illustration see Fig. 1; for details of methods see Strasburger *et al.* (1991, 1994)]. At a given retinal eccentricity, optimum recognition thresholds were obtained as lower bounds of contrast thresholds varying with target size (Fig. 2). The results confirm earlier findings (Strasburger *et al.*, 1991, 1994) and extend their validity to the vertical meridian. Visual fields of character recognition were then obtained for any level of stimulus contrast by inverting the size–contrast interrelations (Fig. 4). Visual fields of detection, on the other hand, were determined by standard procedures of dynamic and static perimetry (Fig. 3) (Aulhorn and Harms, 1972). This procedure was used instead of a *direct* comparison of detection and identification performance with one type of stimulus for two reasons. First, previous work on discrimination (or identification) with *a priori* knowledge about the single dimension of stimulus variability (Tolhurst and Dealy, 1975; Watson and Robson, 1981; Thomas *et al.*, 1982) cannot be extended to character recognition, which is characterized by the presence of multiple, *a priori* unknown, stimulus dimensions. Second, perimetry represents the accepted method of visual field assessment that needed to be included.

Comparison of the visual fields of recognition and detection reveals that the former are much narrower than the latter (Fig. 4). This dissociation can be discerned at high levels of stimulus contrast, but becomes dramatic at low contrast. At a contrast level of 2%, character recognition is confined to the central 4° and is only possible for characters with a linear extent of >3.2°. This lower bound of recognition size exceeds spatial resolution by a factor of 230.

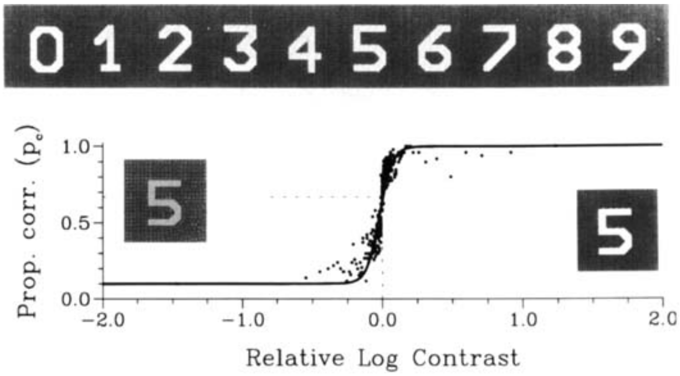

FIG. 1. Procedure for measuring contrast thresholds for character recognition. High-resolution images of single digits were presented as light patterns on a uniform background of constant luminance (L_b of 62 cd/m^2). One of the ten characters was selected at random and singly presented at the preset contrast. Subjects were to identify this target by pressing the appropriate numerical key. The character set is shown at the top of the figure; the insets serve to visualize contrast variation. Pattern contrast was varied according to an adaptive sequential procedure (Harvey, 1986). The ogive shows a Weibull function fitted to the subject's overall recognition behaviour. Thresholds represent the level of the contrast at which 67% correct responses occur. Pattern contrast is given in Michelson units $C_M = (L_p - L_b)/(L_p + L_b)$; presentation time was 100 ms. Subjects fixated a small dark spot and stimulus presentation was at a fixed visual field position for each threshold measurement, i.e. subjects attended to that position. Further details can be found in Strasburger (1991).

Correspondence to: Dr Hans Strasburger, as above

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Our data thus reflect a hitherto unnoticed functional specialization of foveal and perifoveal vision: apart from the ability to resolve fine spatial detail at high contrast, the central visual field is unique in being able to recognize form at low contrast.

