Pattern Recognition in Direct and Indirect View

Hans Strasburger[1] and Ingo Rentschler[2]

1 Introduction

More than a century ago, it was shown that there is an acuity deficit in peripheral vision that can be compensated for by increasing stimulus size (Aubert and Foerster 1857; Wertheim 1894). The corresponding size-scaling approach, or cortical magnification concept, has accounted for much of the eccentricity variation in grating contrast sensitivity (Koenderink et al. 1978; Rovamo and Virsu 1979) and various other measures of acuity (e.g., Levi et al. 1985; Virsu et al. 1987). Yet this cannot be the whole truth since size-scaling fails to establish positional invariance for a wide range of visual tasks, like numerosity judgments (Parth and Rentschler 1984), discrimination of phase-modulated (Harvey et al. 1985) and symmetrical mirror images (Rentschler and Treutwein 1985), face recognition (Hübner et al. 1985), and recognition of numeric characters (Strasburger and Rentschler 1996); (Strasburger et al. 1991).

To explain this discrepancy, we previously suggested that peripheral vision ignores pattern structure independently of scale but detects image energy in much the same way as foveal vision does (Rentschler and Treutwein 1985; Rentschler 1985). Similarly, our previous study (1996) proposed that peripheral vision fails to integrate pattern features. Such explanations of functional inhomogeneity across the visual field remain somewhat vague as long as there is little known about the corresponding neural representation of patterns. To address that issue, we review two recent studies of pattern recognition in direct and indirect view, which used classification paradigms corresponding to two meanings of the term pattern recognition (cf. Watanabe 1985, Chap. 1): Strasburger (2005) elaborated

---

[1] Generation Research Program, University of München, Germany, and Department of Medical Psychology, University of Göttingen, Germany 1

[2] Institute of Medical Psychology, University of Munich, Goethestraße 31, D-80336 München, Germany

Proofs should be sent to: Hans Strasburger, University of Göttingen, Department of Medical Psychology, Waldweg 37, D-37073 Göttingen, Germany. Fax: +■■. Email: Strasburger@uni-muenchen.de 2

on the recognition of numeric characters, i.e., the identification of patterns as members of already known classes. Jüttner and Rentschler (2000) investigated how observers learn to assign unfamiliar grey-level patterns to previously unknown classes.

2 Crowding Effect in Indirect View

A conspicuous limitation of pattern recognition on indirect view is known as the crowding effect, where performance is impaired for test patterns that occur in the presence of neighbouring patterns (Strasburger et al. 1991). The effect is small in foveal vision (Flom et al. 1963) but dramatically reduces recognition performance in extrafoveal vision (Bouma 1970). In amblyopia–a loss of visual function due to disuse in childhood–the effect is strong in the fovea as well (Stuart and Burian 1962). Crowding changes during visual development but shows a slower time course than that for acuity (Atkinson et al. 1986) and plays an important, if not fully understood, role in dyslexia (Geiger and Lettvin 1986). Figure 1 provides a simple demonstration of the effect.

The strong influence of retinal eccentricity on the crowding effect can be explained at least partly as an effect of spatial attention (Strasburger et al. 1991; He et al. 1996). This has been demonstrated by Strasburger et al. who showed that a bar pointing towards the target letter, but not a circle around it, is effective in directing the attention of observers to targets within letter strings. Thus, both spatial attention and lateral masking have been demonstrated. In addition, Strasburger and co-authors performed an error analysis similar to that by Eriksen and Rohrbaugh (1970), for separating sensory and attentional influences on lateral masking. Strasburger et al. succeed in showing that localization errors, i.e., the inadvertent reporting a flanker rather than the target, and failure to recognize the target character in the middle were equally frequent in many cases. They interpreted this result as a consequence of pattern recognition in the absence of positional information or the ability to precisely focus attention.

Strasburger (2005) confirmed and extended these findings using three different recognition paradigms (Fig. 2). A standard crowding condition similar to that in Strasburger et al. (1991) was compared to a cued condition, which used a circle

FIG. 1. Crowding effect. The two representations of the digit "6" are shown at the same contrast and same distance from the fixation target. Yet, when vision is fixated on the dot, the "6" on the right is easily recognized, whereas the same "6" on the left is not

