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PERCEPTION AND ACTION IN 'VISUAL FORM AGNOSIA'

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SUMMARY

A single case study of a patient with 'visual form agnosia' is presented. A severe visual recognition deficit was accompanied by impairments in discriminating shape, reflectance, and orientation, although visual acuity and colour vision, along with tactile recognition and intelligence, were largely preserved. Neuropsychological and behavioural investigations have indicated that the patient is able to utilize visual pattern information surprisingly well for the control of hand movements during reaching, and can even read many whole words, despite being unable to make simple discriminative judgements of shape or orientation. She seems to have no awareness of shape primitives through Gestalt grouping by similarity, continuity or symmetry. It is proposed that many of these perceptual disorders might be the combined result of (1) a selective loss of the cortical elaboration of the magnocellular visual processing stream, and (2) a selective output disconnection from a central processor of visual boundaries and shape primitives in the occipital cortex.

INTRODUCTION

Benson and Greenberg (1969) described a syndrome which they named 'visual form agnosia'. Their patient (Mr S.) had severe object-recognition difficulties, which apparently could not be explained by serious sensory or intellectual impairment. He had poor copying ability, which would tend to put him into the category of apperceptive rather than associative agnosia (Lissauer, 1890). However, Efron (1969) showed that Mr S. had a more basic perceptual disability than would be expected within classical ideas of agnosia, in that he was unable to distinguish reliably between simple geometric shapes. This shape-perception deficit is implied in the introduction of the term 'form agnosia' by Benson and Greenberg, although Efron himself questioned the appropriateness of using the term 'agnosia'.

Other patients have been described in the literature with similar symptom pictures, the fullest accounts being of H.C. (Adler, 1944, 1950) and R.C. (Abadi *et al.*, 1981; Campion and Latto, 1985). Like Mr S., these 2 cases had suffered from anoxia and carbon monoxide poisoning (*see* review by Campion, 1987). More recently, Warrington (1985*a*, *b*) has reported 2 further patients (J.A.F., R.B.C.) who performed poorly on Efron's shape discrimination task, in spite of intact visual acuity and point localization. They were tested after a period of recovery from cortical blindness attributable to bilateral

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occipital infarctions, and would seem to fall into the same category as Mr S. Warrington (1985*b*) classified them as 'pseudoagnosic', along with other patients whose impaired object recognition could be attributed to primary sensory disorders.

Irrespective of terminology, it is generally agreed that these patients should be distinguished from those who have a visual recognition difficulty in the *absence* of impaired shape discrimination (e.g., the patients described by Warrington and James, 1988). This distinct and profound disorder of shape perception merits a name of its own to distinguish it from other causes of impaired object recognition. Both 'visual form agnosia' (Benson and Greenberg, 1969) and 'shape agnosia' (Humphreys and Riddoch, 1987*a*) indicate its specificity, whilst 'pseudoagnosia' does not; however there is force in Warrington's argument against the use of the word 'agnosia' in this context. It may be that a neutral term like 'dysmorphopsia' (impaired vision for shape) would ultimately be a suitable solution to the problem.

Following Efron's (1969) ideas, Warrington (1985*a*) and Humphreys and Riddoch (1987*b*) have argued that patients of this type have a disorder at a stage of perceptual processing where an initial 2-dimensional description of visual shapes is being constructed. Campion and Latto (1985) suggested more radically that a patchy ('peppered') array of small scotomata across the visual field could account for the disorder. We describe here a new case of visual form agnosia, who has recently undergone an intensive series of visual tests. These studies have uncovered a visual disorder of greater complexity than has been previously described.

CASE REPORT

D.F. was born in Scotland (in 1954) and received education in the UK and abroad up to college level, gaining a BA degree in business management. She had a private pilot's licence; and had worked in administrative posts and recently in freelance commercial translation. At the time of her accident, D.F. was aged 34 yrs and was living in northern Italy. She collapsed and lost consciousness while taking a shower at her home, due to carbon monoxide intoxication from a leak in a faulty propane gas water heater. She was admitted to hospital in deep coma with dilated pupils, and received urgent treatment with oxygen, dexamethasone and dextran infusion. She regained consciousness and was transferred after 2 days to the neurological clinic of the Ospedale Maggiore in Novara. On examination there, D.F. appeared blind, with loss of the eyelid response to menace; however, the pupillary light reflex persisted, and the fundi were normal. The cortical blindness began to fade after about 10 days, when it became clear that bright colours could be named; but D.F. continued to show severe difficulties with ocular fixation and pursuit. It was also apparent that she had poor memory, acalculia and disorientation in space and time. She had relatively preserved verbal skills and general knowledge, and no indication of neglect or sensory extinction. After 5 wks in hospital in Novara, D.F. returned to Scotland, where she stayed for 8 mos before returning once more to Italy.

