LUCIA M. VAINA

COMMON FUNCTIONAL PATHWAYS FOR TEXTURE AND FORM VISION: A SINGLE CASE STUDY*

ABSTRACT. A single case study of a patient, D.M., with a lesion in the region of the right occipito-temporal gyrus is presented. D.M. had well-preserved language and general cognitive abilities. Colour discrimination, contrast sensitivity, gross depth perception, spatial localization, and motion appreciation were within normal limits.

On the evaluation of perceptual abilities, he failed to identify two-dimensional shapes from stereoscopic vision, motion, and texture although in all cases he was able to identify the rough area subtended by the shape. These findings are considered in relation to the current anatomical-physiological functional models of vision and it is suggested that D.M.'s deficits provide evidence for the existence in man of a functional pathway involved in the computation of texture and fine aspects of shape, which is distinct from the pathways involved in motion and stereopsis processing on one hand and colour and coarse aspects of form on the other hand.

The hypothesis advanced here is that D.M.'s specific impairment occurs at a stage of visual processing at which details relating to a particular stimulus are assembled in proper local spatial relationships, although they are still not yet appreciated as parts of a shape.

INTRODUCTION

Our present knowledge of the anatomical and physiological organization of the visual system in nonhuman primates supports theories of cortical localization that implies a division of labor between the several areas involved in visual processing. Also we see the primary visual cortex as a branch point in the flow of different types of visual information to different cortical areas. These areas can be identified on several independent grounds, such as their architecture, the pattern of their connections with the primary visual cortex and with other visual areas, and the receptive field properties of their constituent neurons (for a review, see Van Essen 1985).

In the macaque monkey, two major pathways are distinguished in the corticocortical roadmap of visual processing (figure 1). Both coexist in the striate cortex, one following a ventral route through the prestriate region (V2, V3, and V4) into the temporal cortex (Mishkin 1972; Pohl 1973; Ungerleider and Mishkin 1982; Ungerlider and Desimone 1986), and the other following a dorsal route through the prestriate area, reaching into the posterior parietal lobe. The physiological properties

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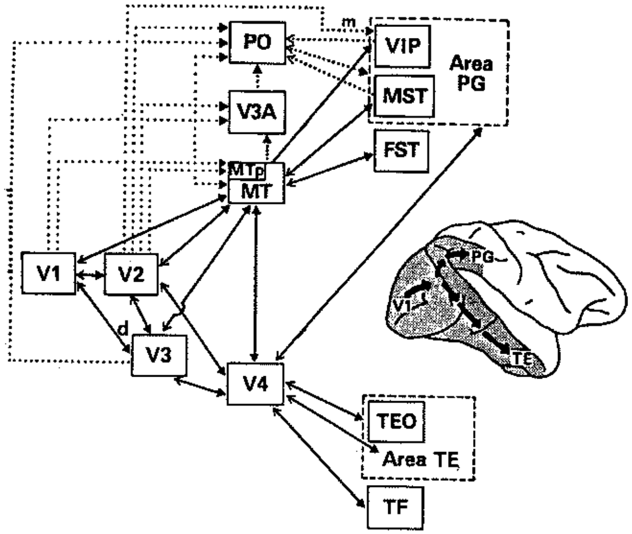


Fig. 1. This figure, after Ungerleider and Desimone (1986), presents a summary of visual cortical areas and their connections, as they follow the two major pathways which both originate in the striate cortex. The anatomical and physiological findings suggest that MT provides a major route from the striate cortex into the parietal lobe. The major route from the striate cortex into the temporal lobe is via area V4.

of these two pathways are different: the first is associated with object perception and the second with spatial perception and visuo-motor performance. Many different areas serve as 'stopovers' on these two main visual roads, and some are shown to have profoundly different functional properties.

One way to approach the complexity of vision is to consider the functional properties of the 'stopovers' as intermediate goals in the task of the whole system and to identify the functional attributes of the pathways connecting them to the primary visual cortex. For example, a pathway of subsets of cells from V1, V2, V3, MT, and MST, is involved in the analysis of motion and depth, while another proceeding through V1, V2, and V3 conveys information to V4 (Zeki 1969, 1978; Allman and Kaas 1971; Gattass et al. 1981) and plays an important role in form and colour processing. By learning the distribution of

cells projecting to various areas, we may be able to associate specific subregions of the preceding areas with specific visual functions and eventually unravel the subtasks of vision.

Much less is known about the processes that underlie visual perception in humans. Until recently, most of what we learned about functional specialization has come from clinical studies of behavioural deficits exhibited after brain lesions.[1] Newcombe and Russell (1969) provided evidence for the coexistence of two major functional pathways in the right hemisphere of the human brain. One is specialized for spatial tasks and is impaired by parietal lesions; the other is specialized for tasks involved in object recognition and is impaired by temporal lesions. The neurological literature abounds in examples of correlations between lesions (often not precisely localized) and specific visual tasks (for reviews, see Damasio 1985; Warrington 1985; Vaina 1985). Gordon Holmes defined visual disorientation as the inability to localize visually the position and relative distance of objects, and he indicated that the critical lesion lies at the occipito-parietal boundary (Holmes 1918; Holmes and Horax 1919). This defect occurs in the absence of impairments in colour perception, visual agnosia or alexia, and general language disturbance. It is accompanied, however, by an inability to avoid obstacles and to find one's way about, or even to carry out any spatial learning.

Functional independence between the analysis of colour and the analysis of other dimensions is well established (Mollon et al. 1980; Meadows 1974; Damasio et al. 1980). Efron (1968) described a patient who exhibited an isolated failure in visual shape discrimination, although he was able to use colour and size cues to identify objects in a given context. In a study of five patients with bilateral occipital lesions, Warrington (1985) demonstrated the disassociation between acuity, shape discrimination, spatial localization, and colour perception. The inability of movement perception has been reported (Goldstein and Gelb 1918; and Zihl et al. 1983) in patients with bilateral occipital lesions, whose visual acuity, colour perception, and form discrimination was normal. More recently, Vaina (1987, 1988) showed in a group of seventeen cases with posterior right hemisphere damage that lesions restricted to the right occipito-parietal region appear to disrupt dramatically tasks of motion interpretation, such as the ability to derive three-dimensional structure from motion and the ability to appreciate speed of motion. Such lesions, however, do not interfere with tasks of motion detection or with the use of coarse motion measurements for separating a moving figure from the static background.

Isolated recognition deficits for faces (Damasio 1985), shapes (Warrington and Taylor 1978), and natural textures (Vaina 1985, 1987) are also reported in patients with lesions localised to areas in the posterior right hemisphere or with bilateral posterior lesions.

In a study of a larger group of subjects with focal lesions to the posterior cortical areas, Vaina (1987b) has documented that texture and fine aspects of shape analysis may be carried out by a specific stream of processing which, in humans, appears to be disrupted by right occipito-temporal lesions. There is increasing evidence for the view that this stream of processing may be segregated both anatomically and functionally from the pathway involved in the analysis of motion and which follows a dorsal route toward the parietal lobe. The present paper reports the findings of a detailed study of a patient, D.M., recovering from a right occipital-temporal lobe infarction due to basilar artery occlusion. One examination he revealed severe impairments on tasks involving visual textures and shapes of two-dimensional visual patterns while the visual analysis of motion remained intact. The results reported here, taken together with our previous findings in a large group of cases, indicate that the aspects of motion and stereopsis perception which are not directly involved in form analysis may remain intact after right occipito-temporal lesions, while pattern and form analysis tend to be severely impaired. This study presents a detailed example of the latter and the experimental data will be used to comment on the existence of streams of processing in the human visual system similar to the streams of processing found in nonhuman primates (Maunsell 1983).

The goal of this investigation was to document in a detailed case study (the patient D.M.) that the processing of visual texture and of small aspects of form may be selectively impaired after focal brain lesions to the right occipito-temporal cortex, while coarse aspects of form, color, and motion processing were unaffected. The paper is organized as follows: first, I shall briefly introduce the topic of texture vision and I will point out its usefulness for the human visual processing. Then I shall present the clinical profile of the patient as revealed by the medical, neurological, neuropsychological, and visual examinations presented here in the Case History section. The findings and specific discussion of the results on a special battery of visual and perceptual tests form the core of the article and are presented next in the Experimental Investigations section. In the General Discussion these findings are related to the following three problems in vision: (a) texture discrimination, that is, the segregation of areas of different structures through the use of texture differences in both preattentive and attentive processing; (b) the description of the shapes of regions obtained through texture segregation, stereopsis, or motion; and (c) the recognition of natural textures (e.g., textures of objects such as tree, cauliflower, pineapple, or snake). The results are discussed in the framework of recent anatomical and physiological views of the functional organization in the visual system. In conclusion, it is suggested that the computation of texture and fine aspects of shape may share a common functional pathway and that this pathway is independent of the motion and perhaps of the colour pathways. The overall focus of this investigation was the study of a variety of aspects of texture vision, from the detection of texture differences to the recognition of natural textures, in a patient with a right occipito-temporal lesion.