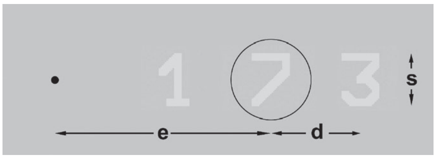

FIG. 2. Stimulus layout in the flanked and cued crowding condition. Letter size *(s)* is specified as letter height in degrees of visual angle; flanking distances *(d)* are measured from the respective character centres. *e*: eccentricity

at the target position appearing just before the target, and a "content-only" condition, where positional information was separated from (semantic) pattern content. Contrast thresholds for the recognition of numeric characters (digits 0–9) were measured using an adaptive algorithm (Harvey 1997). Characters were presented in white on a grey background (50 cd/m^2 luminance) for 100 ms, either in isolation (baseline condition) or laterally flanked by two additional digits. Twenty observers of both genders (aged 20–30 years) were tested under identical conditions. In each crowding condition, three digits (target and flankers) of the same size and contrast were used. Subjects were instructed to report the middle digit, and the dependent variable was the contrast threshold for recognizing the letter. In the flanked condition, the target was surrounded by neighbouring digits. In the cued condition, a black circle was exposed at the target location with an onset of 150 ms before the target. The circle was switched off at target onset.

The content-only condition was established by modifying the threshold criterion of the standard condition. Thresholds were determined by accepting as correct not only responses that identified the middle target but also responses that identified one of the flankers. Thus, subjects reflected the ability to recognize patterns independently of their location with sustained attention focused on the middle target. Taken together, there were two variations relative to the standard flanked condition (1): one, where spatial attention was modulated by a positional cue (2) and one, which separated target location and target content (3).

The magnitude of the crowding effect depends on stimulus size, character separation, contrast, and retinal eccentricity (Bouma 1970; Strasburger et al. 1991; Pelli et al. 2004). Three middle-character eccentricities, namely 1°, 2°, and 4°, were used with (scaled) stimulus sizes of 0.3°, 0.4°, and 0.6°, respectively. The size of the ring cues was scaled to 0.44°, 0.59°, and 0.88° in diameter.

Figure 3 shows the mean recognition thresholds over flanker distances under conditions (1)–(3). Thresholds for the single-digit are indicated by a horizontal line, together with the average standard error. As expected, of all three eccentricity conditions, (1) yields the highest thresholds. Crowding is absent at sufficiently large flanker distances, as seen in the top and middle graph of Figure 3, and gradually sets in at decreasing flanker distance. Contrast thresholds under condition (2) are below those of condition (1) at 1° and 2° eccentricity but still clearly above those under the single-digit condition. Thus, the ring cue was, at these

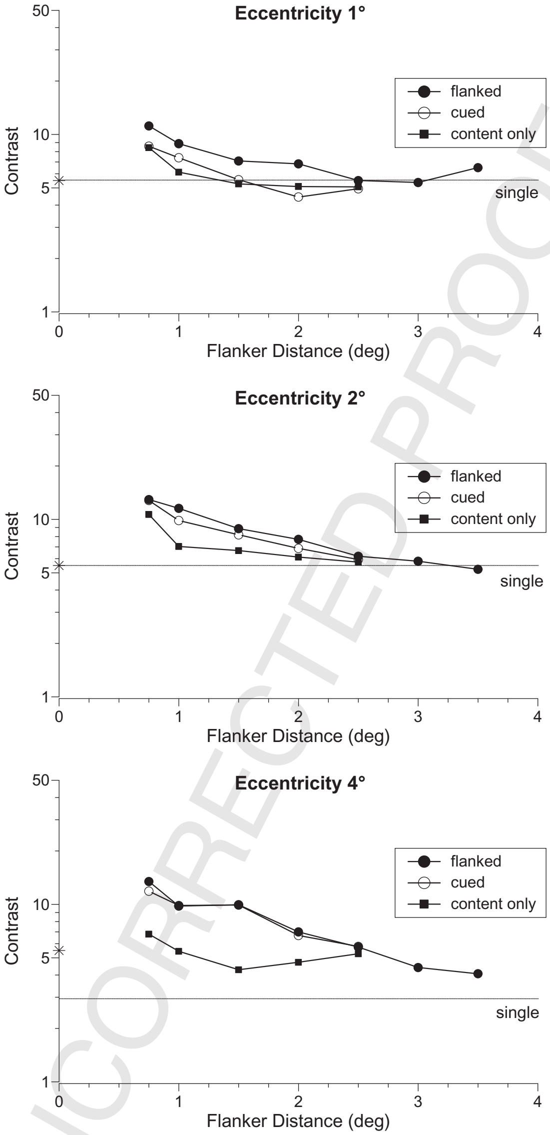

FIG. 3. Recognition contrast thresholds for the three crowding conditions as a function of flanker distance, at three eccentricities on the horizontal meridian (top to bottom graph 1°, 2°, and 4°, respectively). The thresholds for the single-character presentation are shown as thin horizontal lines; error bars on the corresponding data point show the mean for all data points in that sub-graph