CLINICAL INVESTIGATIONS

CT scans

At 11 days. Small low-density areas were seen on the right at the level of the internal capsule and around the body of the left lateral ventricle. No enhancement appeared following intravenous contrast.

At 9 wks. No clear abnormality was observed.

SPECT

At 4 wks. There was evidence of reduced cortical blood flow in the left posterior parietal and temporo-occipital regions, especially at the temporo-occipital junction (*see* fig. 1). There was also evidence of widespread hypoperfusion in the frontal area on both sides.

At 8 mos. Symmetrical hypoperfusion was then reported bilaterally in parieto-occipital regions, with no obvious abnormality in the striate cortex, or in the frontal or temporal lobes.

MRI

The spin-echo technique was used on both occasions of testing.

At 17 days. The lateral ventricles were of normal shape and dimensions, and the third and fourth ventricles lay in the midline, but there was evidence of damage at the level of the lentiform nucleus bilaterally and, less clearly, in temporo-occipital cortex on the left side.

At 13 mos. An altered signal was seen in the globus pallidus bilaterally and, very clearly, in the occipital region bilaterally. This was mainly on the lower aspects of the lateral occipital cortex and at the polar

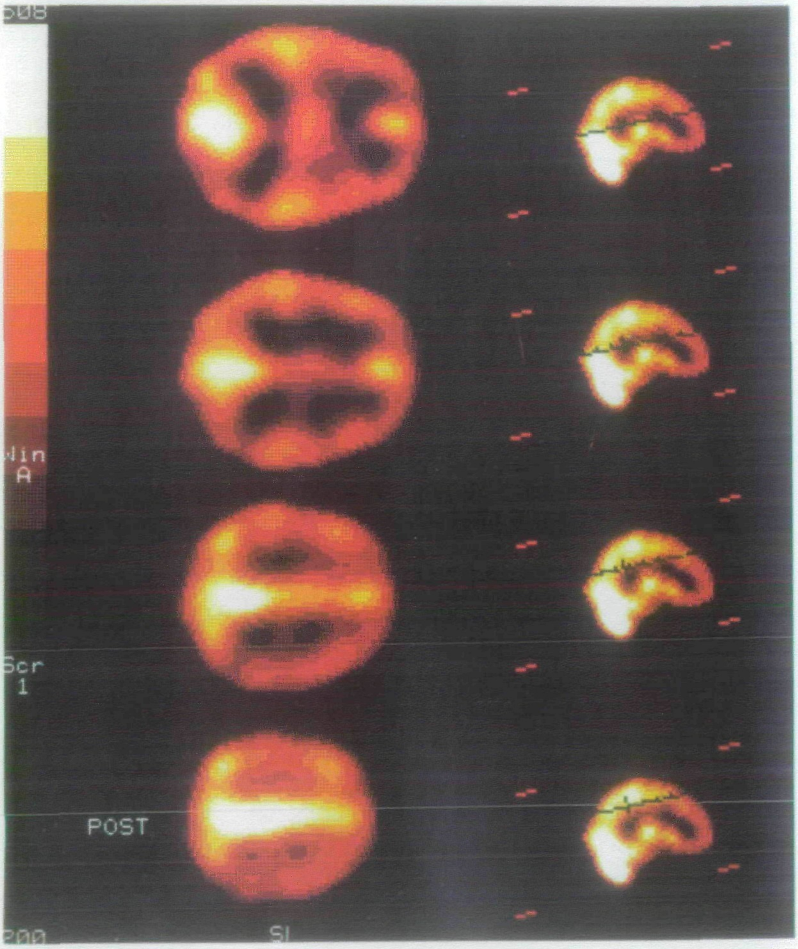

FIG. 1. SPECT images recorded at an early stage (1 mo). Four horizontal sections through the cortical lesion, presented with posterior to the left and with left/right reversed.

convexity (*see* fig. 2), extending into the parasagittal occipitoparietal region. Also a widening of the ventricles and sulci is apparent.

EEG

At 3 wks. Increased bilateral slow wave activity was apparent posteriorly.

At 10 wks. There was a low-amplitude EEG with a poor alpha rhythm, an excess of theta components in the temporal and occipital regions, and occasional small slow waves in both temporal regions, maximal and phase-reversing at the right midtemporal electrode. These features are consistent with diffuse anoxic damage.