From the observed incongruence between recognition and detection fields we conclude that the standard tests of acuity, visual field (perimetry) and contrast sensitivity do not assess the visual sense of form *per se*. This was already implicit in Pirenne's (1962) statement that 'there are in fact as many different 'visual acuities' as there are types of test objects'. Furthermore, an extensive study of acuities revealed, via factor analysis of the performance correlation matrix, that checkerboard resolution was the purest measure of acuity, followed by Landolt-C acuity (Department of the Army, 1948). Another factor, then attributed to 'form perception', was only obtained from letter acuity tasks such as Snellen acuity. Yet another factor, found for example in circle/square discrimination, was called 'simple form perception'. As implicit in principal component analysis, the latter two factors represented independent perceptual abilities. Consistent with this scheme of form perception proper being separate from a simpler ability for discrimination are results in perimetry, where Aulhorn and Harms (1972) found the contrast thresholds for circle/diamond discrimination at small target sizes to be consistent with Landolt-C acuity, i.e. pure, non-form-related acuity. For large targets, their results were predictable from light increment thresholds for the detection of light spots, again implying that discrimination is more similar to detection than to recognition. Such a hierarchy of perceptual abilities further implies that discrimination and identification, as understood in previous psychophysical research (Tolhurst and Dealy, 1975; Watson and Robson, 1981; Thomas *et al.*, 1982), are different from form recognition proper (Duda and Hart, 1973; Watanabe, 1985).

