



Dissociation of Local and Global Processing in Visual Agnosia

INGO RENTSCHLER,*† BERNHARD TREUTWEIN,* THEODOR LANDIS‡

Received 10 October 1992; in revised form 20 August 1993

Subsequent to strokes in the right and left inferomedial occipito-temporal lobes, two patients became prosopagnosic and alexic, respectively. They also show a complementary dissociation of the analysis of handwritten text. The patient with the right posterior stroke can read it but not recognize whose handwriting it is; the patient with the left posterior stroke cannot read the text but knows who wrote it. The analysis of spatial vision revealed that the prosopagnosic patient has no problem with seeing texture elements when presented in isolation. Yet she performs poorly with Moiré and texture perception, i.e. she suffers from a selective loss of *global* visual perception. The alexic patient performs well with Moiré patterns but neither with (complex) texture elements nor with textures. She seemingly can locally *and* globally process patterns composed of simple figural elements but fails with stimuli that require the integration of features. This finding of a concomitant dissociation of local and global visual processes in the two patients supports the view that prosopagnosia as well as alexia are the most conspicuous aspects of more general alterations of visual perception.

Visual agnosia Prosopagnosia Alexia Contrast sensitivity Moiré perception Texture perception

INTRODUCTION

The view of a complementarity of function with respect to the two cerebral hemispheres (Wigan, 1844; Jackson, 1874) is older than the discovery of the dominance of the left hemisphere for language (Broca, 1861). Nevertheless, the concept of complementarity of visual disturbances, especially that of a complementary dissociation of face recognition and reading with respect to the side of lesion, was not considered until 1937, when Hoff and Poetzl published a report entitled "On anoptic-agnosic disturbance of memory for physiognomies". Not only did these authors consider for the first time the inability of identifying familiar faces, later called prosopagnosia (Bodamer, 1947), to be a specific form of visual agnosia, but also specifically opposed the recognition of letters and words to that of the recognition of physiognomies. These two functions were viewed by Hoff and Poetzl as complementary, and consequently prosopagnosia and pure alexia were interpreted as reciprocally linked symptoms. Recently the dissociative nature of prosopagnosia vs pure alexia has gained new interest, regarding their anatomical differences and possible differences between the two syndromes in early visual processing (e.g. Sergent, 1982; Levine & Calvanio, 1989; Farah, 1990; Grüsser & Landis, 1991).

Recently we have described the clinical conditions of two patients with remarkably complementary dissociations of face recognition and reading with respect to the side of lesion (Landis & Regard, 1988). One of these patients, KD, has a right-sided infero-medial occipito-temporal lesion and cannot recognize familiar faces, i.e. she suffers from prosopagnosia (Landis, Cummings, Christen, Bogen & Imhof, 1986, case 2). Similar to other prosopagnosic patients, she scores in the lower range of normal controls in face matching experiments provided that the stimuli are presented for an unlimited time. When exposure duration is reduced, her performance worsens dramatically (Christen, Landis & Regard, 1985). KD also shows deficits in the recognition of facial expressive gestures but can lipread speech (Campbell, Landis & Regard, 1986). Most strikingly, this patient is unable to identify the author of handwriting familiar to her, whereas she has no problem in reading it (Landis & Regard, 1988). Such an observation has also been made earlier (Niessl von Mayendorf, 1933). The other patient, MT, with a left-sided occipito-temporal lesion and a right hemianopia, shows no deficits in face recognition or the classification of facial expressive gestures but she is alexic and impaired at lipreading (Campbell *et al.*, 1986). The latter patient can identify the author of familiar handwriting but is unable to read the written words (Landis & Regard, 1988), again an observation made earlier by Alajouanine, Lhermitte and de Ribaucour-Ducarne (1960).

These findings cast doubt on the notion that prosopagnosia and alexia are caused by the loss of highly

*Institute of Medical Psychology, University of Munich, Goethestrasse 31, 8000, München 2, Germany.

†To whom all correspondence should be addressed.

‡Department of Neurology, University Hospital, Zürich, Switzerland.

specialized visual functions. Rather it seems that these alterations of visual perception constitute the most conspicuous aspects of more general problems that the right and the left hemispheres have, due to their lesions, with the processing of complex and meaningful spatial patterns. This view was, in recent years, surrounded by considerable controversy for both prosopagnosia (see Sergent, 1982; Farah, 1990; Davidoff & Landis, 1990; Grüsser & Landis, 1991) and alexia (see De Renzi, Zambolin & Crisi, 1987; Farah, 1990). With these issues in mind, it occurred to us that recognition and reading of handwritten text can be thought of as tasks of global and local visual processing, respectively. This led us to investigate in the two patients perceptual abilities for which the dichotomy of global vs local processing has been extensively discussed in the literature, namely Moiré and texture perception.

The Moiré effect (Glass, 1969; Glass & Perez, 1973; Glass & Switkes, 1976) can be observed in dot patterns, or patterns made of a wider class of micropatterns, consisting of two superimposed copies of a random-dot pattern where one copy has been slightly rotated, translated, or dilated. In such patterns one perceives *locally* parallel structures, which *globally* reflect the invariance properties of the underlying geometric transformation, i.e. concentric circles, parallel streaks, or radial streaks.

Texture (Beck, 1972; Julesz, 1981; Julesz & Bergen, 1983) is a *global* visual perception in the sense that, with the awareness of an overall picture, one sees a large number of *local* figural elements, or micropatterns as a coherent region in the scene. This ability allows the human observer to segment images into parts and, therefore, rapidly identify physical objects.