TEXTURE VISION

Visual textures are defined as patterns resulting from many small elements repeated over an area so that the pattern as a whole is perceived to have a characteristic visual property, such as lightness, directionality, coarseness, colour, and so on (Beck 1982; Julesz 1984). The ability to distinguish objects by their dissimilar surface structure is an important attribute of the visual system that is strongly dependent on its ability to discriminate texture. Textures are visual patterns composed of elements repeated over an area so that the pattern as a whole is perceived to have a characteristic definition property. The identification of this property of surfaces of objects often guides their recognition. So, for example, we can recognize a pineapple just by looking at the texture pattern of its skin, often without needing other clues such as its shape or colour.

Texture, however, plays an important role in the visual processing of the world much before the stage of processing involved in object recognition. There are many demonstrations showing that clusters of elements sharing some common property, such as orientation, density, velocity, colour, or form, constitute the basis of object separation. Indeed, texture segmentation is one of the techniques used by the visual system to extract forms from an image. The separation of object (figure) from the nonobject (the background) is such a basic need for biological survival that it must be an early stage in visual processing. It must occur without the involvement of higher level knowledge about the meaning of what is perceived, or even about the object's exact shape. In other words, the extraction of visual form must precede its description and recognition. Description often involves in addition to the computation of the coarse borders, the computation of fine details that make up the specificity of a shape or the pattern of textures. We suggested that fine details of shapes result from the integration under focused attention of multiple parameters that share the same spatial location and that this operation is common to the attentive processes involved in analyzing textures.

Recent research (Julesz 1984) in the perception of texture has revealed the existence of a 'preattentive visual system' that is working in parallel and is insensitive to the spatial locations of the stimuli. This system works automatically without relying on scrutiny and, although it cannot process complex forms, it is able to detect differences in 'textons' which are local conspicuous features such as colour, orientation, movements or the end of a line. Julesz remarked that this system is blind to positional information between textons which can be extracted only by time-consuming serial and spatially defined processes which he called 'focal attention'. These processes operate at multiple scales of spatial resolution, the finest scale being as small as 1 minute of an arc.

The experimental results reported in this article, corroborated with our previous work (Vaina 1987a, b), suggest that the positional information plays a major role in the perception of texture and form.

CASE HISTORY

Medical and Neurological Background

D.M., a right-handed 37-year-old construction worker, was in good health until May 1984 when he began to experience severe morning headaches, which cleared during the day allowing him to carry on his work and normal family life. On July 24, 1984, he awoke with an unusually severe headache associated with vomiting, speech difficulties, and diplopia. He was admitted to the Boston University Hospital where he complained of headache and vomiting. Physical examination was remarkable for high blood pressure, dysarthria, dysphagia, vertical nystagmus, bilateral sixth nerve palsy, bilateral internuclear ophthalmoplegia, facial diplegia, and marked cerebellar dysmetria with ataxia of all limbs. Muscle strength and sensation peripherally were normal. A lumbar puncture disclosed no abnormality. A CT scan without and with contrast material (6 mm slices) showed a nonhemorrhagic infarction in the region of the posterior portion of the right colateral sulcus involving the adjacent medial and lateral occipito-temporal gyri and probably involving the white matter above (figure 2). An arteriogram following the acute episode showed abnormality of flow in the left vertebral artery, with occlusion of the basilar artery in its upper portion. The right vertebral artery showed filling of the PICA but no colateral filling. Anticoagulation with heparin and later with warfarin (coumadin) was recommended.

Initially D.M. required feeding tube support, but three weeks later his swallowing abilities returned. The ocular palsies improved, and at subsequent examination he was found to have full right gaze, mild paresis on the right medial rectus, and left lateral gaze with horizontal nystagmus on the left. On August 29, 1984, he was transferred to the New England Rehabilitation Hospital (NERH) in Woburn for further rehabilitation with physical, occupational, and speech therapy.

On admission to the NERH, the rehabilitation medical team noted that he was fully alert and oriented, and he was able to communicate at a moderately complex level. Sensory testing to touch and position stereognosis were intact. Visual fields were full to confrontation.

Neuropsychological Evaluation

The aspects of the neuropsychological evaluation presented in this section discuss D.M.'s intellectual status, perception, memory, learning, and attention.

On December 3, 1984, D.M. was assessed on the WAIS-R presenting a full scale with the Verbal IQ of 94 and a Performance IQ of 80. The detailed scores are summarized in table 1. His performance on abstract tasks, such as those involving mental arithmetic or abstracting semantic relationships in terms of similarities, was within average range. He presented difficulties on tasks requiring paying attention to picture details, such as identifying missing details in a drawing (Picture Com-

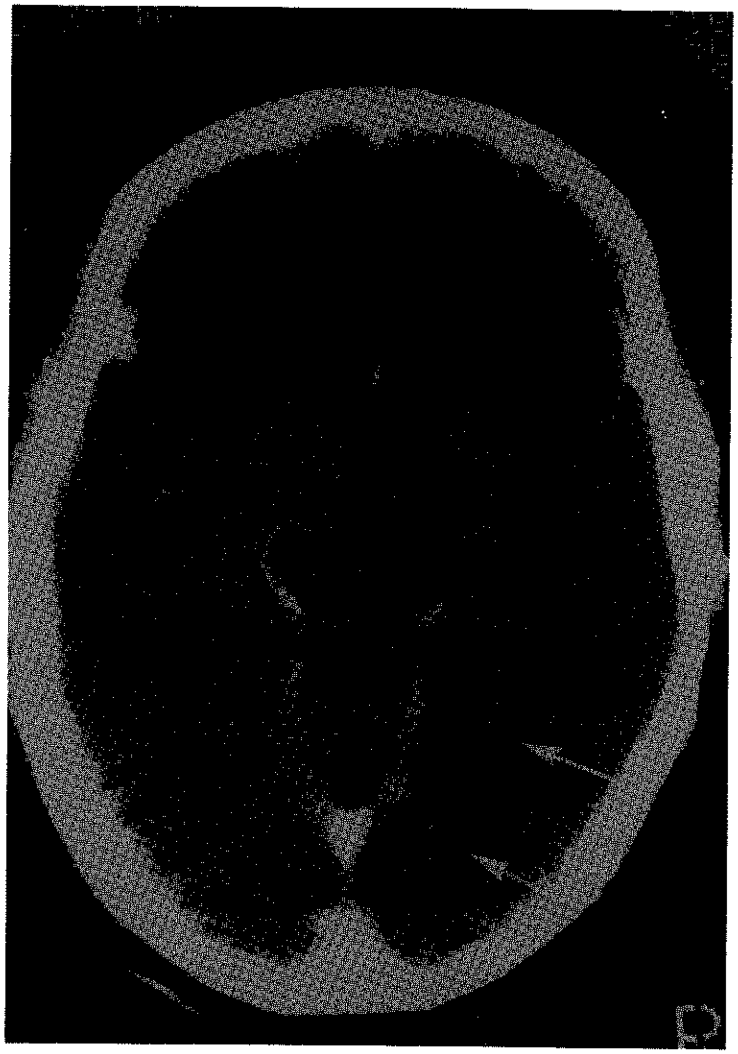


Fig. 2. CT scan with contrast material (24 July 1984) showing an infarction in the right occipito-temporal area.

pletion) and using details for arranging a sequence of pictures in a logical story (Picture Arrangement).

His verbal memory was good, as were all the language functions in spite of his dysarthric speech. Visual memory was in the average range, with recognition (Benton Visual Recognition Test) better than memory for simple drawings: when requested to access a store of visual knowledge, he performed better than when the task involved encoding and remembering visual information. His ataxia interfered with accurate assessment of the visual-motor tasks.

The patient's overall attention span was excellent, and his performance was especially good on tasks assessing auditory vigilance and attention to auditory details (Auditory Continuous Performance tests). His learning ability was excellent both in the visual and in the auditory modality. Thus, in the auditory-verbal modality, he was excellent on learning pairs of lists of words; and in the visual modality, his score on the Wisconsin Card Sort test, a concept formation task using feedback, was normal, indicating mental flexibility.

He showed a mild impairment on mentally constructing puzzles made

Table 1. DM's neuropsychological test results on the Wechsler Adult Intelligence Scale-Revisited (WAISR), on the Wechsler Memory Scale, and other relevant neuropsychological tests.

RESULTS ON THE WAIS

VERBAL

Verbal IQ	94
Digit Span	10
Arithmetic	11
Similarities	9
Vocabulary	8
Comprehension	8

NON-VERBAL

Performance IQ	80
Picture Completion	4
Picture Arrangement	5
Block Design	8

MEMORY AND LEARNING

Memory IQ	99
Long Term Memory	7.5
Verbal Learning	14/15
PA Learning	12.7
Visual Reproduction	8.6

OTHER NEUROPSYCHOLOGICAL TESTS

Wisconsin Card Sorting	6/6
BENTON Visual Retention	8/10
HOOPER Visual Organization	22.5/30
MOONEY Road Map	31/32

up of familiar objects (Hooper test). His ability to discriminate right from left while mentally rotating his body in space was within normal limits, as was his performance on matching two-dimensional and complex three-dimensional configurations.