The extent of visual fields of recognition is further influenced by

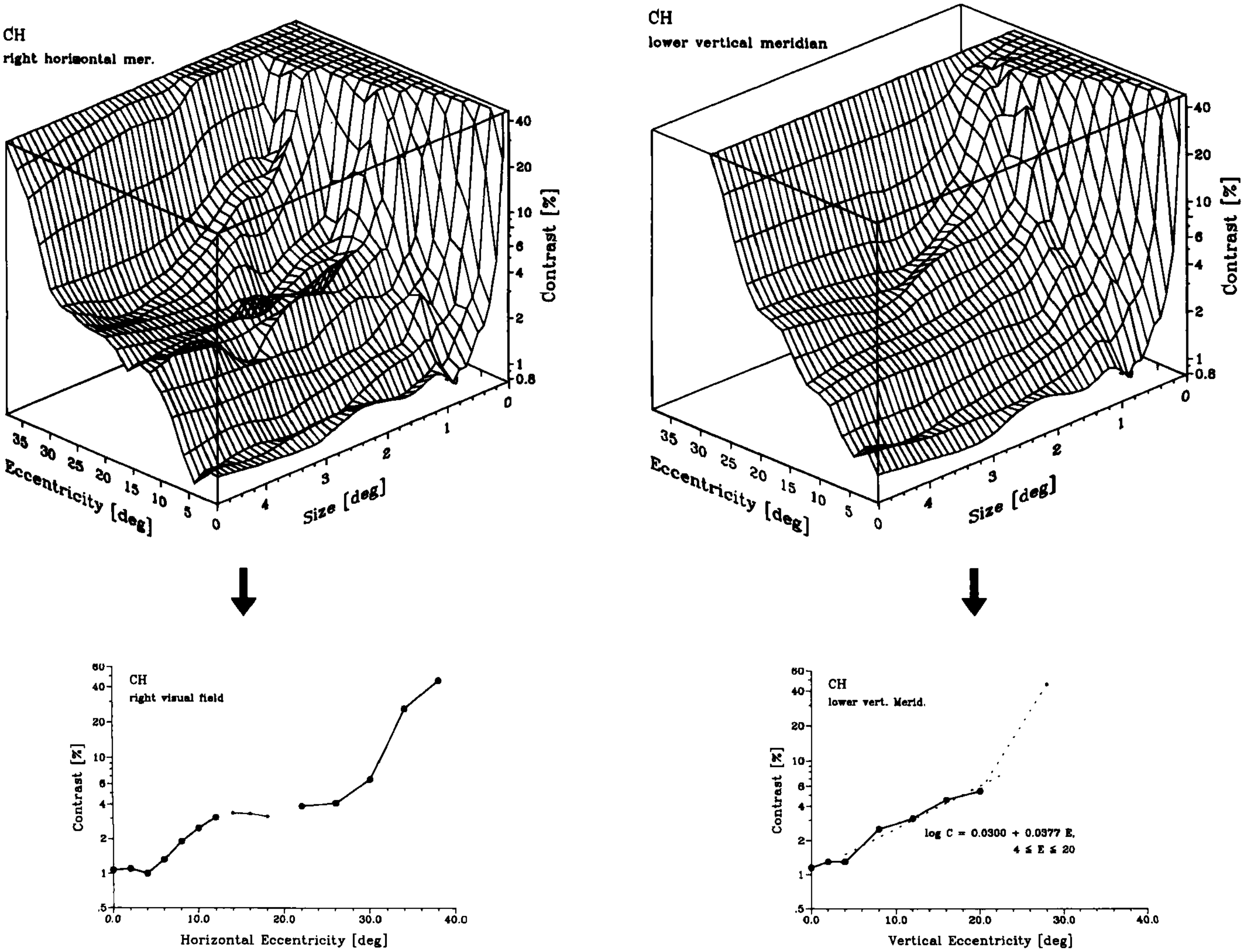

FIG. 2. Recognition of numeric characters on the principal meridians. Contrast thresholds for recognition in binocular viewing, plotted as a function of target size and retinal eccentricity, for one subject (CH, female, age 25). Visual field positions on the right horizontal (left graphs) and the lower vertical meridian (right graphs). (Top left) Three-dimensional grid spanned by 194 data points, sampling being denser at low target sizes. Each data point has a 95% confidence interval of 0.14 log units and constitutes on average 2 × 20 trials. Overall, the graph represents ~7800 responses. (Top right) Three-dimensional graph represents 76 data points or 3000 responses. (Bottom) Optimum recognition thresholds derived from three-dimensional plots. For example, the optimum stimulus contrast for foveal viewing in this subject is 1.2% and occurs at 3.2° target size. To improve reliability, the mean of the optimum and second best value is taken. Between 0° and 4° eccentricity, the subject shows a non-significant decrease in optimum contrast threshold, and since another subject shows a similarly slight opposite trend we consider thresholds as constant in this range, i.e. in the fovea and perifovea. Similarly, the increase is rather shallow between 12° and 26° eccentricity (where another subject had no increase), so the best description is a plateau also within this range.