In the present study we investigated the two patients' abilities of global visual perception by having them

discriminate radial Moiré patterns with different degrees of spatial decorrelation, as well as textures made up of compound Gabor patterns. Local visual processing was analysed in terms of discrimination sensitivities to isolated compound Gabor patterns with different spatial waveforms. Contrast sensitivity function and optotype acuities of the prosopagnosic and the alexic patient were measured for control purposes.

CASE HISTORIES

Since the case histories, including CT scans, of both patients KD and MT have been published on several occasions in the frame of different experiments (Christen *et al.*, 1985; Campbell *et al.*, 1986; Landis *et al.*, 1986; Landis & Regard, 1988; Davidoff & Landis, 1990; Grüsser & Landis, 1991) their clinical picture is given here only briefly in table form.

As Table 1 shows, both patients exhibit extremely similar pictures of primary ophthalmological and neurological symptoms except for the side of lesion. However, the clinical pictures strongly dissociate at the level of higher visual associative processing.

GENERAL METHOD

Stimuli

Stimulus patterns were generated as digital images with 8-bit grey levels on a TV monitor (Barco TVM 3/3.2, P4 phosphor) linked to a Videograph image processing system with 50 Hz frame rate (interlaced). The frame buffer was interfaced to a LSI 11/73 computer. The mapping between frame buffer content and display luminance was linear (for details see Rentschler, Hübner & Caelli, 1988).

TABLE 1. Clinical and neuropsychological findings in the patients KD and MT

KD	MT
Right-handed secretary, known hypertension (1 yr)	Right-handed housewife, uneventful medical history
Right posterior cerebral artery stroke in 1981 at age 61	Left posterior cerebral artery stroke in 1984 at age 64
Left homonymous hemianopia (partial recovery of the lower left quadrant)	Right homonymous hemianopia
Visual acuity (decimal notation) 0.7–0.8	Visual acuity 0.9–1.0
CT: large right medial temporo-occipital hypodensity including fusiform, lingual and posterior parahippocampal gyrus	CT: Large left medial occipito-temporal hypodensity including fusiform, lingual and posterior parahippocampal gyrus
Dense and persistent prosopagnosia, initially topographagnosia, impaired memory for non-verbal material but relatively spared memory for verbal material	Pure alexia, initially global, recovered to unreliable single letter reading, initially associative object agnosia for line drawings and photographs, colour anomia, impaired memory for verbal material, relatively spared memory for non-verbal material
Recognition of familiar handwriting impaired	Intact recognition of familiar handwriting
Lip reading intact	Lip reading impaired
Episodes of visual pseudo-hallucinations	
Mood depressed	Mood unchanged

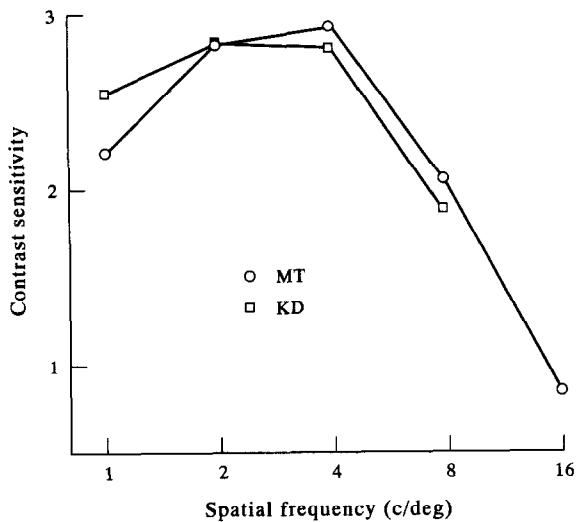


FIGURE 1. Contrast sensitivity functions of the two patients, KD and MT, to vertical sinusoidal gratings. Binocular viewing conditions. Exposure duration, 1 sec, space average luminance, 60 cd/m². The 95% statistical confidence interval of threshold estimates was set at 0.15 log units.

Experiment I: Contrast Sensitivities for Sinusoidal Gratings

Stimuli and procedure

Six sinusoidal gratings and one blank field were generated as 128 × 128 pixel digital images. Stimulus size was 2 × 2 deg at a viewing distance of 123 cm; spatial frequencies were 1, 2, 4, 8, and 16 c/deg. Space average luminance of patterns was 60 cd/m²; background luminance was 5 cd/m². Threshold contrasts were found by means of an adaptive psychophysical procedure with maximum likelihood estimation (Harvey, 1986). A temporal two-alternative forced-choice (2-AFC) procedure was used for experimental trials. The latter continued until a criterion of 82% correct had been reached. The 95% statistical confidence interval of the corresponding threshold value was set at 0.15 log units. To achieve this degree of accuracy, between 20 and 40 trials were required for each stimulus pair. Stimuli were binocularly tested with 1 sec exposure duration and 700 msec ISI.

Results and discussion

The results are presented in Fig. 1, where contrast sensitivities (i.e. the logarithms of the inverse detection thresholds) are plotted vs spatial frequency. The two patients' data are virtually identical and display the usual inverted-U shape. Clearly, there is no way to predict their behavioural deficiencies from the contrast sensitivity function (or from visual letter acuities; see Table 1).

Experiment II: Moiré Perception

This experiment measured the perception of Moiré structure in two-tone dot patterns such as discussed by Glass *et al.* (Glass, 1969; Glass & Perez, 1973; Glass & Switkes, 1976). A prototype Moiré pattern and a number of distorted copies thereof were generated and Moiré

perception was studied by measuring discrimination sensitivities for prototype/distorted-copy stimulus pairs.