Measurement of Colour Discrimination, Visual Acuity, Contrast Sensitivity, and Stereopsis

Colour Vision. For testing foveal colour discrimination, the Farnsworth–Munsell 100 hue test was used (Farnsworth 1943) under binocular viewing conditions.[2] Colour matching was tested using a series of coloured cards. Four trials were given with the following targets: red, blue, green, and yellow. The ability to sort and name colours was addressed by asking the subject to group together coloured chips of the same colour: red, green, yellow, and blue.

Acuity and Contrast Sensitivity. The patient's visual acuity for each eye was measured with the Snellen letter chart (Bernell Corp. no. 11930) at reading distance. Contrast sensitivity was evaluated with the Visitech Vision Contrast Test system (Vistech 1984) for spatial frequencies of 1.5, 3, 6, 12, and 18 cycles/degree.[3]

Binocular Stereopsis and Monocular Depth Perception. We first used a simple informal clinical bedside test. A yellow pencil was held about 30 cm and a blue pencil was held 60 cm from his eyes, and he was asked to determine by vision alone their relative position.

Depth vision was further tested in two ways. First, we tested monocular depth by using the Depth Perception Apparatus.[4] The subject viewed through a slit two rods positioned by the examiner at various distances in depth one from the other. The subject was asked to judge whether one rod was closer or farther than the other.

Second, in order to evaluate binocular stereopsis, D.M. was tested with a series of random dot stereograms from the Randot Forms clinical test. When these targets are viewed monocularly, each appears as a random array of small light and dark tokens in which no form or depth is apparent. The central figure consisted of a simple geometric figure. In three figures the disparity of the correlated elements was 500 seconds of an arc, and in the other three figures the disparity was 250 seconds of an arc of 16 inches. Each stereogram subtended approximately 15° with a central global figure of 9°.

Results and Comments. D.M. presented an interesting pattern of these basic perceptual functions. His hue discrimination was excellent (figure 3) throughout the entire range. He made no errors in colour sorting and colour matching.

The patient's acuity was 20/30 in each eye with correction glasses, and he was able to read fine print. Figure 4 presents the plot of D.M.'s contrast sensitivity for all spatial frequencies, indicating that he preserved a high contrast sensitivity for all spatial frequencies tested (the highest was 18 cycles/sec).

He presented no difficulties in measuring distance and depth. Even when the distance between the two pencils was decreased, he still

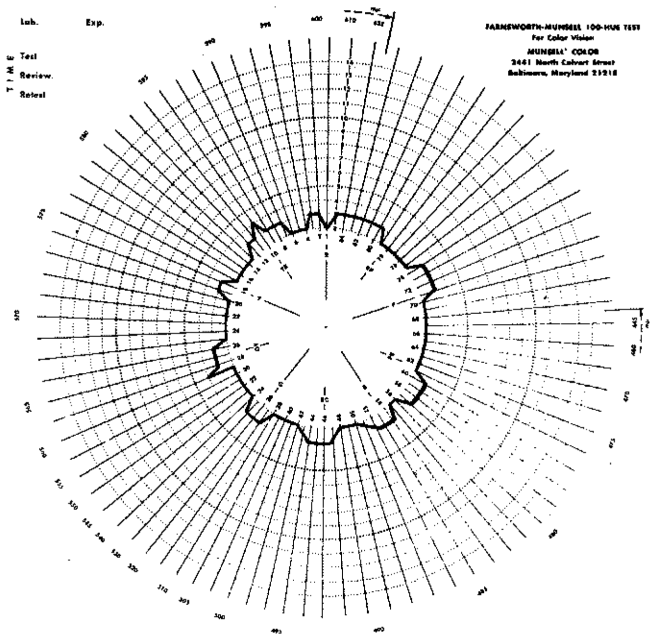


Fig. 3. The results of the Farnsworth–Munsell 100 Hue test. Errors are plotted radially and positions on the circumference represent points along a continuum of hue.

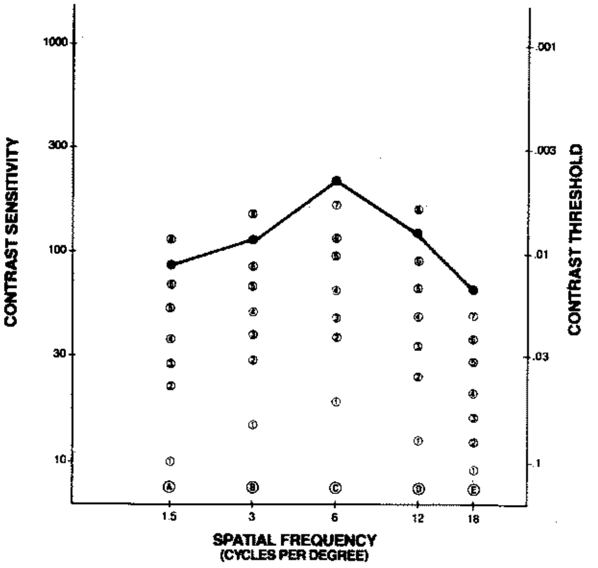


Fig. 4. The result of the contrast sensitivity testing. The corresponding values are: (1) 1.5 cycles/deg; (2) 3 cycles/deg; (3) 6 cycles/deg; (4) 12 cycles/deg; (5) 18 cycles/deg.

located them accurately. Asked to estimate how far the blue or the yellow pencil was, his visual judgement of distance was accurate.

On the depth vision evaluated with the Depth Perception Apparatus, D.M.'s responses were fast, effortless and 100% accurate, which indicated again that his depth perception was intact. However, in judging the relative distance of two lines presented in a featureless background, the retinal image is simple and the information from tuned disparity units or from near and far cells will easily give rise to an unambiguous percept (Cowey 1985).

D.M. demonstrated an interesting pattern with the random dot stereograms at all the disparities tested (250 sec and 500 sec): in all cases he was able to discriminate whether some figure was standing away from the background; he could point to it accurately, but he was unable to identify the specific shape or to match it against a set of silhouette drawings.

EXPERIMENTAL INVESTIGATIONS

In the following series of experiments my aim was to document and explore D.M.'s perceptual capabilities on tasks which addressed aspects of visual analysis of form, motion, spatial relations, and texture.

Methods

Several psychophysical visual tasks were administered to D.M. for assessing his ability to perceive aspects of textures, motion, size, length, and spatial relations. The experimental procedures were performed in November 1984. Five 45-minute sessions were undertaken over a period of two weeks while D.M. was an inpatient at the New England Rehabilitation Hospital, Woburn, Massachusetts. With the exception of the texture to object matching and the naming tests which will be discussed separately at the end, all the tests were generated on an Apple 2E computer with 64K of memory and displayed on a 12-inch Commodore colour monitor Model 1702, subtending 20° by 15° of visual angle. The resolution of the display was 280 by 192 pixels. In our application, only one intensity of dot is used.

The displays were viewed from a distance of 65 cm at which distance each pixel subtended 5 min by 4.3 min of arc. When text characters were used such as /,>, or letters, all were drawn in a region approximately 5 pixels wide and 7 pixels high. Unless we shall note otherwise in the specific subsequent test descriptions, the individual symbols forming the displays were separated one from another by 2 pixels horizontally and 1 pixel vertically. In all cases, the examiner made sure through giving examples that the subject was able to perceive the whole display in central vision.

The rate of presentation of pictures is about 12 per minute. The display time was adjusted by the examiner and will be discussed separately with each test. The responses were recorded by pressing specially designated keys on the computer keyboard.

Prior to administering each experimental task the subject was usually trained on 5 examples so that he became familiar with the computer display and the specific task requirements. All the stimuli were viewed binocularly and were presented in central vision. All the tasks were administered by the same examiner and in the same room under the same lighting conditions (the room was darkened with a constant low-level ambient illumination). The raw data were transferred to our perceptual data base (Naili and Vaina 1987) for further comparisons with results from the normal controls and other subjects with brain lesions documented by CT scan. These comparisons are reported in the results section of each experiment and are summarized in table 2. The following subjects groups were selected for comparison: normal controls, posterior left hemisphere lesions, and posterior right hemisphere lesions. The subjects in these groups were chosen automatically from the data base to match D.M.'s demographic profile (e.g., age, education, handedness, and sex).