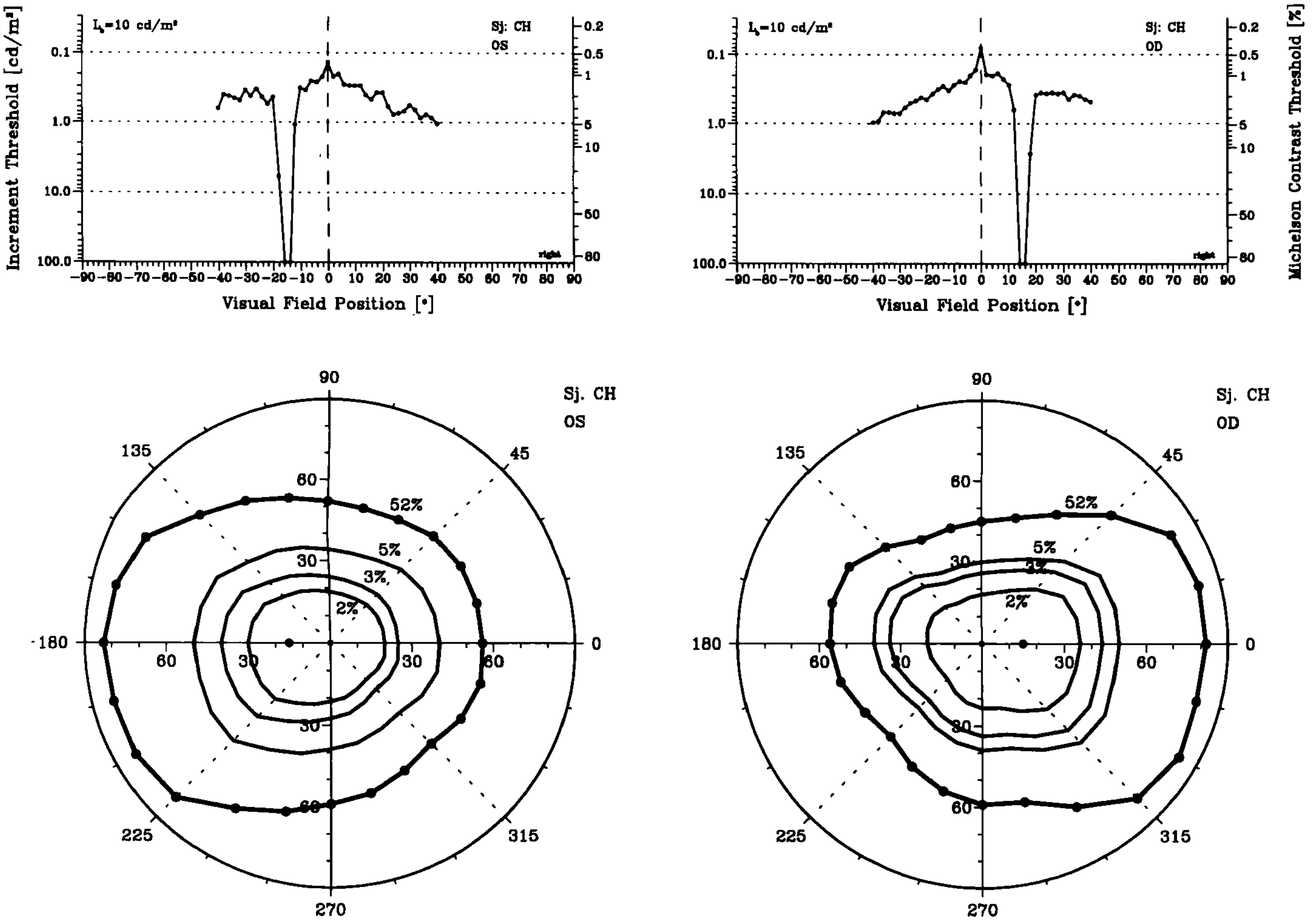

FIG. 3. Standard perimetry for subject CH and contours of equal contrast detection thresholds. Disk target of 44′ diameter on a 10 cd/m^2 background ['Oculus' or 'Tübinger' perimeter (Aulhorn and Harms, 1972)]. To determine the absolute field of view (shown by the outer contour), a 32 cd/m^2 target is moved along one of 24 half-meridians towards the field centre until it is visible. A luminance level of 32 cd/m^2 is routinely used since higher luminance does not increase the field of view. This procedure yields a field extension of 82 × 60°. For a threshold profile (top), a target of variable luminance is presented at one of 41 positions on the horizontal meridian, and the luminance threshold is determined by the method of adjustment (three repetitions per point). From the profile, the inverse function is read at three contrast levels (Michelson), 5, 3 and 2% (corresponding to increments of 1.0, 0.6 and 0.4 cd/m^2). Since the slope of the profiles is shallow, the inverse function is less reliable than the profile itself, but reliability is sufficient for the intended comparison with fields of recognition. No profile outside the horizontal meridian had been measured, so the shape of field contours is estimated by down-scaling the absolute field of detection. Viewing is monocular. The binocular field is the union of the two monocular fields. Low-contrast contours constitute a lower bound for binocular viewing.

attentional factors. As already noted by von Helmholtz (1871), peripheral recognition is best when attention is separated from fixation, as is the case in our experimental conditions. When attention is attached to the point of fixation, smaller recognition fields result (Geiger *et al.*, 1992). The presence of flanking patterns distracts attention and further reduces recognition performance (Strasburger *et al.*, 1991). Thus, our recognition fields are not invariant but constitute upper bounds for recognition performance under optimum attentional conditions.