Summary

In the early stages of the disease, neither CT nor MRI scans revealed the posterior cortical lesion which became clearly apparent in the later MRI (*see* fig. 2). However, there was a clear indication of this cortical pathology in both the early and the later SPECT scans.

NEUROPSYCHOLOGICAL TESTING

At Novara

Several tests were administered both during D.F.'s initial stay in hospital in Italy (at about 1 mo. postaccident) and then again approximately 12 mos after the accident.

Eisenson Battery. No evidence was found of aphasia (sentence and story comprehension) on either occasion, but clear evidence of a deficit on the agnosia subtests, with zero scores on visual recognition at 1 mo., despite comparatively good auditory (6/6) and tactile (4/6 left, 4/6 right hand) recognition. At 12 mos, hearing and touch were at 100% correct, but visual recognition remained impaired (common objects 4/6; drawings 0/4; shapes 1/4; small-size drawings 0/4; but colours 5/5).

Gelb/Goldstein tests. The coloured skeins were correctly pointed to only in the lower visual field, at 1 mo.; they were all indicated correctly at 12 mos. When presented with 20 objects together, D.F. was able to identify none without prompting at 1 mo.; at 12 mos she correctly identified 7/20. Objects indicated by the examiner were identified verbally at a level of only 4/10. In contrast, objects named by the examiner were pointed to accurately (17/17), though with hesitation. (A similar dissociation was noted informally between naming indicated letters and pointing to named letters. Presumably in the pointing task a search for the 'target' could proceed by comparing the stimuli on a simple feature or features, whereas correct performance in the naming version would require a more complete perceptual analysis.) On the Gelb/Goldstein verbal classification tests, performance was predominantly good.

Wechsler-Bellevue scale (Italian: form 1). D.F.'s verbal IQ was average at 1 mo. on most subtests (Information, Comprehension, Analogies and Vocabulary), but low on Arithmetic (scaled score of 2) and Digit Span (1). At 12 mos, scores on 2 subtests had risen to a high level (Comprehension 16 and Analogies 14) but Arithmetic (3) and Digit Span (4) remained low.

Other cognitive tests. Historical and geographical knowledge was patchy, though the latter had improved greatly at 12 mos. Severe acalculia was apparent at 1 mo. on the Milan test, though this showed substantial improvement at 12 mos.

Memory was tested by various means, and was found to be low for spatial span (Corsi block-tapping task, tested at 12 mos only: span of 2), Wechsler Memory Scale difficult paired associates (score of 0 on both test occasions), verbal free recall (no recall at 1 mo.; impaired primacy at 12 mos), and story recall (0 score at 1 mo.).

In De Renzi's modification of the Weigl sorting test (administered at 12 mos only) D.F. could not produce any self-initiated classification of the blocks. When the examiner sorted them in different ways, D.F. correctly identified some sorting criteria visually (colour, and size after long reflection) but not others (shape, thickness or suit).

At St Andrews

The tests began 3 mos after the accident.

Object recognition. A severe disorder of object recognition was confirmed, with several errors being made with everyday items (e.g., a cup misidentified as an ashtray, a fork as a knife). Some objects could