Stimuli and procedure

The Moiré stimuli (Fig. 2) were generated in a 512 × 512 pixels format using *one* random distribution of dots. Seven copies of this pattern were perturbed by randomly displacing each dot within a square area whose side was $n = 1, 5, 9, 13, 17, 21,$ or 25 pixels (with the original corresponding to $n = 1$). The resulting maximum vertical and horizontal displacement was $(n - 1)/2$ pixels. The Moiré patterns were obtained by superimposing a copy of the original pattern and one of the seven perturbed copies with a relative rotation angle of 3 deg about the centre of the patterns. Dot luminance was 80 cd/m²; background luminance was 18 cd/m². Stimulus size was 4.5 × 4.5 deg at a viewing distance of 220 cm. Exposure duration was 120 msec.

The Moiré patterns were shown one at a time. Subjects were instructed to press one of six buttons, depending on whether they believed that a pattern with pronounced (buttons 1–3) or weak (buttons 4–6) structure was being displayed. From these rating responses, signal detection parameters were obtained for each of the perturbed dot patterns (see Green & Swets, 1975, chap. 4). A suitable measure for discrimination sensitivity is the area under the receiver operating characteristic (ROC). This measure is equivalent to the percentage of correct responses in a 2-AFC situation. It was determined by least-squares fit (Program RSCORE, L. O. Harvey Jr; original version by Dorfman & Alf, 1969). The reliability of this parameter is given as SE which can be used for statistical hypothesis testing in the same way that the SEM is used [95% confidence interval for a parameter value is this value ± 1.96 * SE (Harvey, unpublished observation)].

Results were derived from four (MT) and two (KD) experimental runs totalling 80 and 40 exposures per pattern, respectively.

Results and discussion

Figure 3 shows the results for the experiment on Moiré perception. The alexic patient, MT, had no problem with detecting the gradually increasing perturbations of the original Moiré pattern. Indeed, her performance was virtually the same as that of two younger control subjects (aged 26 and 27 yr; data not shown). The performance of the prosopagnosic patient, however, was much worse.

To assess the implications of these findings, we note that Moiré perception has at least two components. The one is the detection of locally parallel structure, and the other is the appreciation of the properties of the underlying global transform of the random-dot distribution, i.e. of concentric circles in the present stimulus patterns. What can be inferred from the data shown in Fig. 3 is, therefore, that KD has a problem with recovering either the local or the global component of Moiré structures or both, whereas these functions are seemingly unimpaired in MT.

Experiment III: Micropattern and Texture Discrimination

The aim of the following experiment was to decide whether the deficiency of KD in seeing global structure stems from a weakness in global or local visual processing. To examine this issue, we compared the discrimination of micropatterns with that of textures made up from such micropatterns. The rationale of this experiment is the following. We can assume that the discrimination of micropatterns depends on local processing if they are presented successively to the same retinal location, whereas the study of global visual processing requires the grouping of such micropatterns in textures (see Beck, 1972; Julesz, 1981).

It would be erroneous, however, to assume that a task of texture discrimination necessarily involves global visual processing. Unless a suitable experimental paradigm is used, the discrimination of two successively displayed textures might be simply achieved by monitoring a fixed location in the stimulus display. If there were a difference in micropatterns detected, this could then be the clue to the existence of a texture difference. To prevent our subjects from using such a local strategy, we employed for measuring texture discrimination an experimental paradigm introduced by

Rizzolatti and Buchtel (1977) in the context of face recognition.

Stimuli and procedure

Stimuli were generated as 256×256 pixels images. Stimulus size was 6.2×6.2 deg at a viewing distance of 80 cm; space average luminance was 60 cd/m^2 . Compound Gabor signals, or compound grating patches (see also Lawden, Hess & Campbell, 1982; Lawden, 1983), were used as micropatterns. They consisted of small sub-images (32×32 pixels) which were generated by superimposing two Gabor signals (see Marcelja, 1980) of same location and same parameters of the Gaussian window [see Fig. 4(a)]. The modulation frequencies of the superimposed Gabor signals were kept fixed at $f_1 = 2 \text{ c/deg}$, and $f_3 = 6 \text{ c/deg}$. The respective (Michelson) contrasts were also kept fixed at 70 and 23%. The fundamental f_1 was in cosine phase, the third harmonic f_3 either in 0 or 180 deg phase. Hence the two types of micropatterns differed in spatial phase by 180 deg. The resulting waveforms are shown in Fig. 4(a).

In case of micropattern discrimination, test patterns were centered on an otherwise empty image set at space average luminance [Fig. 4(b)]. Stimulus pairs were