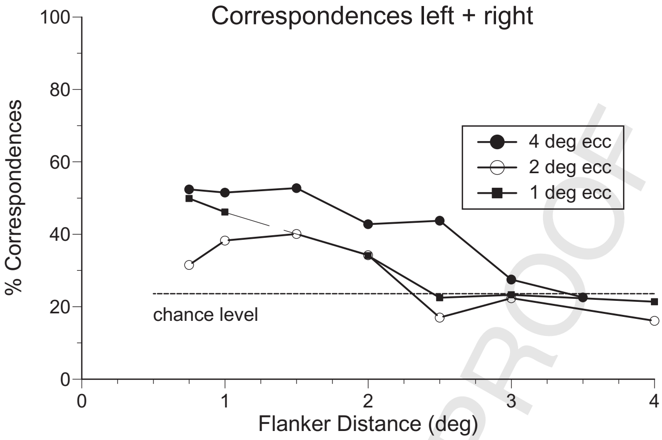

Fig. 4. Correspondences of the observers' incorrect responses with one of the flanking characters in the flanked condition, as a function of flanker distance. Chance level (23.6%) is indicated by the dashed line

eccentricities, partially effective in focusing attention on the middle character. Reasons for the cue not being effective at 4° could be a circle size that was too small, thus introducing some masking along with attention guidance (Averbach and Coriell 1961). Contrast thresholds are lowest under the content-only condition (Fig. 3, filled squares). For eccentricities of 1° and 2°, thresholds are nearly equal to those corresponding to the single-digit condition (horizontal line). At 4° eccentricity, thresholds are elevated but still clearly below those of the standard flanking condition. Thus, when the position of a character within a letter string was ignored, its recognition under crowding conditions was almost as good as that when presented in isolation.

Figure 4 shows the results of error analysis. The dependent variable "correspondences" indicate how often a character, that was erroneously reported to be present at the target location, actually occurred as one of the flanking characters. Related chance performance (23.6%) is indicated by the dashed line in Figure 4. The difference between the proportion of correspondences and chance level can be attributed to localization errors, where observers correctly identified a pattern but missed its location. Such errors do not occur at large flanker distances and clearly increase with decreasing flanker distance. At their maximum, observed correspondences are as high as 52% (filled circles), thus demonstrating close to 30% recognition levels at the wrong location (52%–23.6% chance). The remaining errors (100%–52% = 48%) can be attributed to a failure in recognizing pattern content. The comparison of Figures 3 and 4 further shows that flanker distances, below which crowding and mislocalization, respectively, take place, are about equal. Thus, localisation errors occur if and only if there is crowding.

The effects of crowding conditions on contrast thresholds and on correspondences were tested for statistical significance using two one-way analyses of covariance with crowding condition as the factor (and linearized eccentricity as covariate). All effects were highly significant at the 1% level. Importantly, the correspondences are nearly equal (38.6% *vs* 39.1%) between the flanked (1) and the flanked-and-cued condition (2). Therefore, the cue is effective in improving recognition performance (as shown above under condition 2) but the improvement does not stem from moving attention away from the flanking characters.

To summarize, at flanker distances up to 2.5° (eccentricity ≤4°), the crowding effect is to a large part (up to 30%) explained by imprecise coding of the target character's position. Remaining errors (48%) can be attributed to insufficient coding of pattern content. A ring cue preceding the target enhances (content) recognition by sharpening transient spatial attention but leaves positional coding unaltered. Thus, it appears that pattern identity and pattern location are separately encoded.

3 Attentional Spotlight and Feature Integration

As has previously been conjectured, the visual periphery seems to have a restricted ability to encode spatial relations between pattern components or integrate pattern features (Rentschler and Treutwein 1985; Strasburger and Rentschler 1996). Similarly, Pelli et al. (2004) characterized crowding as a process of impaired feature integration occurring in the visual periphery, in distinction to lateral masking from impaired feature detection occurring anywhere in the visual field. Strasburger (2005) proposed that the range of feature integration is related to spatial attention and might reflect the spread of attentional spotlight. Distinguishing sustained and transient visual attention (Nakayama and Mackeben 1989; Mackeben 1999), the standard crowding task involves *sustained* attention since subjects were well aware in advance of where the stimulus would appear. The role of the ring cue in that framework was to enhance content coding by increasing *transient* attention, leaving position coding unaffected.