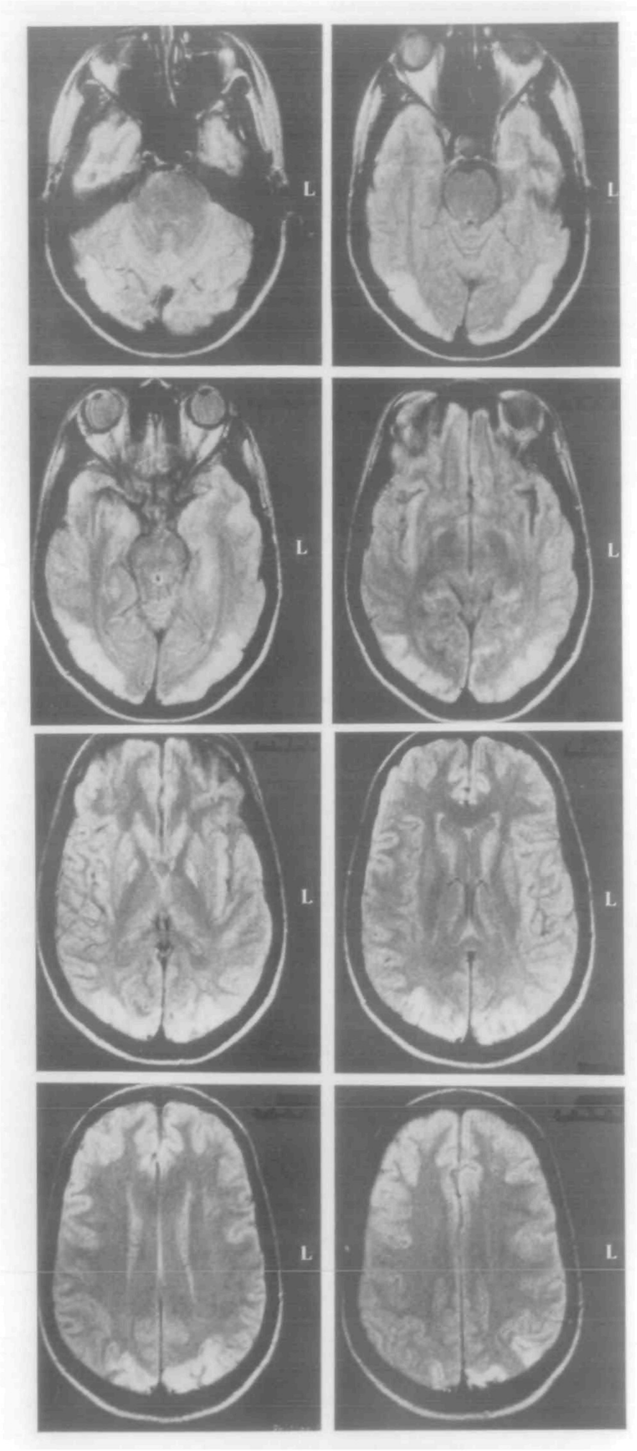

FIG. 2. Magnetic resonance images recorded at 13 mos. Horizontal sections through the cortical lesion, spaced 9 mm apart, are shown (left/right reversed).

not be named but could be partially described (e.g., a screwdriver as 'long, black, thin', and a pair of scissors as 'long, thin, silver'). D.F. was able to make intelligent guesses on the basis of such features, but this tended to be a slow process. In all cases the objects were readily identified tactually.

Recognition of drawings. Standard drawings of common objects (Snodgrass and Vanderwart, 1980) projected onto a screen could not be identified at all. Attempts to copy drawings of a simple house and of a Necker cube produced impoverished copies consisting of a few unconnected lines. The difficulty in recognizing line drawings was apparent at 4 mos even in a multiple-choice task (the Peabody Picture Vocabulary Test, which requires pointing to 1 of 4 pictures in response to a word). Performance was equivalent to a mental age of only 2 yrs 2 mos. By 8.5 mos postaccident, a comparable test (the short form of the British Picture Vocabulary Scale) gave an improvement up to a mental age score of 6 yrs 5 mos, with much hesitation and 'educated guessing'. Even this improved score is far below the level expected from the above-average WAIS vocabulary scaled score of 11.

Intelligence. WAIS verbal IQ tests were confirmed at 3 mos to be at an average level (including digit span, scaled score of 8: possibly the use of the English language permitted an improvement here), except for Arithmetic. Performance subtests were found to be impossible. Memory was confirmed still to be impaired on the Wechsler Memory Scale, with the delayed tests of logical memory and the difficult paired associates being severely affected.

Letter recognition. Singly-presented letters of the alphabet could not be recognized correctly (1 out of 10 correct) and although it became apparent 3 mos after the accident that D.F. had recovered some word-reading ability, she has remained unable to identify letters. This failure has been found in a variety of tests, including oddity, which would exclude a naming difficulty.

Reading. Single-word reading was tested 6 mos after the accident using the Word Reading Test of the British Ability Scales, yielding a score of 48 out of 90, i.e., a reading age of 7 yrs 6 mos. Simple words like 'up', 'on', 'go', and 'he' were misread, while complex words like 'transparent', 'environment', and 'curiosity' were read correctly. Errors of misidentification were usually visual (e.g., 'tentacle' as 'rectangle', 'dough' as 'enough', and 'lethal' as 'lethargic'). The National Word Reading Test elicited 10 correct responses out of 50, giving a predicted WAIS IQ of 95; she correctly read irregular words such as 'gauche' and 'catacomb'.