As for the physiological basis of character recognition, we contend that the magnocellular (*M*) pathway is probably the exclusive mediator of form recognition at low contrast (Strasburger *et al.*, 1994): contrast thresholds for foveal character recognition are below 1% (Michelson) contrast, which is similar to grating detection performance and is far below the parvo cell (*P*) threshold of 10% (Hicks *et al.*, 1983; Derrington and Lennie, 1984). *M* cells, on the other hand, have optimum thresholds of ~1%. It is unlikely that neuronal summation bridges this large gap (Kaplan *et al.*, 1990, p. 300). Further, the fact that the threshold values depend on the chosen firing rate criterion (Derrington and Lennie, 1984) is unlikely to explain a *P* cell contribution at lowest contrast: that criterion is set, in relation to the cell's noise floor, equally for *M* and *P* cells, and substantially lower criteria for *M* cells would predict better psychophysical detection behaviour than is actually observed. Similar reasoning applies to the peripheral visual field (for details see Strasburger *et al.*, 1994). The hypothesis that the *M* pathway contributes to pattern recognition contradicts the belief that pattern vision is the exclusive domain of the *P* pathway (Livingstone and Hubel, 1988). Recent reports of mixed *P* and *M* signals in visual area V4, however, support the involvement of *M* (Ferrera *et al.*, 1992). We propose the farther reaching hypothesis of *M* signals being the exclusive mediator of low-contrast pattern recognition. *Hence we predict that selective functional elimination of the* P *pathway* (Schiller *et al.*, 1990; Ferrera *et al.*, 1992) *will leave low-contrast pattern recognition intact.* Note that this prediction is compatible with *P* lesion impairment of high-contrast recognition (Figs 1 and 18 in

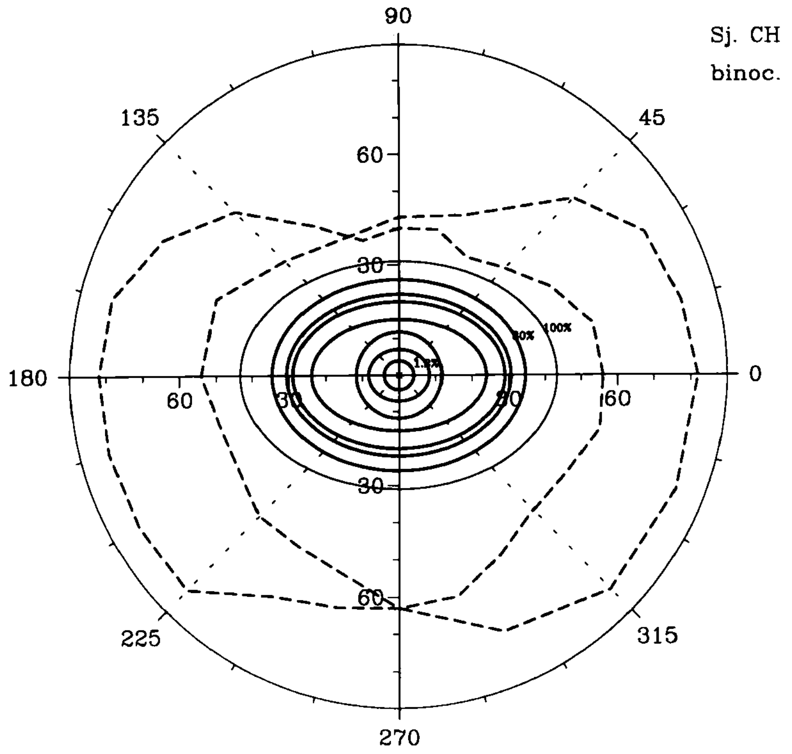

FIG. 4. Visual fields of recognition and detection. Recognition fields (heavy lines) obtained by taking the inverse functions from those shown in Figure 2 (bottom). The former give the critical eccentricity range beyond which a character cannot be recognized irrespective of its size. For the plateau in the central visual field, the mean contrast between 0 and 4° eccentricity is taken. The form of the field is approximated by ellipses. Each ellipse shows the border of recognition at a given level of contrast, at the values 30, 10, 6, 4, 3, 2 and 1.2% (contrast in Michelson units). Note the performance plateau on the horizontal meridian between 10 and 20°, similar to the one found in perimetry (Harvey and Pöppel, 1972; Pöppel and Harvey, 1973). The 100% contrast ellipse represents a maximum field of recognition obtained by extrapolation; its diameter is ~46 × 32°. Also indicated in dashed lines are the fields of detection from Figure 3.