How does the concept of attention mediating feature integration fit with neurophysiological findings? Flom et al. (1963) have shown that lateral interactions do also occur when target and flankers are presented to one eye and the other eye, respectively (dichoptic viewing conditions). Interactions therefore occur at the cortical stage. Results of dichoptic masking in the fovea and in the periphery, support this view (Tripathy and Levi 1994). Strasburger (2005) elaborated on that within a concept of attention involving the spatially selective control of bottom-up activation through top-down connections. Selectivity was assumed to be mediated by retinotopically organized brain structures (cf. LaBerge 1995; Vidyasagar 2001). The gating itself could occur in early cortical areas or even in the lateral geniculate nucleus. The latter is commonly thought to subserve a gating function in the retino-cortical pathway. Indeed, Vidyasagar has shown attentional modulation in single-cell studies as early as in V1 (see also the chapter by S. Schwartz, this volume).

These observations suggest that, mediated through the pulvinar and V1, brain regions involved in attention selectively control retinotopically organized bottom-up activation. Owing to the function of a winner-take-all network (perhaps subserving Gestalt closure and related to object-based attention), the dominant stimulus representation might be selectively relayed to cortical areas performing visual feature integration like the inferotemporal cortex (ITC, see Tanaka 1996). Feature integration could occur in an unintended region of the visual field if the information encoded in the neural map is imprecise in location or spatial extent. In such cases, the perceived pattern would not coincide with the target. The ring cue, however, would seem to pre-activate the corresponding (retinotopic) location in the map without affecting other locations.

4 Category Learning *vs* Discrimination Learning

To explore pattern encoding in direct and indirect view, Jüttner and Rentschler (1996, 2000) used a paradigm of supervised learning, where unfamiliar grey-level patterns ("compound Gabor signals") are assigned to a given number of pattern classes. The luminance profiles of stimuli were varied through the modulation of phase relationships and, to some extent, amplitudes between spatial frequency components. Resulting classification tasks therefore largely involved the distinction of pattern structure.

Two types of classification tasks were compared, each involving a learning set of 15 patterns. Learning patterns were to be assigned to three classes having a fixed mean pattern vectors for identical image energy (Fig. 5). Set A, with a large variance in signals within each class and relatively small variance of signals between classes, presented participants with a difficult task. Set B, with a small variance within classes and large variance between classes, presented subjects with an easy task (Fig. 5a, left). Discrimination tasks involved the same stimulus sets used in three consecutive experiments, each requiring observers to assign sub sets of 10 learning signals to one of two pattern classes (Fig. 5b). Discrimination tasks thus conformed to the Delayed-Matching-to-Sample paradigm of behavioural research (see Miller and Desimone 1994). Three viewing conditions were employed: pattern exposure at the locus of fixation (central) and fixation 3° to the left and 3° to the right of the pattern centre, respectively (left and right). Pattern size was scaled according to cortical magnification (Rovamo and Virsu 1979). Learning performance was characterized using the number of learning units to criterion and a computational model providing mappings of internalized pattern representations onto their physical counterparts (probabilistic virtual prototypes, PVP; Rentschler et al. 1994).

PVP solutions for discrimination learning are obtained by making use of the fact that "dipole configurations" of pairs of pattern representations can be combined as in vector addition (see Jüttner and Rentschler 1996, Appendix I). Thus, it is demonstrated that such solutions for discrimination learning veridical1y represent the physical signal configurations in both direct and indirect view for