Nonwords, closely matched for orthographic similarity to real words, were poorly read (4 correct out of 24 that were homophones of English words, and 0 out of 24 that were not homophones); normal readers of similar reading age (7–6) would read 63% (15) and 41% (10), respectively. In a series of tests (to be reported in more detail elsewhere), no sign has been found of differences between concrete and abstract words, nor any evidence of semantic errors. On the Schonell Spelling Test, 15 out of 50 was scored: a spelling age of 6–5. At 8 mos postaccident, some improvement on the British Ability Scales was apparent (73 correct: reading age 9 yrs 7 mos), although there was still impairment, notably on 2 and 3 letter words.

Everyday behaviour. It was noted that D.F. had no ability to recognize the faces of people familiar to her throughout the time of our testing, but she is adept at using other cues, including context and voice. She has indeed progressively improved her ability to cope with everyday activities (including shopping and cooking) over the 3 yrs that have now elapsed since the accident, though little sign of strictly visual improvement has been apparent in our tests. She has difficulty describing her visual experience, only saying that objects tend to appear 'blurred' and that separate elements 'run into each other'; words, however, are not seen as blurred, but rather as lacking structure. Although she shows no signs of aphasia, D.F. has a lowered verbal fluency and spontaneity in her behaviour.

SENSORY TESTS

Visual fields

An initial attempt in Italy (at 3 wks postaccident) to carry out perimetry was unsuccessful, since D.F. was unable to see both the fixation and the target stimuli simultaneously. At 8 mos, a preliminary assessment was achieved in St Andrews, using static 500 ms presentations of a 0.5° LED; this revealed constricted fields, particularly in the upper right quadrant (from 30° outwards). Reliability was questionable due to a tendency for responses to be inconsistent.

Detection of targets defined by luminance

Achromatic displays were created on a video graphics monitor, with square patches (4 mm) of differing intensities placed as targets on a uniform grey background (2.4 cd/m^2). D.F. was asked to point to any patch she could see. The indicated patch was then removed from the screen and she was asked to find a further patch. At all contrast levels, even with Michelson contrast as low as ±0.02, D.F. detected the patches quickly and pointed accurately to each of them.

Brightness judgements

For this task the same stimuli were used, but D.F. was asked to point to a patch and then to describe it as brighter or darker than the background grey (2.4 cd/m^2). These judgements of brightness direction were imperfect (8 or 9 correct from 10 trials) at virtually all contrast levels (target brightness levels ranged from 0.1 to 14.4 cd/m^2), and performance was highly inaccurate for a shade slightly darker than the surround (1.5 cd/m^2: contrast = 0.23). These were consistently (80%) mislabelled as 'brighter' than the surround, though always easily seen as darker by normal observers.

Eye movements

Recordings using an A.C.S. infrared sensing device showed that D.F. was able on instruction to fixate and move her eyes to and fro between 2 LEDs (15° apart, with flash durations of 0.2 or 0.3 s and an equal interflash interval), in both the horizontal and vertical planes. The saccades were made without hesitation and were accurate within the 3° amplitude resolution of the system used, showing no abnormal tendency for overshooting or for correction saccades. She moved her eyes along a piece of text when asked to read it, making horizontal saccades and fixation pauses in the normal fashion. She was also able to make tracking eye movements around the perimeter of an outline rectangle (10° × 15°) or circle (15° diameter), although the recording technique was not accurate enough to enable us to claim that this demonstrated 'implicit' access to the shape being traced.

DETAILED SENSORY INVESTIGATIONS

Visual acuity

Clinical tests of acuity could not be used because of D.F.'s inability to name letters and to report consistently the orientation of visual stimuli (*see below*). Informally it was observed that D.F. could distinguish between a grey patch and a fine dot pattern (26 dots per cm, equivalent to a resolution of 1.7 min arc).

Psychophysical detection thresholds were determined between 5 and 6 mos postaccident, using sinusoidal gratings with spatial frequencies in the range 0.625 cpd – 20 cpd. They were presented on a P31-phosphor oscilloscope screen at 35 cd/m^2, contrast being ramped on and off as a gaussian window of time (1/e = 250 ms) demarcated by a warning tone. Testing was self-paced and a yes/no (i.e., grating or no grating) one-interval procedure followed. The patterns spanned 4° of visual angle at a 114 cm viewing distance under binocular viewing conditions with head restraint, and were presented at either vertical, horizontal, or 45° orientation. A double randomly interleaved staircase method with a 50/50 protocol was used, and contrast thresholds were calculated as the mean of 5 determinations, each of which were the mean of 4 reversals on each of the 2 staircases.