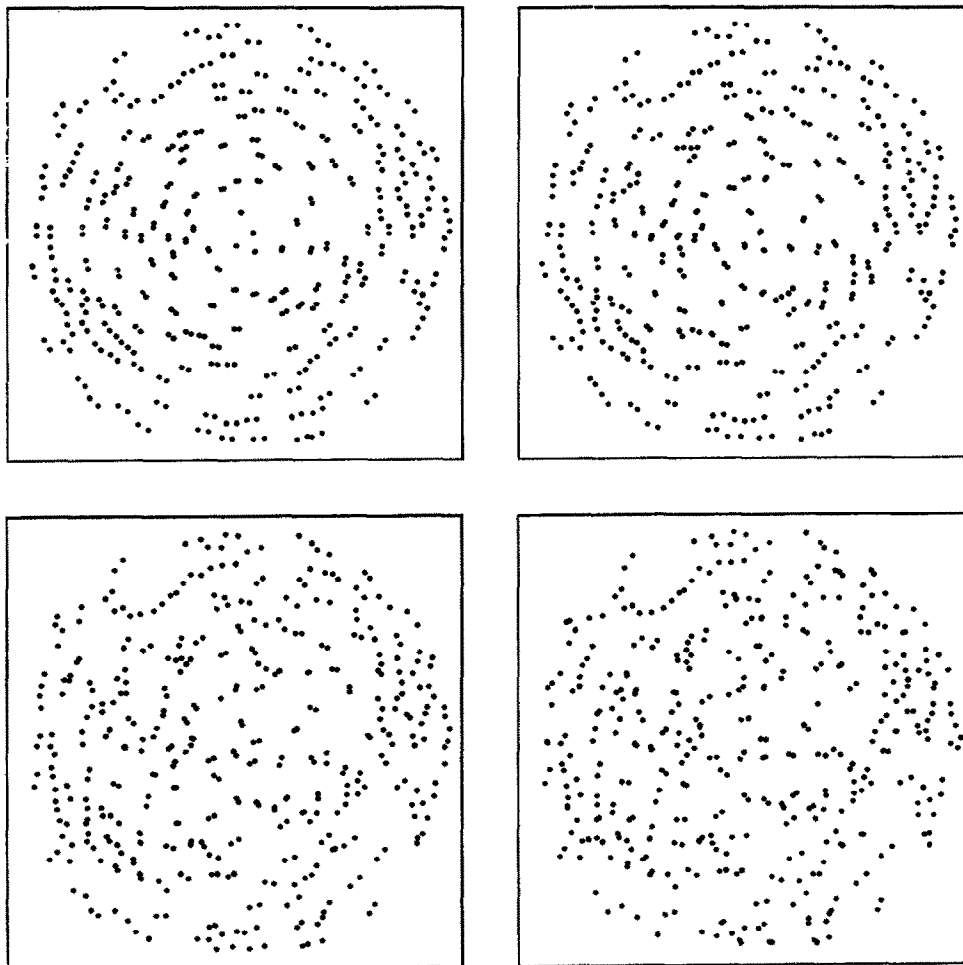


FIGURE 2. Moiré test patterns. Four of the seven stimulus patterns with zero, intermediate and maximum spatial distortion (from top left to bottom right) are shown.

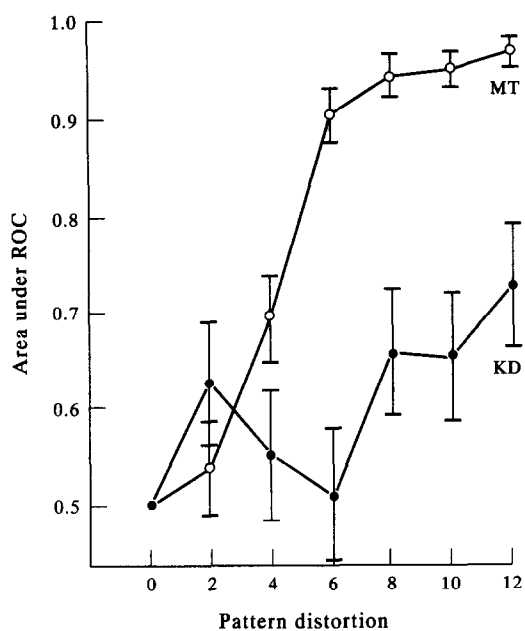


FIGURE 3. Discrimination of Moiré patterns. Abscissa, maximum vertical and horizontal displacement of corresponding dots, i.e. amount of spatial decorrelation in stimulus patterns. Ordinate, area under ROC as obtained from a signal detection rating procedure. Exposure duration, 120 msec. Solid symbols, prosopagnosic patient KD (40 exposures per condition); open symbols, alexic patient MT (80 exposures per condition). Error bars: ± 1 SE.

sequentially displayed for 120 msec with an ISI of 700 msec. Subjects were instructed to press one of six buttons, depending on whether they believed that a pair with same (buttons 1–3) or different (buttons 4–6) patterns was being displayed. Discrimination performance was evaluated as area under ROC as in Expt II.

In case of texture discrimination, two types of non-targets (NT) and two types of targets (T) were used. The non-targets consisted of displaying textures made up from 8×8 identical micropatterns (nontarget NT₁ consisting only of micropatterns with 0 deg phase; nontarget NT₂ consisting only of micropatterns with 180 deg phase). The targets consisted of 8×8 textures made up from a central array of 4×4 micropatterns with 0 deg phase surrounded by micropatterns with 180 deg phase (T₁), or vice versa (T₂). The four non-target and target textures are shown in Fig. 4(b).

Texture stimuli were presented one at a time with 120 msec exposure duration. Subjects were presented at each experimental condition with 100 non-targets and 50 targets. They had to rate their confidence of whether they saw a non-target (1–3) or a target texture (4–6). Discrimination performance was evaluated as area under ROC as in Expt II.

Results and discussion

Figure 5 shows the results of Expt III. The prosopagnosic patient, KD, displayed perfect discrimination sensitivities for micropatterns, whereas with textures her performance virtually dropped to chance level. By contrast, the alexic patient, MT was about equally impaired with micropatterns and textures.

The fact that KD had no problem with distinguishing the micropatterns *per se* (i.e. when seen in isolation, at the same retinal location, and at sufficiently long exposure duration) is consistent with her relatively good visual acuity and contrast sensitivity (Expt I). Her poor performance with the texture discrimination task could simply mean that this task is very difficult. However, normal subjects have no problem with discriminating such textures even when the phase separation between the two types of micropatterns is only 120 deg [Rentschler *et al.*, 1988, Fig. 6(a)]. Thus we conclude that KD, is selectively impaired in *texture discrimination*. This answers the question that we were left with from Expt II, in that it is the *global* and not the local component of texture perception which is deficient in this patient.