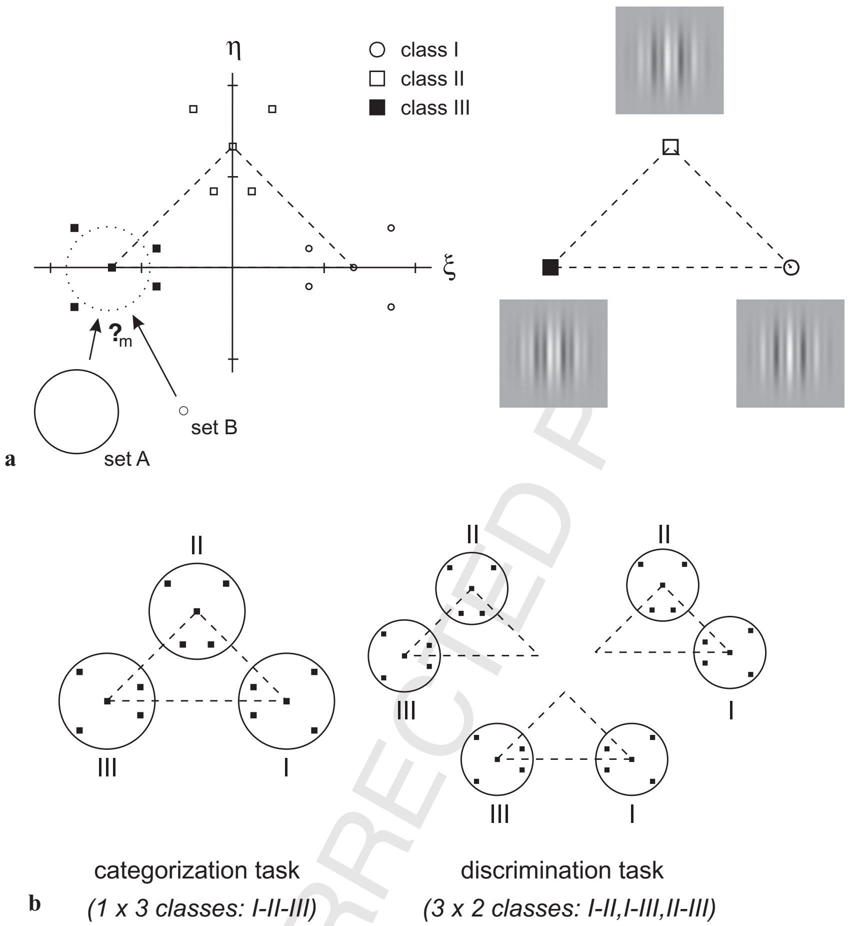

Fig. 5. **a** Pattern stimuli for discrimination and category learning. Stimulus sets consisted of 15 compound Gabor signals defined by a cosine waveform and its third harmonic, both modulated by an isotropic Gaussian aperture. The third harmonic was varied in amplitude b and phase φ. The physical signal representation used the features of evenness, $\eta = b \cos \varphi$, and oddness, $\xi = b \sin \varphi$. Pattern classes consisted of three clusters of five samples each. Scale: 1 unit = 15 cd m^{-2}. Mean pattern luminance 70 cd m^{-2}. Right: Images corresponding to the mean vectors of pattern classes. **b** Category learning (left) involved three pattern classes simultaneously. Discrimination learning (right) successively involved pairs of pattern classes (reproduced with permission from Jüttner and Rentschler 2000)

both difficult and easy tasks (Fig. 6, first rows, sets A and B). Similar results are obtained for category learning with the easy stimulus set B (Fig. 6, second row, set B). For the difficult set A, however, quasi-congruence of physical signal configurations and reconstructed pattern representations is only obtained for stimulus exposure at the locus of fixation (Fig. 6, set A, second row, centre). For off-axis stimulation, pattern representations degenerate to linear configurations