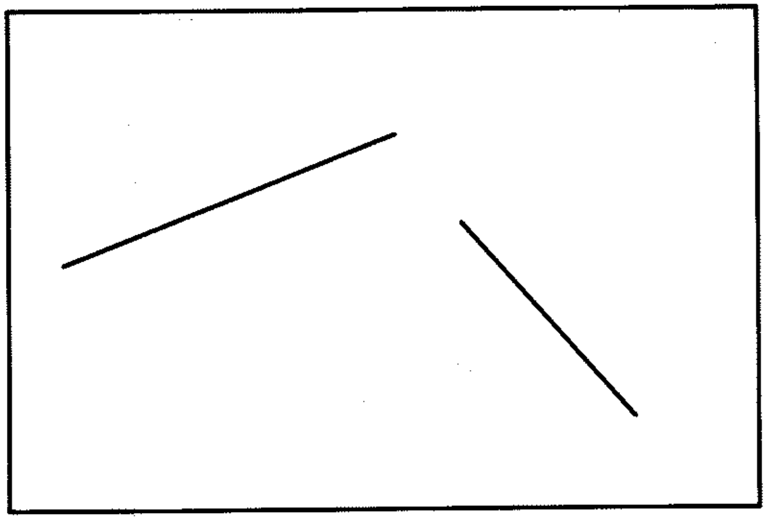
PERCEPTUAL TESTS

Appreciation of Length and Size

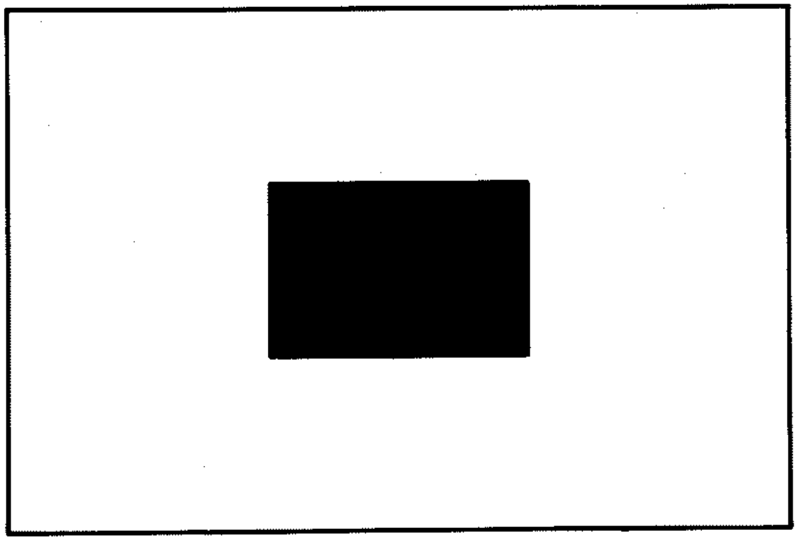
These tasks were essentially devised after Holmes's (Holmes and Horax 1919; Warrington 1974) clinical bedside tests for the appreciation of size and length, which we modified slightly to best exploit the display capabilities of the computer monitor.

Length. Two colinear lines were presented simultaneously on the screen, and the task was to determine as quickly as possible which of the two lines was longer (figure 5a). The position of the longest line was randomly allocated to the right or left side of the display. Some trials contained pairs of parallel lines, and others contained lines drawn obliquely to one another. The lines were displayed 4.6° from the fixation point which was situated in the middle of the computer screen. The width of the lines was equal to 8.6 arcmin. The smallest line lengths were equal to 4° of an arc, and the longest was 8° of an arc. The maximum difference in length between two lines in a trial was 2.2° of an arc and the minimum was 13.2 arcmin. Thirty trials were presented and chance response was 50%.

Size-Shape. This task was a close approximation of Efron's Shape Discrimination test (Efron 1969). Rectangular white silhouettes were displayed in the center of the computer screen. The task was to determine as quickly as possible whether the shape viewed was a square or an oblong (figure 5b). The standard shape was a square subtending 4.4° × 4.4° of visual angle. The subject was given five sets of twenty trials



(a)



(b)

Fig. 5. (a) Example of length appreciation stimulus: (b) Example of size discrimination stimulus.

each, differing one from another in the order of difficulty, measured by the difference in length between the adjacent sides (the minimum was 0.5 cm, and the maximum was 7.5 cm).

Results and Comments. Table 1 presents the percent correct for each test. D.M. scored overall 96.6% on the test for appreciation of length, which was in the range of the normal controls. This score suggested that he was able to appreciate linear extension and that he judged correctly one-dimensional figures.

He was impaired (44% correct responses) on the Shape Discrimination task when the dimensions of the squares and the oblongs differed only by 0.5 cm. This was worse but consistent with the scores obtained by the right posterior group (56%), and it was significantly worse than the scores obtained by the normal controls (96%) and by the left hemisphere group (90%).

D.M. did not present difficulties in evaluating real objects, in comparing them for size, or in manipulating them. As the above results indicate, his gross discrimination was intact in all cases. However, fine shape discrimination was impaired. Warrington (1985, 1988) demonstrated that a poor performance on the Efron-Shapes test is indicative of deficits at the visual sensory level which is a primary stage of visual processing. Going one step further, one could interpret a poor performance on the Efron Shapes as a failure to appreciate two-dimensional figures, that is, the conjunction of two parameters (e.g., length and width).

It is interesting to note that the comparison or estimation of linear extensions was well preserved in this patient. It is possible that the nervous system may treat lines as literally one-dimensional, that is, shapeless, and not subject them to the mechanisms that underlie shape processing. Recent physiological findings (Gross et al. 1981; Schwartz et al. 1983) support such a possibility, indicating that inferotemporal neurons in the macaque cortex respond better to shapes and objects than to line segments.

Spatial Discrimination

Spatial relations. This test was designed after Warrington's spatial discrimination task (Warrington 1974). Two squares, each 9° × 10.4°, were displayed simultaneously side by side on the computer screen. The center of each square was marked with a dot, and the distance between the center dots was 9.6°. Another token, of the same size, was placed randomly in each square, and the subject was asked to state whether the positions of the dots in the squares relative to the center of the square were the same or different (figure 6). There were 100 trials and chance was 50% correct responses. The difference in positions between the corresponding tokens in the two squares varied between 0.37 min and 2.6° of visual angle.

Point Localization. This was similar to the previous task, except that the display presented only one square subtending 9.6° × 9.6° and a single dot was placed inside. The subject was asked to determine whether the dot was in the middle of the square or not. There were 100 trials, and 40% of the trials had the dot in the center of the square. The displacement in the other 60% was between 0.21 min and 3.5° of visual angle.

Results and Comments. Table 2 shows the percent correct of the test results. D.M.'s ability to determine whether the dot was in the center of the square was good (82%), compared with his rather poor appreciation of the relative spatial arrangements of the dots (57%) which was significantly below the scores of the normal group (91%; SD = 4.5) and of the left posterior group (75% SD = 12). The point localization task

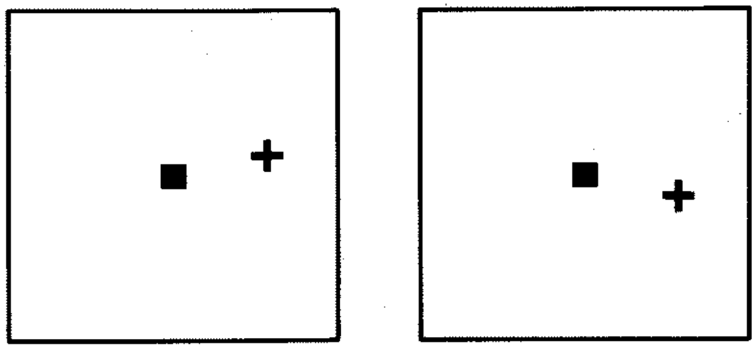


Fig. 6. Examples of spatial discrimination tests: the task is to determine whether the spatial relations between the center token and the second token are the same in the two squares.

is indeed much easier; however, the striking difference in performance between the two tasks is intriguing.

One way to interpret the discrepancy between the two tests is to consider that a possible strategy for the evaluation of the relative positions of the dots would involve drawing an imaginary line between dots in each square and then comparing the dimensions of the lines and their position in the plane of the squares. The results on the previous tests indicated that he was able to appreciate length and the spatial position of a single dot. It is possible that D.M.'s difficulty may lie in the composite task of computing the conjunction of the two parameters: length and position.

Appreciation of Movement

Star Gaze. In this test the display showed 100 small star-shaped items scattered across the screen. Stars at any location on the screen began to move, one at a time, and the task was to detect as quickly as possible when a star starts to move. The time intervals between the falling stars varied randomly from 20 msec to 1 sec. The total number of trials was 60.

Speed Comparison. This test addressed the capacity of measuring and interpreting the speed of movement. Two squares, 6.7° × 6.7° each, were displayed simultaneously, side by side, on the screen. The distance of the squares from the fixation point was 6.3°. In each square, twelve white small square-dots, each subtending an area equal to 21 min × 21 min of visual angle moved in random directions. The dots in each square moved with the same speed. The subject's task was to determine in which square the dots moved fastest. The viewing time was two seconds for each trial. There were 30 trials. The speeds were: 1.5°/sec, 3°/sec, 4.5°/sec. The ratio of the difference in speed in the two squares between 1.5, 2, and 3 (Vaina 1987c, 1989).