The data obtained from MT prove that she suffers from a weakness in local visual processing. Given her good performance in Moiré perception (Expt II), this suggests that her weakness in discriminating compound Gabor textures is simply a consequence of her inability to properly see their micropatterns. This raises the question why MT is impaired in seeing compound Gabor patterns but not in dots (i.e. the elements of Moiré patterns). The answer might be that there exist visual neurons specialized for the detection of dots [“dot responsive cells” (see Zetzsche & Barth, 1990)], whereas the discrimination of compound Gabor patches involves the (nonlinear) integration of the outputs of at least two types of detectors (Caelli, Rentschler & Scheidler, 1987). In other words, it seems that MT’s problem with local visual processing is not located at the level of visual resolution but at some integrative neural function of local pattern analysis. This would explain why her visual deficit does not interfere with visual acuity and contrast sensitivities.

GENERAL DISCUSSION

We studied Moiré and texture perception in two patients with ischemic infarctions in the territory of the right and left posterior cerebral arteries, respectively. They not only dissociated with respect to the recognition of faces and words but also in the meaningful analysis of handwritten text. The patient with the right posterior lesion could read the text but could not recognize who had written it. The patient with the left posterior stroke could not read but recognized the author of the text.

We found that the prosopagnosic patient performed poorly with Moiré (Expt II) and texture perception (Expt III). This weakness may be the result of a deficiency in either the local or the global or both modes of visual processing. Yet the patient had relatively good visual acuity and contrast sensitivity, and she had no problem with the discrimination of micropatterns (i.e. compound Gabor patches, Expt III) which apparently require more complex local processing. We conclude that she must be deficient at some aspect of global processing, a result which implies the existence of a disassociation of local and global processing.

The alexic patient performed well with Moiré patterns but not with compound Gabor micropatterns and textures. That is, she can locally and globally process the dots of which Moiré patterns consist but has difficulties to do so with stimuli that require the integration of features. We have no definite proof that this difficulty arises only at the level of local processing but the findings with Moiré patterns suggest that this is the case. If this were true, we could assume that the alexic patient also displays a dissociation of local and global visual perceptions.

One may ask whether these findings are consistent with the hypothesis that the intact right cerebral hemisphere is faster and more accurate in processing low spatial frequencies and the left hemisphere in processing high spatial frequencies (Sergent, 1982). In the present experiments, the spectra of the texture elements (Gabor patches) contained more energy at lower frequencies than those of the Moiré elements (dots). From this one would expect that the alexic patient, due to her intact right hemisphere, would perform better than the prosopagnosic one in micropattern discrimination. This, however, was not the case. In much the same way, the argument fails with the global patterns of which, again,

the textures have more energy at lower spatial frequencies.

Thus we shall proceed to considering more elaborate concepts of local and global modes of visual perception. To begin with, the original explanation of the Moiré effect by Glass (1969) had two components. One was the stimulation of oriented receptive fields of cortical simple cells by pairs of dots. These cells were expected to evoke a relatively strong signal due to the locally parallel orientation of correlated pairs (i.e. dots and their transformed images). The other was the recovery of such signals from noise resulting from random stimulation of cortical units by uncorrelated pairs. For obvious reasons, the latter process involved integration over limited regions of the random pattern. This concept has been examined by Stevens (1979), who computed locally parallel structure from the orientation statistics of "virtual lines" connecting pairs of dots (see also Marr, 1982). Yet the same author noted that "the global structure is derived from the local pairings and constitutes a later, distinct computational problem" (Stevens, 1979, p. 23). The situation is the same with Encke's (1990) study, who analysed Moiré perception in terms of local autocorrelation functions. Thus we can assume that global processes