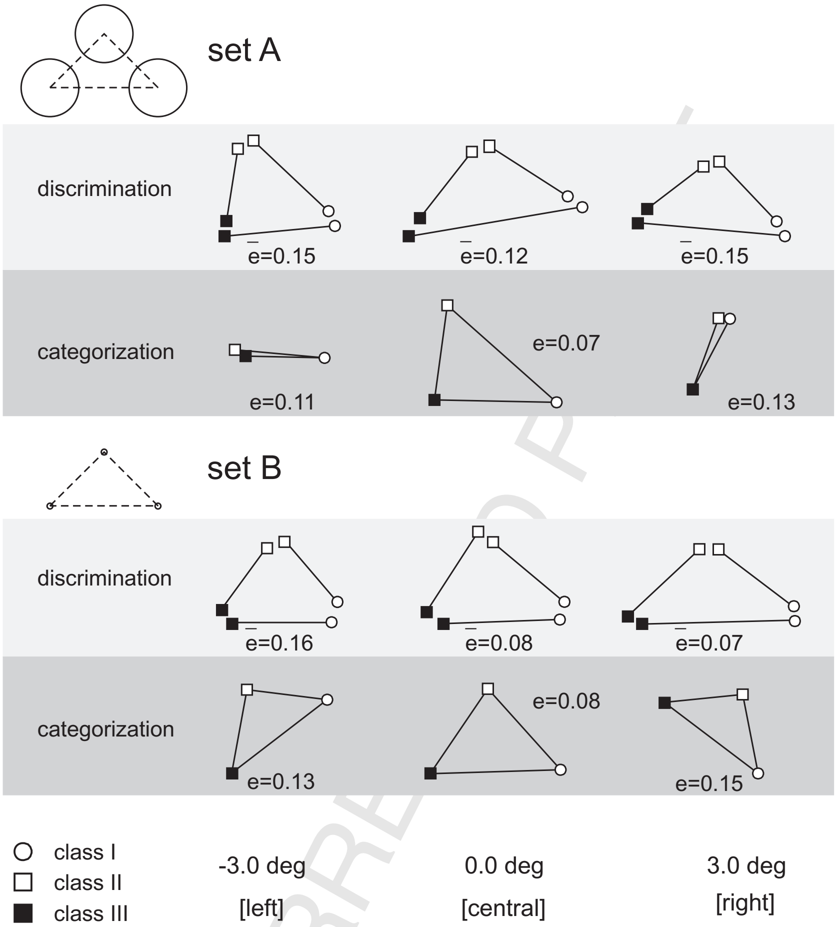

Fig. 6. Pattern representations generated through discrimination and category learning in direct and indirect view. Data obtained by re-projecting "virtual" class prototypes from behavioural classification data in physical feature space by means of probabilistic Bayesian classifiers (reproduced with permission from Jüttner and Rentschler 2000)

(Fig. 6, set A, second row, left and right). Similarly, learning duration was massively prolonged (about 8-fold) for category learning with the difficult stimulus set A under conditions of off-axis observation only.

These results falsify our original hypothesis according to which relational pattern encoding is impossible in indirect view. Instead, they indicate that structure-based discrimination and easy categorization tasks can be performed in indirect view provided size-scaling is applied. Yet there is an inability to perform difficult pattern classification tasks by indirect view that occurs even when sampling characteristics are accounted for by size-scaling.

5 Object Selective Attention in Direct and Indirect View

Concerning the difference between discrimination learning and category learning in direct and indirect view, it is noteworthy that for discrimination learning it is sufficient to construct in short-term memory a model of the comparison signal using a bottom-up process. This model is used as a template against which a comparison signal is matched. Supervised category learning, by contrast, requires activation from long-term memory of class models under the instructions of a "teacher". These models are matched against input signals and modified in the event of mismatches. The ability to activate the contents of long-term memory according to the requirements of current tasks is a defining property of working memory (Baddeley 1986; Fuster 2003). Within the biased-competition model (see the chapter by G. Deco and co-workers, this volume, and Deco and Rolls 2004), representations of pattern categorization in working memory can be considered templates for object selective attention (Desimone and Duncan 1995).

In the monkey, DMS tasks were studied by having the animal recognize a stimulus as being equivalent to another one presented shortly before. Neurons both in the inferior temporal cortex (ITC) and in the prefrontal cortex (PFC) may show related sample-selective delay activity (Miller and Desimone 1994; Miller et al. 1996). However, sample-selective delay activity in the PFC survives intervening irrelevant stimulus pairings, whereas in the ITC, this is not the case (Miller et al. 1996). Miller and co-workers therefore concluded that working memory is mediated through the PFC in terms of explicit representations of sample stimuli, whereas the ITC allows the automatic detection of stimulus repetitions only.

It is tempting, therefore, to speculate that, in distinction from discrimination learning, human category learning relies on pattern representations in working memory as have been found in the PFC of the monkey by Miller and colleagues. Our findings would then imply that memories from pattern stimulation in the peripheral visual field are not only spatially under-sampled due to cortical magnification but can also be activated in working memory to a restricted extent only. Thus, we suggest that the restricted ability to classify complex patterns in indirect view reflects a restricted capacity of object-selective attention.

6 Structured Pattern Representations in Direct and Indirect View

The proposal of pattern classification involving the representation of class models in working memory warrants further consideration. Traditional approaches to pattern recognition are based on the notion that members of a given class share certain features or feature vectors. Such descriptions allow the classification of simple isolated patterns but problems arise as pattern complexity increases and/

or patterns are embedded in scenes. Feature vectors are then found to be inadequate for encoding the variability of class samples. One reason for this is that patterns of different classes may share common feature vectors yet be structurally different (Bischof and Caelli 1997). This difficulty led to the development of structural or syntactic pattern recognition that underlies more recent approaches to object recognition within the domain of machine intelligence (see Caelli and Bischof 1997). Strategies of learning structural pattern representations based on part attributes (unary features) and part relations (binary features) have been developed in that context. Moreover, such strategies have been employed successfully for the analysis of category learning by humans (see the chapter by M. Jüttner, this volume).