3-D Structure from Motion. This test addressed the subject's ability to recover three-dimensional structures of objects from a sequence of 72 frames of random dots in movement. The displacement between two consecutive frames was 5°, and the presentation rate was 18 frames/second. Each frame consisted of 32 dots lying on the surface of an imaginary cylinder with the radius of 4.4° and the height of 5.7°. The 3-D coordinates of all the dots were stored in the computer's memory, and their projection on the frontal plane was computed and presented on the screen. Each single static view of the cylinder appeared as a collection of random dots; when in movement, in a movie-like fashion, the elements in motion were easily perceived as a cylinder. The angular velocity of the dots was 90°/sec. The movie was presented for several seconds or until the subject identified the cylinder. The answers were scored as correct or incorrect and there was only a single trial, assuming that the subject either identified the cylinder-like structure or did not.

Results and Comments. D.M.'s performance on all three tests was very good, in the range of the scores obtained by the normal subjects and other subjects with occipito-temporal lesions (table 2). This suggests that the pathways involving the measurement and computation of motion were functionally intact. Although these results are interesting in their own right and were discussed elsewhere as pertinent to motion perceptions (Vaina 1987; Vaina 1988a, b), here they will be considered only to show that D.M.'s perception and interpretation of motion parameters was not impaired.

In the next section, however, we shall see that when the motion cues were used to process the shape of the stimulus, as a two-dimensional pattern, D.M.'s performance was dramatically impaired.

TEXTURE TASKS

The following sets of experiments addressed D.M.'s ability to use texture information at various levels of visual processing: (a) segmentation of figure from ground; (b) the identification of the shapes of the figure obtained; and finally, (c) the recognition of natural objects. The results are presented in table 2. First the texture experiments will be described. Second, D.M.'s results will be contrasted with the results of different subject groups and of normal controls, and this will be used as a frame of reference in the subsequent discussion.

Textural Segmentation

Homogeneous Squares. This experiment addressed immediate, automatic segregation of figure from ground. The display consisted of a textured pattern which subtended an area of 10° × 10°. The stimulus

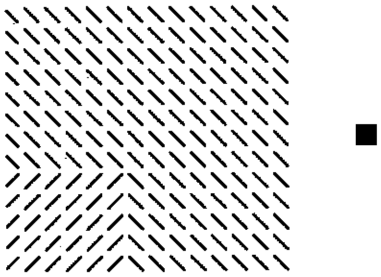


Fig. 7.

was presented to the right or left side of a fixation point located in the middle of the screen. The distance between the fixation point and the center of the textured square was set to 6.8°. In order to avoid scrutiny by scanning, the exposure time was set to 150 msec. The size of each token was approximately 0.7° by 0.7° visual angle, and in all cases the layout of the stimulus was regular. There were thirty trials; twelve had a homogeneous textured pattern (all the tokens were the same everywhere) and 18 contained an embedded square with a different texture. Texture differences (figure 7) were formed from different colours (e.g., green and red), lines at different orientation (e.g., / and \), and different densities (e.g., the center region was twice the density of the background region). The differences in textures could be readily perceived and provided a visual impression of a segregated area (a square). The square subtended an area of 4° × 4°. The subject was asked to determine as quickly as possible whether the display had a homogeneous texture or not. The answers were scored right or wrong.

Textured Squares. The stimuli consisted of two textured squares of high contrast white tokens (17 cd/m^2) on a dark background (1 cd/m^2). Each square subtended an area of 9° × 9° of visual angle. The squares were displayed simultaneously on the screen each 6° from the fixation point which marked the center of the screen. The size of the individual tokens was the same as in the previous experiment.

In 40% of the trials the two squares consisted of identical micropatterns obtained by the repetition of the same token. In the remaining 60% of the trials, one quadrant of the left or right square contained a different texture obtained by (a) angles of lines open to the left or to the right; (b) local spatial distribution of the structure of the tokens such as in: T and L; p and b; M and W; and (c) differences in local detail such as in O and Q; C and G; I and 1; S and 8; V and U; and E and F (Figure 8). The test contained four trials with each type of different stimuli; the task was to determine as quickly and as accurately as possible whether the elements in the two squares were the same everywhere. The display time was 500 msec, followed by a masking grid.

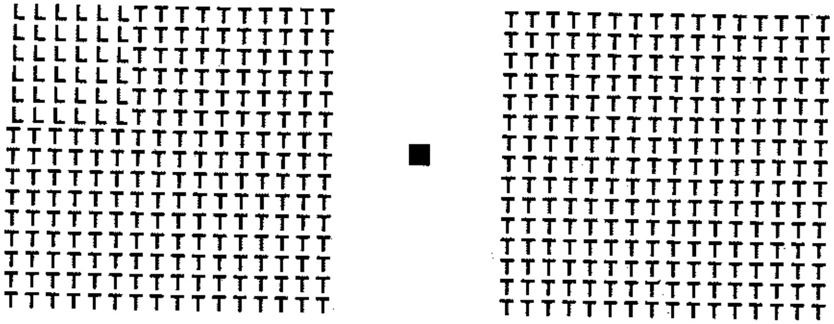


Fig. 8. Example of the homogeneous square test stimulus. This test addresses the problem of preattentive figure-ground segregation. The figure shows an example of figure-ground discrimination based on the differences in the orientation of the texture elements.

The subject was presented with all the stimuli individually before the testing session to assure that he was able to distinguish all the tokens. The answers were scored as correct or incorrect (table II).

Shape from Texture

The following two experiments address the second texture problem, which involves constructing and identifying the specific shapes of the regions obtained by textural segregation. The first experiment was designed to measure the ability of the subject to identify a shape from a differently textured background, while in the second, the shape must be obtained by identifying the form of a cluster of tokens moving across the screen with constant velocity.

Textured Shapes. The display consisted of textured patterns subtending an area of 12° height and 20° width (figure 9). In half of the trials, a

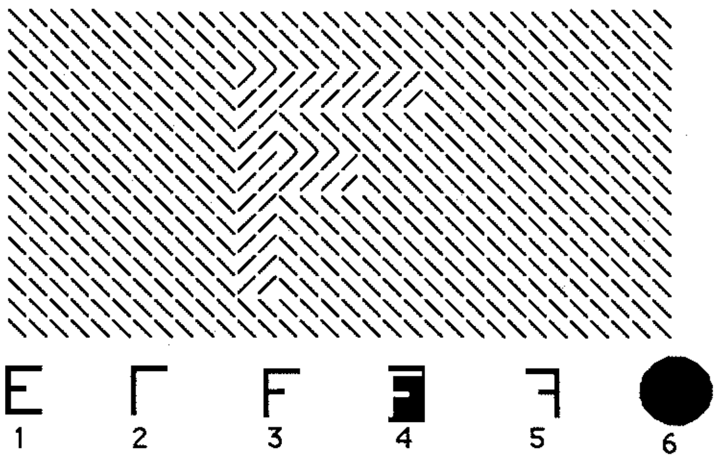


Fig. 9. Shape from texture: the task is to match the textured shape perceived in the middle of the screen to the corresponding shape from the silhouettes displayed at the bottom of the screen. In this example the figure in the center of the screen differs from the background in the orientation of the texture elements.

subset of tokens outlined a shape differing from the background tokens in colour, density, or orientation. In the other half of the trials, the subset of tokens differed from the background tokens in the microstructure of the component texture features.

The difference between figure and ground results in two ways. First, segmentation is achieved by a sharp difference in contour produced by a difference in luminance or colour, without necessarily involving the specific computation of the individual texture tokens. Such differences between the tokens in the figure and those in the background create a vivid and immediate impression of a texture border. Scrutiny is involved only for obtaining the specific shape of the figure and matching it against the multiple choices displayed at the bottom of the screen.

Second, the construction of the figure outline requires first determining the composition of the local texture tokens, and then gluing them back together to obtain the component tokens of the figure and of the background. Only subsequently the shape is computed from grouping together identical tokens.

Silhouettes were displayed at the bottom of screen 6. In addition to the correct answer and a shape totally different from the target, the other choices are: two shapes that approximate the target by omission or completion of the area, figure ground reversal, and the same figure as the target but rotated in the plane of the screen. There were 20 trial items and the task was to select from the figures displayed on the bottom of the screen the figure that corresponds to the target.

The answers were scored as percentages correct, and subsequently the wrong answers were analyzed by types of errors.