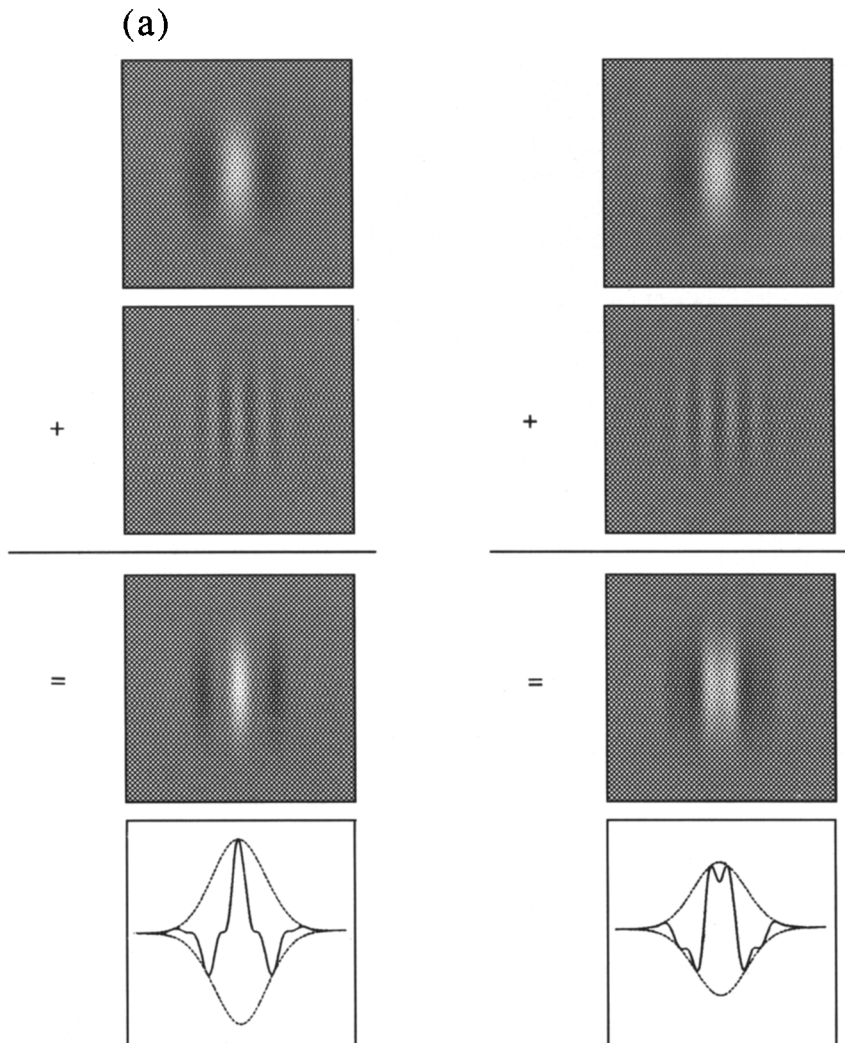


FIGURE 4(a). *Caption on facing page.*

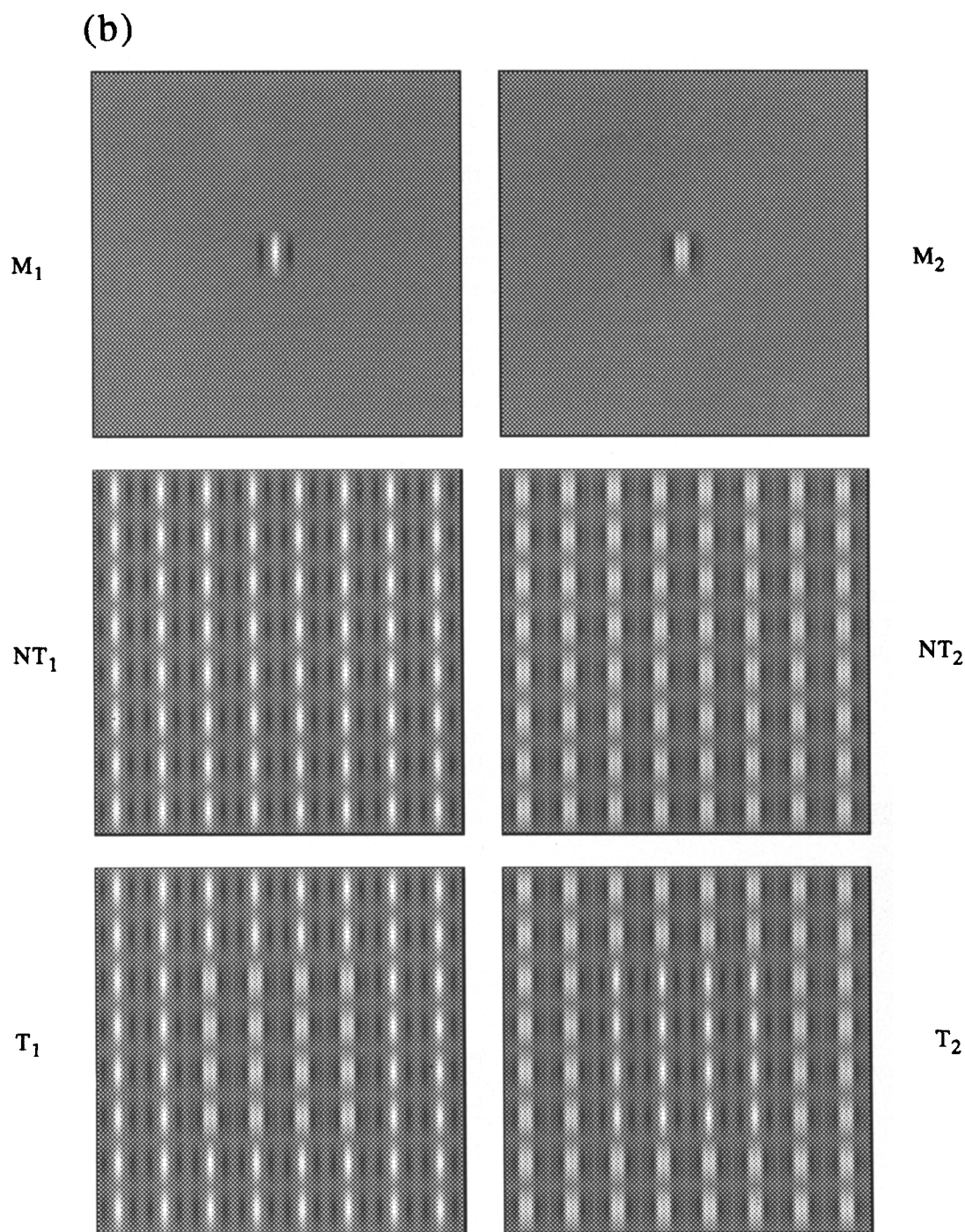


FIGURE 4. Compound Gabor micropatterns and textures. (a) The micropatterns consisted of two superimposed grating patches with 2 and 6 c/deg modulation frequencies. The two types of micropatterns used differed in spatial phase of third harmonic by 180 deg [peaks add, (a) bottom left; peaks subtract, (a), bottom right]. (b) For measuring micropattern discrimination, these two stimuli were presented in isolation on a background of space average luminance (top). For measuring texture discrimination, four types of texture pairs were used. Two of them were non-targets [NT_1 , NT_2 , (centre)], consisting of identical micropatterns in the centre and surround areas. Two of them were targets [T_1 , T_2 (bottom)] consisting of the two different types of micropatterns in the centre and the surround areas.

act on the results of local processes in Moiré perception, although we are ignorant about the nature of the global process itself.

Theories of texture perception are also based on the assumption of local and (more) global processes of visual pattern analysis. Psychologically oriented theories (Julesz, 1981, 1986; Beck, 1983) characterized texture via

the extraction of features by means of spatial filters of the centre-surround type and the evaluation of the spatial density of such features ("textons", e.g. elongated blobs, line crossings, and line ends). Computational models of texture perception addressed the problem of how these texture boundaries are formed (Caelli, 1985, 1988; Malik & Perona, 1990; Vorhees & Poggio, 1988).