With regard to pattern classification in direct and indirect view, it is important to note that there are several types of part-based recognition strategies (see Caelli and Bischof 1997). Such strategies may use "attribute-indexed" representations only, thus ignoring the associations between features and pattern parts. For instance, two patterns may be distinguished by a difference in the distributions of distances between pattern parts. In case of mirror-image signals, however, these distributions would be identical as such patterns are characterized by the same sets of unary features and (undirected) binary features. The classification of mirror-image patterns therefore requires "part-indexed" representations providing explicit associations between relational attributes and the pattern parts these refer to. Part-indexed representations for visual pattern recognition may be implemented using the attribute of "position" relative to an allocentric or scene-based frame of reference (Rentschler and Jüttner 2006). In general, part-indexed representations allow for more powerful but computationally more expensive strategies of structural pattern processing (Caelli and Bischof 1997).

It might be hypothesized, therefore, that pattern recognition in indirect view relies on attribute-indexed representations only, whereas attribute-indexed as well as part-indexed representations are available in direct view. Consistent with this proposal would be an inability to distinguish mirror-image patterns in extrafoveal vision (Rentschler and Treutwein 1985; Rentschler 1985; Saarinen 1987). It is impossible, however, to decide whether such a functional restriction of recognition on indirect view could be attributed to a limitation with regard to the access to working memory or origination at earlier stages of visual processing.

7 Conclusions

3

The size-scaling concept fails to account for the functional inferiority of peripheral vision in a wide range of pattern recognition tasks. We have hypothesized in the past that this can be explained, additional to a coarser grain, by an inability to properly integrate pattern features or encode structure. Here we have reviewed more recent findings demonstrating the possibility of recruiting or learning structured representations for pattern recognition in direct and indirect view. Yet we delimited the following shortcomings of pattern recognition on sideways viewing:

(1) The recognition of numerical characters in indirect view depends on whether digits occur in isolation or in combination with flanking characters (crowding effect). The interference of distractors and spatial cueing with the recognition of target characters indicates separate neural encoding of semantic pattern content and pattern position within certain spatial arrays, possibly based on a limitation of spatial selective attention.

(2) Peripheral vision not only fails in distinguishing mirror-symmetric patterns but also in solving difficult tasks of structure-based pattern classification. The latter type of functional restriction can be attributed to a limited access to working memory or, in other terms, of object selective attention. It is not clear, however, whether the difficulty with mirror images is a consequence of this limitation or originates at an earlier level of visual processing.

These findings are consistent with the view that objects are represented in the brain at several levels from the sensory to the semantic (cf. Fuster 2003), with different mechanisms of attention operating at each of these levels (cf. Desimone and Duncan 1995).

Acknowledgements. We are indebted to Sophie Schwartz, Gustavo Deco, Naoyuki Osaka, and Keiji Tanaka for helpful discussions of our work.

References

Atkinson J, Pimm-Smith E, Evans C, Harding G, Braddick O (1986) Visual crowding in young children. Doc Ophthalmol Proc 45:201–213

Aubert H, Foerster R (1857) Beiträge zur Kenntnis des indirecten Sehens. (I). Untersuchungen über den Raumsinn der Retina. Arch Ophthalmol 3:1–37 4

Averbach E, Coriell AS (1961) Short-term memory in vision. Bell System Tech J 40:309–328

Baddeley A (1986) Working memory. Clarendon Press, Oxford

Bischof WF, Caelli T (1997) Scene understanding by rule evaluation. IEEE Trans Pattern Anal Machine Intell (PAMI) 19:1284–1288

Bouma H (1970) Interaction effects in parafoveal letter recognition. Nature 226:177–178

Caelli T, Bischof WF (1997) Machine learning and image interpretation. Plenum Press, New York

Deco G, Rolls ET (2004) A neurodynamical cortical model of visual attention and invariant object recognition. Vision Res 44:621–642

Desimone R, Duncan J (1995) Neural mechanisms of visual attention. Annu Rev Neurosci 18:193–222

O Eriksen CW, Rohrbaugh JW (1970) Some factors determining efficiency of selective attention. Am J Psychol 83:330–343

Flom MC, Weymouth FW, Kahnemann D (1963) Visual resolution and contour interaction. J Opt Soc Am 53:1026–1032

Fuster JM (2003) Cortex and mind. Oxford University Press, Oxford

Geiger G, Lettvin JY (1986) Enhancing the perception of form in peripheral vision. Perception 15:119–130

Harvey LO, Jr. (1997) Efficient estimation of sensory thresholds with ML-PEST. Spat Vis 11:121–128

Harvey LO, Jr., Rentschler I, Weiss C (1985) Sensitivity to phase distortion in central and peripheral vision. Percept Psychophys 38:392–396

He S, Cavanagh P, Intriligator J (1996) Attentional resolution and the locus of visual awareness. Nature 383:334–337

Hübner M, Rentschler I, Encke W (1985) Hidden-face recognition: comparing foveal and extrafoveal performance. Hum Neurobiol 4:1–7