Form-from-Motion. In this test the whole display was filled with a fine-grained random dot pattern. Each dot subtended 4.33 × 4.97 min of visual arc. A patch of these dots subtending 2.2° × 2.2° of the visual angle began to move in a translational motion across the computer screen from left to right in 50% of the trials and from right to left in the other 50%. The shape of the moving patch was either a square, a circle, a flower, a cross, or a triangle, for example. The subject was asked to identify from six silhouette drawings displayed at the bottom of the screen the one that was identical with the moving patch. The distractors were shapes that had a totally random shape, a shape which had a different area than the target shape, or a shape that had the same rough area with the target and which approximated its shape by completion or omission.

There were 30 trials and the answers were scored right or wrong for calculating percentages correct.

Results and Comments. The Homogeneous Squares test addresses the ability to discriminate textured patterns that differ in density, orientation, or colour. In less than 150 msec, the figure is segregated from the background by the fact that a sharp boundary is detected effortlessly, without scrutiny. Julesz (1980) demonstrated that this level involves automatic and parallel processing and depends on the ability of the visual system to detect effortlessly the occurrence of certain local features that are present in one part of a texture and absent in the other. The hypothesis is that differences between a few conspicuous features, or 'textons' (e.g., colour, line terminators, density, or local orientation of the components) are at the basis of preattentive texture discrimination.

D.M. scored very well on this test, regardless of whether the square was presented to the left or to the right of the fixation point, suggesting that there was no visual field deficit for this task. Posthoc measurements

Table 2. The table presents the percentage correct and standard deviations on the experimental perceptual tasks presented as computer displays. The first column presents DM's performance (percent correct); the other columns present the data on these tasks from other patients subgroups matched by age and sex with DM. The data is extracted from Vaina and Naili's Neuropsychological Perceptual Database.

Group / Test name	DM	Normals	Left Posteriors	Right Posteriors
Length-Size	93.0 -	95.0 -	-	-
Size-Shape*	44.0 -	96.0 -	90.0 -	56.0 -
Spatial-Relation	57.0 -	90.4 4.6	75.0 12.0	70.0 14.0
Point-Localization	82.0	90.0 1.0	-	82.0 .8
Star-Gaze	95.0	94.0 4.6	68.0 20.0	73.0 17.0
Speed-Comparison	93.0	87.0 8.0	79.0 6.0	70.0 13.0
Structure-from-Motion	YES	YES	YES	**
Homogeneous-Squares	96.0	97.0 4.0	- -	88.0 13.0
Textured-Squares	46.0	85.0 8.0	84.4 22.0	80.0 22.85
Textured-Shapes	55.0	91.7 9.3	74.5 20.0	58.0 19.5
Shapes-from-Movement	33.0	95.3 5.20	85.0 14.0	76.0 25.0

TABLE 2

* Side difference between squares was 0.5 cm.

** Right occipito-parietals were unable to derive the 3D structure.

Second numbers for normals, left and right posteriors are the standard deviation.

of the luminance of the stimuli showed that in 13 out of the 16 trials in which the stimulus displayed was nonhomogeneous, the global luminance was the same in the figure and the background (30.2 f/lamb). Thus the good performance on this test could not be explained by D.M.'s ability to use luminance cues to detect borders (Nothdurft 1985).

In the Textured Squares test D.M.'s performance was rather poor (46%) compared with the results of the normal controls (85% correct responses: S.D. = 8), and with the left posterior group (84.4% correct responses; S.D. = 22), and with the right posterior-parietals who scored 80% (S.D. = 22.85).

The texture segregation is harder in this test for the difference between tokens consists in the detailed spatial arrangement of their microcomponents. Such texture differences can be detected only after a time-consuming search under focused attention (Julesz 1981; Treisman et al. 1980). The goal of the search is to determine the relative spatial position of local features and to identify the different texture tokens. The Julesz–Treisman theory suggests that this must occur under the small aperture of focused attention, which is shifted across the entire stimulus in a scanning process.

The Textured-Shape test has the additional objective that beyond the segregation of a figure from the background, the subject must determine the specific shape of the figure contour in the textured pattern.

In general, the segmentation of a region into figure and ground occurs in two ways. One is at contours, that is, at places of abrupt changes in brightness or colour. The other is through texture differences, such as lightness, orientation, directionality, density, movement, or coarseness of texture tokens in some area which make this area different from the surrounding texture.

D.M.'s performance was markedly impaired (55%), considering that the performance of the normal controls was 92% correct with a S.D. = 9 and that the left posteriors scored 85% correct with S.D. = 5.6. The right posteriors, both the occipito-parietal and the occipito-temporal group produced a rather low score on this test. A qualitative analysis of the types of errors produced by D.M. indicates that most frequently the choices of an incorrect answer were due to the approximation of the target shape by omission or completion and that this did not depend on the nature of the differences between tokens in the figure and the background. Consistently, he was able to identify correctly the rough area subtended by the shape, but tended to ignore holes or finer details in the contour, which prevented the correct identification of the shape.

Most interesting and puzzling was D.M.'s performance on the Form-from-Motion test in which the figure is obtained by segregation through motion alone. Here he scored 33%, which is much below the scores of all the other subject groups, but similar to the scores range of the occipito-temporal subjects (Vaina 1987b; Vaina et al. in prep.). Thus, for example, the normals scored above 95% correct, and both the left posteriors and the right occipito-parietals were statistically not different from the normals.

This task also involves several stages of processing (Vaina 1988b, c):

the measurement of motion, which presumably may be used to segregate figure from ground, the computation of the coarse area subtended by the figure, the computation of fine aspects of the contour and, finally, the integration of the results of these processes in the shape as a whole.

The results of the last two experiments indicate that D.M. was able to compute the rough area subtended by the shape, but failed to achieve the recognition of the two-dimensional shape. Thus, for example, when the moving shape was a square, he chose as a match a circle, a cross, or a flower subtending the same general spatial distribution. A heart was often identified as a triangle pointing in the same direction, but a triangle was never confounded with a square, with a triangle of a different orientation, or with a flower of a different area.

Texture Recognition

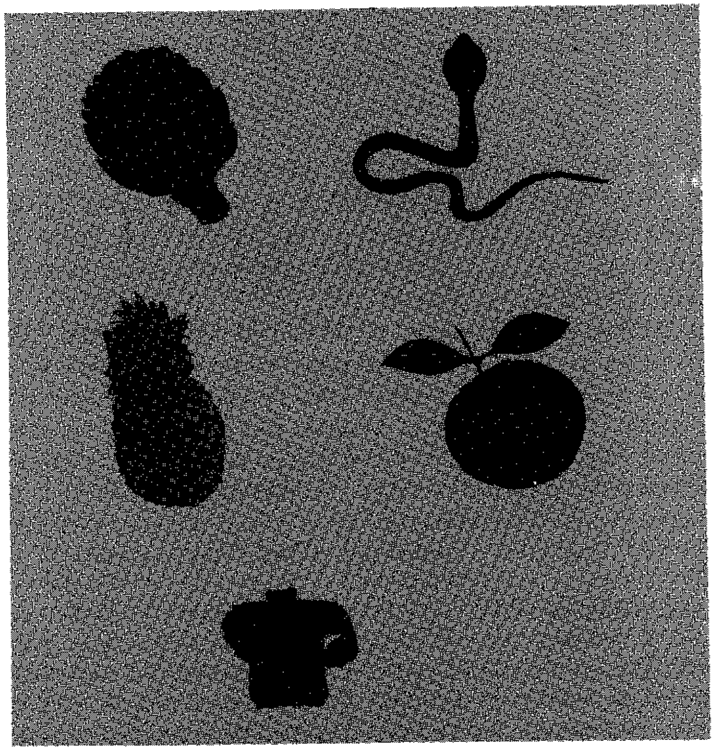
This experiment addressed D.M.'s ability to recognise texture of different objects, which is a task carried out at the level of perceptual categorization of visual information (Vaina 1985, 1987a).

Texture to Object Matching. A series of familiar objects (plants, animals, man-made objects) was photographed under oblique morning lighting (45°) using Kodak Super XX techpan black and white film with a contrast index of 0.92. A section of the photographs was enlarged and the enlargements were cropped to exclude the identifying shape and size of the object (figure 10a).

Twelve objects were photographed, and the corresponding cropped enlargements presented the texture of these objects. Eight of these textures exhibited various types and degrees of structure such as: tiled (e.g., pineapple), nestedness (e.g., cauliflower), wovenness (e.g., sweater), furry (e.g., sheep, bear), striped (e.g., zebra, watermelon), etc. Two textures were fine repetitive structures (e.g., leather), and two had fine grain structures (e.g., elephant skin). The textures did not belong to mutually exclusive categories.

On separate 12 × 17 cm cards, silhouettes of objects were drawn in black ink. In each trial the subject was presented with a picture of a texture and a collection of five silhouette drawings (figure 10b). The silhouettes were so chosen that in addition to the correct answer and an unrelated answer, there were two silhouettes whose texture was

(a)



(b)

Fig. 10. Example of the texture recognition stimulus. (a) the cropped texture of a pineapple; (b) the multiple choice silhouettes: pineapple, snake, artichoke, orange, and sweater. The task is to match the texture to the corresponding silhouette.

similar to that of the target, and one which was semantically similar to the target.