They have again in common that they assume filtering by receptive fields (possibly completed by further local processing) and global evaluation of resulting neural activities via associative networks.

These similarities between models of texture and Moiré perception may not be by coincidence. On the one hand, as has been conjectured by Glass (1969) and proven by Encke (1990), the locally parallel structure of Moiré patterns may be recovered by evaluating local autocorrelation functions. On the other hand, the (global) autocorrelation of a binary texture is nothing else but its "second-order statistics", and a sufficient difference in this property renders two textures discriminable (Julesz, 1981). Thus one may say that Moiré structure is brought about by an ordered distribution of (local) texture differences.

To summarize then, it seems that models of global visual perceptions cannot avoid the assumption of local receptive-field type of filtering and subsequent global evaluation of filter responses. It is conceivable that such processing strategies can be disturbed either on the level of local filtering or of global interactions, or both. This concept is consistent with our conjecture of the existence

of dissociations of local and global visual processing in our patients.

This conclusion implies an affirmative answer to the question of whether KD's prosopagnosic condition is one aspect of a more general alteration of perception and the situation seems to be the same for the alexic patient MT. Yet this does not necessarily imply that there is a causal relationship between the present findings and the main behavioural impairments of the patients, i.e. prosopagnosia and alexia. However it is noteworthy that the prosopagnosic patient, KD, is well able to discriminate textures which are shown long enough [Fig. 2(top right)]. This adds to the observation that, at unlimited exposure duration, she is in the lower range of normal controls in face matching (Christen *et al.*, 1985). We conclude that, as a substitute for global perception, the prosopagnosic patient employs a compensatory strategy by means of scanning eye movements—if only she has enough time to do so.

The perceptual alteration of the alexic patient is quite different. On the one hand, she has problems with rapidly discriminating local luminance modulations as well as textures composed of such signals. On the other hand, she has virtually perfect visual resolution and is able to rapidly recover structure from dot patterns. Her deficit of global perception results, therefore, most likely from a weakness to rapidly build up and use an internal visual representation of more complex items. Such a weakness would explain why she has difficulties to recognize patterns but not why these difficulties occur mainly with verbal material.

REFERENCES

- Alajouanine, T., Lhermitte, F. & de Ribaucour-Ducarne, B. (1960). Les alexies agnosiques et aphasiques. In *Les grandes activités du lobe occipital*. Paris: Masson.
- Beck, J. (1972). Similarity grouping and peripheral discriminability under uncertainty. *American Journal of Psychology*, *85*, 1–19.
- Beck, J. (1983). Textural segmentation, second order statistics, and textural elements. *Biological Cybernetics*, *48*, 125–130.
- Bodamer, J. (1947). Ueber die Prosop-Agnosie (Die Agnosie des Physiognomieerkennens). *Archiv. Psychiatrie. Nervenkrankheiten*, *179*, 6–54.
- Broca, P. (1861). Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphémie. *Bulletin de la Société d'anatomie*. Paris, *6*, 330–357.
- Caelli, T. (1985). Three processing characteristics of visual texture segmentation. *Spatial Vision*, *1*, 19–30.
- Caelli, T. M. (1988). An adaptive computational model for texture segmentation. *IEEE Transactions on Systems, Man, and Cybernetics*, *18*, 9–17.
- Caelli, T., Rentschler, I. & Scheidler, W. (1987). Visual pattern recognition in humans I. Evidence for adaptive filtering. *Biological Cybernetics*, *57*, 233–240.
- Campbell, R., Landis, T. & Regard, M. (1986). Face recognition and lip reading—a neurological dissociation. *Brain*, *109*, 509–521.
- Christen, L., Landis, T. & Regard, M. (1985). Left hemispheric functional compensation in prosopagnosia? A tachistoscopic study with unilaterally lesioned patients. *Human Neurobiology*, *4*, 9–14.
- Davidoff, J. & Landis, T. (1990). Recognition of unfamiliar faces in prosopagnosia. *Neuropsychologia*, *28*, 1143–1161.
- De Renzi, E., Zambolin, A. & Crisi, G. (1987). The pattern of neuropsychological impairment associated with left posterior cerebral artery infarcts. *Brain*, *110*, 1099–1116.

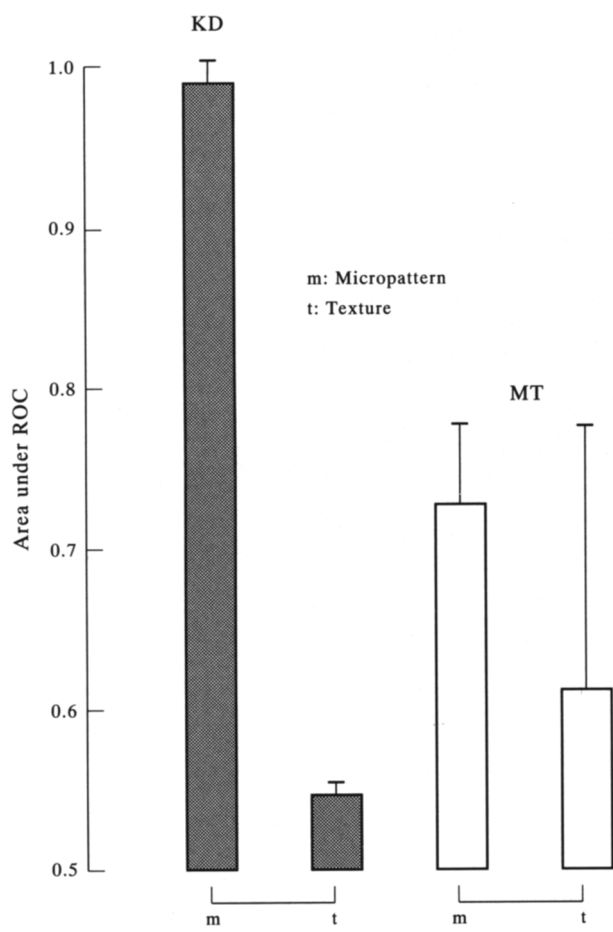


FIGURE 5. Discrimination of micropatterns and textures. Ordinate, discrimination sensitivities for compound Gabor micropatterns and textures given as area under ROC. Exposure duration, 120 msec. Prosopagnosic patient, KD, left; alexic patient, MT, right. 100 trials with non-targets and 50 trials with targets were used at each experimental condition and for each subject. Error bars: ± 1 SE.