Jüttner M, Rentschler I (1996) Reduced perceptual dimensionality in extrafoveal vision. Vision Res 36:1007–1022

Jüttner M, Rentschler I (2000) Scale-invariant superiority of foveal vision in perceptual categorization. Eur J Neurosci 12:353–359

Koenderink JJ, Bouman MA, Bueno de Mesquita AE, Slappendel S (1978) Perimetry of contrast detection thresholds of moving spatial sine wave patterns. I. The near peripheral visual field (eccentricity 0°–8°). J Opt Soc Am 68:845–849 5

LaBerge D (1995) Computational and anatomical models of selective attention in object identification. In: Gazzaniga MS (Ed) The cognitive neurosciences. MIT Press, Cambridge MA, pp ■■–■■ 6

Levi DM, Klein SA, Aitsebaomo AP (1985) Vernier acuity, crowding and cortical magnification. Vision Res 25:963–977

Mackeben M (1999) Sustained focal attention and peripheral letter recognition. Spat Vis 12:51–72

Miller EK, Desimone R (1994) Parallel neuronal mechanisms for short-term memory. Science 263:520–522

Miller EK, Erickson CA, Desimone R (1996) Neural mechanisms of visual working memory in prefrontal cortex of the macaque. J Neurosci 16:5154–5167

Nakayama K, Mackeben M (1989) Sustained and transient components of focal visual attention. Vision Res 29:1631–1647

Parth P, Rentschler I (1984) Numerosity judgements in peripheral vision: limitations of the cortical magnification hypothesis. Behav Brain Res 11:241–248

Pelli DG, Palomares M, Majaj NJ (2004) Crowding is unlike ordinary masking: distinguishing feature integration from detection. J Vis 4:1136–1169

Rentschler I (1985) Symmetry-coded cells in the visual cortex? Nature 317:581–582

Rentschler I, Jüttner M (2006) Mirror-image relations in category learning. Vis Cognit (in press) 7

Rentschler I, Treutwein B (1985) Loss of spatial phase relationships in extrafoveal vision. Nature 313:308–310

Rentschler I, Jüttner M, Caelli T (1994) Probabilistic analysis of human supervised learning and classification. Vision Res 34:669–687

Rovamo J, Virsu V (1979) An estimation and application of the human cortical magnification factor. Exp Brain Res 37:495–510

Saarinen J (1987) Perception of positional relationships between line segments in eccentric vision. Perception 16:583–591

O

Strasburger H (2005) Unfocussed spatial attention underlies the crowding effect in indirect form vision. J Vis 5:1024–1037

Strasburger H, Rentschler I (1996) Contrast-dependent dissociation of visual recognition and detection field. Eur J Neurosci 8:1787–1791

Strasburger H, Harvey LOJ, Rentschler I (1991) Contrast thresholds for identification of numeric characters in direct and excentric view. Percept Psychophys 49:495–508

Stuart JA, Burian HM (1962) A study of separation difficulty: its relationship to visual acuity in normal and amblyopic eyes. Am J Ophthalmol 53:471–477

Tanaka K (1996) Inferotemporal cortex and object vision. Annu Rev Neurosci 19:109–139

Tripathy SP, Levi DM (1994) Long-range dichoptic interactions in the human visual cortex in the region corresponding to the blind spot. Vision Res 34:1127–1138

Vidyasagar TR (2001) From attentional gating in macaque primary visual cortex to dyslexia in humans. Prog Brain Res 134:297–312

Virsu V, Näsänen R, Osmoviita K (1987) Cortical magnification and peripheral vision. J Opt Soc Am A 4:1568–1578

Watanabe S (1985) Pattern recognition: human and mechanical. John Wiley, New York

Wertheim T (1894) Über die indirekte Sehschärfe. Z Psychol Physiol Sinnesorg 7:172–187

O

AUTHOR QUERY-FORM

Dear Author,

During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof.
Many thanks for your assistance.

Query References	**Query**	**Remarks**
1.	Au: Please provide the full street address.	
2.	Au: Please provide the corresponding fax.	
3.	Au: Section number 6 has been changed to 7 so that they appear in sequence. Please confirm this is correct.	
4.	Au: Aubert and Foerster (1857): Foerster's initial R has beed added here, please confirm this is correct.	
5.	Au: Koenderink et al. (1978): Page range 854–849 has been changed to 845–849. Please confirm this is correct.	
6.	Au: LaBerge (1995): Please provide the page range.	
7.	Au: Rentschler and Jüttner (2006): Please update the volume number and page range if possible.	