Schiller *et al.*, 1990), since in that latter case much smaller targets (finer detail) have been used than are suitable for low-contrast recognition. In a more general context, this hypothesis fits well with previous theorizing in cat neurophysiology based, for example, on the finding that the removal of the striate cortex of the cat, together with *X* cell (i.e. fine grain) input, by no means suppressed form vision (Sherman, 1985; Krüger *et al.*, 1986, 1988). Sherman (1985) proposed that the role of the *X* (or *P*) system is to add capacity for high acuity (at high contrast) to a basic (low-contrast) *Y* (or *M*) form vision system.

We are then left with the question of why recognition at low pattern contrast is confined to the central visual field. The limitation cannot be explained within the cortical magnification concept, which describes the consequences of the topographic mapping from retina to cortex (for reviews see Pointer, 1986; Drasdo, 1991; Virsu *et al.*, 1987). Reduced recognition at low contrast persists under the condition of optimal stimulus size and is thus unaffected by spatial mapping. Size-unrelated properties of the retino-cortical pathway, on the other hand, such as the positional variation of the average contrast thresholds of retinal ganglion cells, the ratio of *P* to *M* cell numbers at given field positions, and the amount of receptive field overlap, fit rather well with what we know about grating detection, but are likewise insufficient for explaining the discrepancy between stimulus recognition and detection (Strasburger *et al.*, 1994). It follows that the relatively higher recognition thresholds reported here arise at a later, i.e. extrastriate, stage of visual processing.

Recent neurophysiological and neuroanatomical studies have shed light on the crucial role of the ventral visual pathway in pattern recognition, i.e. the serial pathway constituted by cortical areas V1, V2 and V4 and the posterior and anterior inferotemporal cortex (Desimone *et al.*, 1984; Zeki and Shipp, 1988; Kobatake and Tanaka, 1994; Fujita *et al.*, 1992; Ito *et al.*, 1995; Tanaka, 1996). In the anterior inferotemporal cortex, cells are organized into columns (Fujita *et al.*, 1992), with cells of the same column responding selectively to similar specific patterns. These patterns are of great variety and are in complexity not unlike letters. The preceding stages V4 and posterior inferotemporal cortex differ in that cells with simple and complex specific stimuli are intermingled (Kobatake and Tanaka, 1994). The local neuronal networks in these two areas are the likely site for elementary features to be combined to allow the recognition of form. How such feature combinations can be formally described is made explicit in the technical literature on pattern recognition (Duda and Hart, 1973; Ahmed and Rao, 1975; Watanabe, 1985). Consequently, these two areas are the likely site where recognition contrast thresholds arise.

The maximum field of recognition, beyond which no complex pattern can be recognized, reaches out horizontally to about ±46°, i.e. the field of detection is nearly twice as wide (Fig. 4). In the anterior inferotemporal cortex, cells with complex critical features studied so far had receptive fields that always included the fovea and were of diameter 25 ± 15° (Ito *et al.*, 1995). It is tempting to speculate that these cells provide the physiological basis of the limited visual field. Accordingly, *we predict that cells in the higher ventral pathway respond at low pattern contrast if, and only if, their receptive fields cover the central visual field.*

Thus we have shown that spatial resolution is but one factor of the visual sense of form. Form vision proper is characterized by algorithms that allow the recognition of the input *as something* (Duda and Hart, 1973; Ahmed and Rao, 1975; Watanabe, 1985). Recognition competence at all levels of stimulus contrast is a unique feature of the central visual field, and this *window of visual intelligence* shrinks to a peephole of diameter 2–4° at very low contrasts. While the variation of spatial resolution across the visual field conforms with the retino-cortical projection properties, the recognition of form depends on extrastriate activation (Zeki and Shipp, 1988; Baumgartner, 1990) mediated, at low contrast, through the *M* pathway. In brief, it seems that the *depth of insight* into aspects of form requires a corresponding depth of processing in the brain at the cost of a *narrower field of view*.

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Abbreviations

M cells	cells from the magnocellular pathway
P cells	parvo cells
X, *Y* cells	cells in the cat's visual system

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