- Dorfman, D. D. & Alf, E. Jr (1969). Maximum likelihood estimation of parameters of signal detection theory and determination of confidence intervals—rating method data. *Journal of Mathematical Psychology*, 6, 487–496.
- Encke, W. (1990). Moirémuster. In *Experimentelle und theoretische Analyse eines Wahrnehmungsphänomens*. Munich: Kyrill & Method.
- Farah, M. J. (1990). *Visual agnosia*. Cambridge, Mass.: MIT Press.
- Glass, L. (1969). Moiré effect from random dots. *Nature*, 223, 578–580.
- Glass, L. & Perez, R. (1973). Perception of random dot interference patterns. *Nature*, 246, 360–362.
- Glass, L. & Switkes, E. (1976). Pattern recognition in humans: Correlations which cannot be perceived. *Perception*, 5, 67–72.
- Green, D. M. & Swets, J. A. (1974). *Signal detection theory and psychophysics*. Huntington, N.Y.: Krieger.
- Grüsser, O. J. & Landis, T. (1991). Visual agnosias and other disturbances of visual perception and cognition. In Cronly-Dillon, J. R. (Ed.), *Vision and visual dysfunction* (Vol. 12) London: Macmillan Press.
- Harvey, L. O. Jr (1986). Efficient estimation of sensory thresholds. *Behavioral Research, Methods, and Instrumentation*, 18, 623–632.
- Hoff, H. & Poetzl, O. (1937). Ueber eine optisch-agnostische Störung des "Physiognomie-Gedächtnisses". *Zeitschrift für die gesamte Neurologie und Psychiatrie*, 195, 367–395.
- Jackson, J. H. (1874). On the nature of the duality of the brain. *Medical Press and Circular*, 1, 19–41. [Reprinted in *Brain* (1915), 38, 80–103.]
- Julesz, B. (1981). Textons, the elements of texture perception, and their interactions. *Nature*, 290, 91–97.
- Julesz, B. (1986). Texton gradients: The texton theory revisited. *Biological Cybernetics*, 54, 245–251.
- Julesz, B. & Bergen, J. R. (1983). Textons, the fundamental elements in preattentive vision and perception of textures. *Bell Systems Technical Journal*, 62, 1619–1645.
- Landis, T. & Regard, M. (1988). Hemianopsie und Agnosie. *Klinische Monatsblätter für Augenheilkunde*, 192, 525–528.
- Landis, T., Cummings, J. L., Christen, L., Bogen, J. E. & Imhof, H. G. (1986). Are unilateral right posterior cerebral lesions sufficient to cause prosopagnosia? Clinical and radiological findings in six additional patients. *Cortex*, 22, 243–252.
- Lawden, M. C. (1983). An investigation of the ability of the human visual system to encode spatial phase relationships. *Vision Research*, 23, 1451–1463.
- Lawden, M. C., Hess, R. F. & Campbell, F. W. (1982). The discriminability of spatial phase relationships in amblyopia. *Vision Research*, 22, 1005–1016.
- Levine, D. & Calvanio, R. (1989). Prosopagnosia: A defect in visual configural processing. *Brain and Cognition*, 10, 149–170.
- Malik, J. & Perona, P. (1990). Preattentive texture discrimination with early vision mechanisms. *Journal of the Optical Society of America*, 7, 923–932.
- Marcelja, S. J. (1980). Mathematical description of the responses of simple cortical cells. *Journal of the Optical Society of America*, 70, 1297–1300.
- Marr, D. (1982). *Vision*. San Francisco, Calif.: Freeman.
- Niessl Von Mayendorf, E. (1933). Beiträge zur Lehre von der Seelenblindheit. *Zeitschrift für die gesamte Neurologie und Psychiatrie*, 149, 68–102.
- Rentschler, I., Hübner, M. & Caelli, T. (1988). On the discrimination of compound Gabor signals and textures. *Vision Research*, 28, 279–291.
- Rizzolatti, G. & Buxtel, H. A. (1977). Hemispheric superiority in reaction time to faces: A sex difference. *Cortex*, 13, 300–305.
- Sergent, J. (1982). The cerebral balance of power: Confrontation or cooperation. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 253–272.
- Stevens, K. A. (1979). Computation of locally parallel structure. *Biological Cybernetics*, 29, 19–28.
- Voorhees, H. & Poggio, T. (1988). Computing texture boundaries from images. *Nature*, 333, 364–367.
- Wigan, A. L. (1844). *A new view of insanity: The duality of the mind*. London: Longman.
- Zetzsche, C. & Barth, E. (1990). Fundamental limits of linear filters in the visual processing of two-dimensional signals. *Vision Research*, 30, 1111–1117.

Acknowledgements—This study was supported by Deutsche Forschungsgemeinschaft, DFG, grant Po 121/13, Project 5, to I.R. and the Swiss National Science Foundation grant No. 32-31260-91 to T.L. We thank Walter Encke for help with experiments, and Terry Caelli and Norman Cook for critical remarks on the manuscript.