The subject was first asked to identify by choosing from a multiple choice the silhouette to which the target texture corresponded (perceptual matching). Second, he was requested to name the silhouette chosen or to describe its function (semantic matching). The answers were scored as right or wrong. Failures were differentiated among perceptual, semantic or naming, and unrelated errors.

Results and Comments. D.M. scored 41% correct in the perceptual matching task while the normal controls scored 93% and of left hemisphere scored 85% correct (Vaina 1987a). The further analysis of the specific types of errors shows that D.M. was unable to identify perceptually highly structured textures, such as those of a cauliflower, pineapple, tree, or snake. Further errors occurred on some of the fine-grained textures, such as orange, canteloupe, and leather. The only correct items that he obtained were those in which significant texture features embodied coarse orientations, such as the leaf, zebra, tire, or the elephant skin. Here the smaller details or the pattern of the possible line intersections was not essential for the identification of the texture. His performance on the semantic scoring was very good; he made only one naming error (horse instead of bear).

This pattern of impairment is similar to that reported by Vaina (1987a) in a group of patients with right occipito-temporal lesions. She found that these patients were unable to match structured textures. The pattern of errors seem to indicate that the ability to access the perceptual category of the texture was preserved in this group; they failed, however, to identify the specific item in the category. D.M. also made errors which were in the same perceptual category with the target texture (e.g., sheep for cauliflower, or snake for pineapple).

Object Recognition

Naming Task. The lack of time forced us to address this issue only informally. A subset of 12 object drawings from the Boston Naming Test were presented one at a time. The task was to name or to describe verbally or by gestures the use of the objects.

Results and Comments. D.M. scored 66% correct, while the normals' scores were 98%. D.M.'s object recognition was excellent when the drawings portrayed objects with coarse relevant features. When the recognition depended on the identification of the detail (e.g., asparagus, acorn), he had great difficulties; his responses were slow and inaccurate. This suggests again that a system that processes fine features might have been impaired.

GENERAL DISCUSSION

We have described and quantified visual acuity, stereopsis, contrast sensitivity, colour vision, appreciation of movement, size and length, spatial localization, and perceptual segregation through textures and recognition of textures and objects in a patient with a lesion in the right occipito-temporal gyrus.

D.M. had normal colour vision, contrast sensitivity, depth perception, point localization, and motion appreciation. He was impaired in the appreciation of fine distinctions between two-dimensional sizes, in the evaluation of relative positions of dots in a plane, and in determining the exact shape of a contour from texture, stereoscopic vision, and motion. These deficits could not have been explained by a somewhat reduced acuity, as in general he was able to make fine distinctions between small stimuli, and the size of the tokens forming the test items was larger than his resolution ability.

Integration of Different Visual Parameters

It is natural to ask whether the pattern of D.M.'s deficits could have resulted from a specific impairment of a visual process that might have been common to the tasks on which he had a poor performance. Interpreting D.M.'s errors along this line reveals that all involved the appreciation and integration of multiple parameters. Thus, for example, the conjunction of length and width is involved in the shape appreciation, the conjunction of length, orientation, and position in plane in the relative spatial position between dots, and positional relationships between textons characterize the texture tests. In other words the above tasks require integration of relative spatial positions of different local features, and we conjecture that this may indeed form the essence of texture vision and that also it may intervene in an important way in shape recognition. The conjunction of these features occurs under scrutiny, which is a process that allocates the focus of attention to small spatial areas. Subsequently attention is shifted across the visual field for scanning it (Julesz 1981, 1984; Treisman et al. 1980).

These deficits occurred in the context of good memory and cognitive abilities, and good appreciation of motion, colour, depth, spatial localizations and of unidimensional sizes. D.M. was also able to use these visual parameters as a basis for preattentive, almost instantaneous figure-ground segregation. This suggests that a deficit in the integration of multiple parameters under focused attention could indeed underlie his impairment.

Computing Two-Dimensional Form

D.M. was markedly impaired on the tasks of determining forms through stereoscopic vision, motion, or static textures. In all cases, he was able to obtain correctly the rough, coarse area subtended by the shape, but he failed to obtain the details of the contour necessary for the identification of the shape. This may suggest that the recognition of a two-dimensional figure may involve several main stages: the computation of coarse contours which may achieve coarse recognition, while a different mechanism would be involved in the detailed inspection of borders for deriving finer aspects of the precise shape contour. The shape identification would occur somewhere later in the processing, and I suggest that it results from the integration of the coarse contours and the fine details. The specific goal of the computation of coarse contours might just be segmentation of figure from ground, which can be obtained in different ways: from stereopsis, motion, or texture. This is consistent with earlier results of Julesz (1971), who showed that stereopsis preceded the perception of objects, and of Ternus (1926), who indicated that motion correspondence can be established between simple elements in successive images without requiring object recognition.

My contention is that the coarse figure will serve as a workspace for subsequent, more precise processes that operate under focused attention and have as a goal identification of objects and for spatial processes involved in the computation of spatial relations.

In this framework, I suggest that D.M.'s poor performance on a variety of perceptual tasks might just consist in an inability of computing fine details resulting from the integration, under the focus of attention, of parameters that do not share common descriptional features. One is naturally tempted to think that this ability may be characteristic of one of the 'stopovers' on the road to shape and texture categorization, that it may occur beyond the stage of segregation of figure from ground, and that it does not participate in it.

Recognition of Visual Textures

Would this impairment interfere with the visual texture recognition and with the recognition of objects from drawings? The results of the experiments indicated that D.M. was markedly impaired on textures: he was able to identify the perceptual category, but failed to determine the specific item in the category (whether the texture was of a sheep or of a cauliflower). As discussed in detail elsewhere (Vaina 1985), this type of error may be interpreted in terms of an impairment of addressing the fine details of textures. I have hypothesized that the computation of details involves processes carried out at small scales and, hence, implicitly, at high spatial resolutions.

In the companion paper, we showed the texture of a sheep and a cauliflower viewed at three levels of spatial resolution. On a large scale, no difference is perceived between the two textures. At smaller scales, however, we easily see the directionality of the hairs in the sheep wool and the 'groupiness' that characterizes the texture of the cauliflower. A similar interpretation may explain D.M.'s deficit in identifying objects whose recognition may possibly depend on the identification of details. These deficits could not be accounted by a reduced visual acuity as D.M. demonstrated no impairment on fine appreciation of visual stimuli that differed in a single dimension, such as length, or orientation, or colour discrimination. D.M.'s clusters of impairments may be explained by and large by a deficit of 'gluing' visual details onto larger features of the figure such as onto a coarse contour, for example, in order to obtain shapes, or assembling these details into specific texture patterns. This deficit would occur at a level of processing carried out under the focus of attention.

SHAPE AND TEXTURE: COMMON PATHWAYS

The preceding discussion was centered on the nature of the processes involved in both texture and shape processing. A detailed clinical study of the cluster of perceptual deficits in a patient with a right occipito-temporal lesion suggested that the local integration of different visual parameters under the focus of attention may be a visual process involved in both texture vision and in 2-dimensional shape recognition. I shall now turn to a more speculative aspect of the problem: what may be the hardware involved in handling this type of information?

Physiological studies in combination with cytochrome oxydase histochemistry provide a good framework for thinking about this. It has been shown that in the upper layers of the striate cortex, the tissue stained for this enzyme forms a mosaic-like pattern whose components differ in their projections to and from the prestriate cortex and in their physiological properties. This pattern segregates into three pathways that have been determined in the output layers of the area V1 (the primary visual cortex), and continue segregated through area V2 (in the prestriate cortex), all the way through V4 and MT: (1) blobs; (2) interblobs; and (3) layer 4B. In the 'blob' tissue there are concentrated cells selective for wavelength (colour) but not for orientation, while in the 'interblob' regions the cells are highly orientation selective (Hubel and Livingstone 1985; Tootell 1985). Their input from the LGN appears to come from the parvocellular system, which projects first to level 4Cb in the striate cortex and continues to the levels 2 and 3. The magnetocellular system of the LGN seems to project to the layer 4Ca in the striate which projects further to 4B.

Tangential sections of the area V2 stained for cytochrome oxydase, show dark stripes that correspond to the enzyme-rich regions, and are separated by lighter regions, the 'interstripes'. The dark stripes are alternating thick and thin. Physiological recordings indicated that cells in the thin stripes have a double opponent organization suitable for detection of colour contrast, while cells in the interstripes are end-stopped and primarily respond to short slits. The thick dark stripes are particularly concerned with stereoscopic depth and movement. Finally, the thin stripes and the interstripes project to V4 (Zeki 1985) which occupies a critical position in the occipito-temporal system for object vision, whereas the thick stripes project to MT which is an important component of the occipito-parietal system of spatial vision (Ungeleider and Desimone 1985, 1986).

Where can we place D.M.'s deficits? Table 2 showed that the perception of movement, depth and of coarse features of objects and colour were within the normal limits. This suggests that the magnocellular-4B-thick stripes-MT system and the interlaminar-blob-thin stripes-V4 system were probably not affected (figure 11).

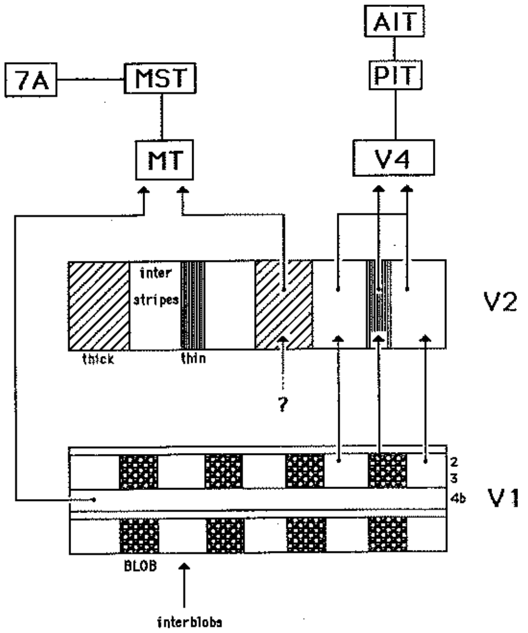


Fig. 11. (after Maunsell and Newsome, 1987). Major components of the motion, color and form pathways. At the level of V1, the color and form pathway arises from the blobs and interblobs regions in the layer 2 and 3. These regions project to the thin stripes and interstripes of the area V2, which in turn projects to V4. The outputs of V4 lead to the posterior inferotemporal and anterior inferotemporal areas, thus being part of the "what" pathway postulated by Ungerleider and Mishkin (1982) and refined by Ungerleider and Desimone (1986). The motion pathway is found in the layer 4b in V1, which projects directly to the middle temporaal areas (MT). Mt also received projections from the thick stripes in V2, whose inputs are not yet well established. The outputs of MT lead to MST and the area 7a in the posterior parietal lobe, thus showing that MT is a central component of the "where" system.

His poor performance on texture and the inability to achieve reliably the conjunction of visual features which he could perceive correctly in isolation, appear to suggest that D.M.'s deficit could lie within the parvocellular-interblob-interstripe system which may be substantially involved in the visual processing of fine aspects of form and in texture vision (Vaina 1985, 1987a, b).

The findings of the cytochrome oxydase studies corroborated with the experimental data presented here and replicated elsewhere (Vaina 1985, 1987a, b) suggest indeed that the blob system may be involved primarily in the large-scale, coarse processing at a low spatial resolution, while the interblob system is involved in the processing of fine spatial detail, which requires higher spatial resolution processing of the image at smaller scales. Additional support for this hypothesis is the finding that the receptive fields of blobs are much larger than the receptive fields of interblobs (Livingstone and Hubel 1984).

Thus, I suggest that two types of neuronal hardware may be involved in the computation of shapes and textures: one, whose goal is range, processes shading, and the general, coarser aspects of shape or texture; the other, whose goal is resolution, handles finer aspects of the surface which are orientation-dependent, such as the specific hairs of an animal fur, the details of the pineapple skin, the finer details of a shape or perhaps the specificity of a face. Perhaps the thin stripe system organizes the large features into coarse contours, or surface regularities, while the interstripes might carry out grouping of smaller features. Indeed there is some evidence that the interstripes process end stoppings or terminators (Desimone and Schein 1986). Further, it has been demonstrated that V4 (the suggested equivalent of DL in the owl monkey) has a high frequency of dimensionally-selective cells for both unidimensional and bidimensional features of the stimulus (Petersen et al. 1980).

Based on this anatomical and physiological data corroborated with the experimental results in humans, I have suggested elsewhere (Vaina 1985, 1987a) that the blob-thin stripe-V4 system may be involved in the processing of colour and those coarse aspects of textures and shapes which may constitute the basic criteria for membership into a perceptual category. The interblobs-interstripes-V4 system on the other hand, addresses more specific aspects useful for computing differences between instances in a perceptual category. V-4 is also an important place of convergence of various intermediary results, for a laminar connection between MT and V4 has also been described (Maunsell and Van Essen 1983; Ungerleider and Desimone 1985, 1986).

I suggest then that V4 may, indeed, collect information about coarse areas and boundaries of shapes, or about coarse texture features, which at this level of processing may serve as a 'reason', or reference context for integrating parameters that do not share common dimensions, but which share a common location on the coarse shape. Recent physiological and behavioural studies in the macaque indicated that the area TEO, situated between V4 and the inferior temporal lobe (IT), plays a central role in visual discrimination, and that a large portion of its neurons respond selectively to textures (Fenstemaker 1986). TEO may represent then a stage in visual processing that mediates computations whose goal is to 'glue' together details in their proper spatial relationship. It is possible that TEO may represent a 'full stop' for texture and fine detail processing, while the information pertinent to form would be further processed in IT whose task would be to encode fine and coarse information as a coherent whole.

I suggest that the processing of shape and textures for perceptual categorization (recognition), follows serially the same route through the same 'stopovers' from the primary visual cortex through the prestriate and to the TEO similarly to the route suggested for the processing of colour. Evidence has been provided (Ungerleider and Mishkin 1984) for the fact that these visual modules, or stopovers, form a hierarchy which processes visual characteristics relevant and useful for object recognition. Within each of these modules the various types of information are processed in parallel submodules as if each level in the hierarchy contributes to the perceptual descriptions of an object's colour, shape, and texture. Texture seems to have as its final destination the area TEO while the processing of form seems to continue into IT. As both these areas no longer preserve a retinotopic organization, it is possible to hypothesize that damage to the corresponding areas in the right hemisphere in man, may cause specific impairments in the processing of visual texture and form respectively.

NOTES

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Informed consent was obtained from the patient and healthy volunteers used in this work in accordance with the Declaration of Helsinki.

[1] New imaging techniques, such as PET scan and MRI, began to give us new and more accurate ways to obtain functional localization in the intact brain (Fox et al. 1986).

[2] The Farnsworth–Munsell 100 Hue test consists of 85 small discs of different hues but

equal saturation or brightness. The discs are equally divided into trays: one forms a series from red to yellow, the second from yellow to blue-green, the third from blue-green to blue, and the fourth from blue to purple-red. A fixed coloured disc is placed at each end in all the trays, the two end discs are the same as the first and the last disc in a specific series. The movable discs belonging to each specific series are presented in random order, and the subject's task is to arrange them in each tray into a continuous colour series.

Each of the movable discs has a number on the back, and its error score is the sum of the differences between the number of the disc and the numbers on the adjacent discs. The score for all discs is plotted on a polar graph in which each axis line represents a particular coloured disc and the distance from the center is the error score for each disc.

[3] The Vistech Vision Contrast Test system (1984) consists of spatially modulated round patches of sinewave gratings presented on a test card, organized in five rows and nine columns (Ginsburg 1984). Each row contains, from left to right, one sample patch and eight test patches. The rows differ one from another in spatial frequency, which have the following values: 1.5, 3, 6, 12, and 18 c/degree. The patches on each row differ one from another in grating contrast, ranging from zero contrast to contrast above and below visual threshold in about 0.1 log unit steps. The patches at the far left end of each row are high contrast sample patches which exemplify the size bars on the corresponding row. The bars in the first eight patches on each row are oriented vertically, slanted slightly up to the left or slanted slightly up to the right. The last patch of each row is blank. The contrast sensitivity is defined by the minimum contrast that is required to distinguish that there is a bar pattern rather than a uniform screen. Contrast sensitivity is the reciprocal of this threshold. The luminance level is kept constant all the time, to assure that the measurement is of the subject's contrast, rather than luminance sensitivity. The mean luminance of the grating patches is 70 cd/m^2; and the mean luminance of the white matte mounting board is 100 cd/m^2.

The subject's task in this test is to read across each row, starting with the first row on the top of the card, and the first patch and determine whether the patch is oriented to the left, right, straight up or down, or is blank. The highest numbered patch that can be correctly read in each row of the card is the observer's contrast sensitivity for that spatial frequency.

The card is fixed on a chin rest so that the subject views the gratings at the same distance (65 cm) and the grating patches subtend 30.

[4] The Depth Perception Apparatus consists of two illuminated vertical rods that were viewed through a 2 1/2 inch slit. The rods were mounted on sliding tracks, and the experimenter arranged them parallel to each other, or 7 mm, 12 mm, 25 mm, or 30 mm in front or behind one another. The subject was asked to judge whether one rod was closer or farther than the other.

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Intelligent Systems Laboratory
College of Engineering and Department of Neurology
School of Medicine
Boston University
Boston, Massachusetts