As fig. 3 shows, D.F. showed a greatly impaired level of detection (by almost 1 log unit) at the lower spatial frequencies used, but appeared to detect the higher frequency gratings at normal levels. It should be noted that she tended to show perseverative responding in some threshold determinations, particularly towards the end of a test session; although these suspect determinations were repeated, the data for detecting horizontal and oblique gratings remained incomplete at 20 cpd.

Pattern evoked potentials

The P100 visual evoked potential was recorded at 15 wks from a transverse chain of occipital electrodes (each referenced to a midfrontal site) in response to chequerboard reversal (32° total horizontal extent, 50 min arc checks, 95% contrast ratio, and reversal rate 1 Hz). The P100 component was consistently prominent and bilaterally symmetric; its mean latency (108 ms) was well within the normal range, for both binocular and monocular stimulation, as was its amplitude. This demonstrates a substantial recovery

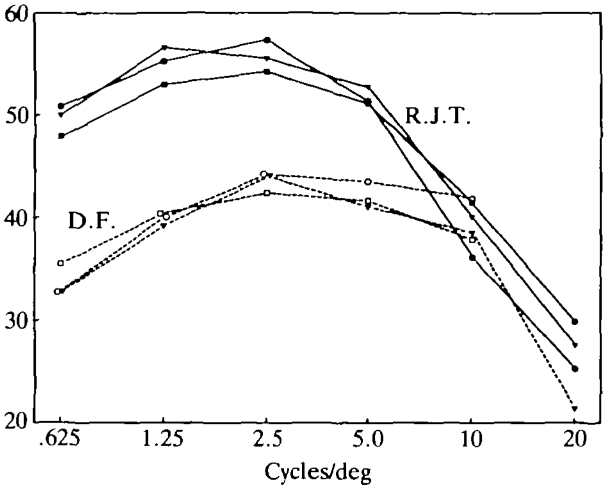

FIG. 3. Contrast sensitivity function for D.F. Sensitivity is plotted on the ordinate as dB attenuation from a Michelson contrast of 0.7. Squares denote mean thresholds using horizontal gratings, triangles, vertical gratings, and circles oblique gratings. D.F.'s data are compared with those for a matched normal control subject (R.J.T.).

from an early test carried out at Novara during week 1, when both an increased latency and a decreased amplitude had been apparent.

Stereoscopic depth

A series of Julesz (1971) stereograms were presented as anaglyphs for viewing through red/green filters. D.F. generally succeeded in identifying the 3-D direction of the stereoscopic depth (16/20 correct) when the dot patterns were presented at reading distance, although she was never able to recognize the shape defined by the binocular disparity. However, she failed at both direction (12/20) and shape (12/20) identification when the patterns were projected on a screen at a viewing distance of 3 m. It is possible that in these latter conditions the binocular disparity used fell below her threshold for depth perception: it was found using the Frisby stereotest that her stereoacuity was abnormally high (110 s arc as opposed to the usual ~20 s arc).

Colour and lightness discrimination

D.F. was successful in identifying most of the colours of the spots comprising the Ishihara pseudoisochromatic plates, but was never able to perceive the digit (or trace a route) that the colours depicted. The Farnsworth-Munsell 100-hue test of hue discrimination yielded scores that are outside the normal range, but which nonetheless were far better than her scores when tested for lightness (reflectance) discrimination with the equivalent Munsell achromatic (grey) series (*see* fig. 4). This superiority for hue over lightness discrimination was confirmed at 8 mos postaccident by use of the 'oddity' tests devised by Heywood *et al.* (1987), in which triplets of 7.5 cm×5 cm Munsell hue samples, or shades of grey, were presented to the subject for simultaneous comparison. For each task (2 hue sets and the grey set), there were 110 test trials. D.F. performed at a much lower level with the achromatic stimuli than with stimuli differing in hue only (Milner and Heywood, 1989). There is a notable dissociation between these results and the converse picture found in an achromatopsic patient (C.B.) tested by Heywood *et al.* (1987).

A dissociation between chromatic and achromatic channels was also strikingly apparent in a test where (9 mos postaccident) D.F. was presented with triplets of the letter 'o' (lower case typeface, 12 point), with 1 'o' in each triplet filled in. When asked to judge the 'odd' member in each triplet, D.F.'s performance was 100% correct (20/20) when the 'o's were printed and filled with red ink, but was no better than chance (9/20) when they were printed and filled with black ink (chance would be 33% correct). Repeating the same task with the 3 'o's embedded in a triplet of 4-letter words (e.g., 'lone lone lone') did not affect

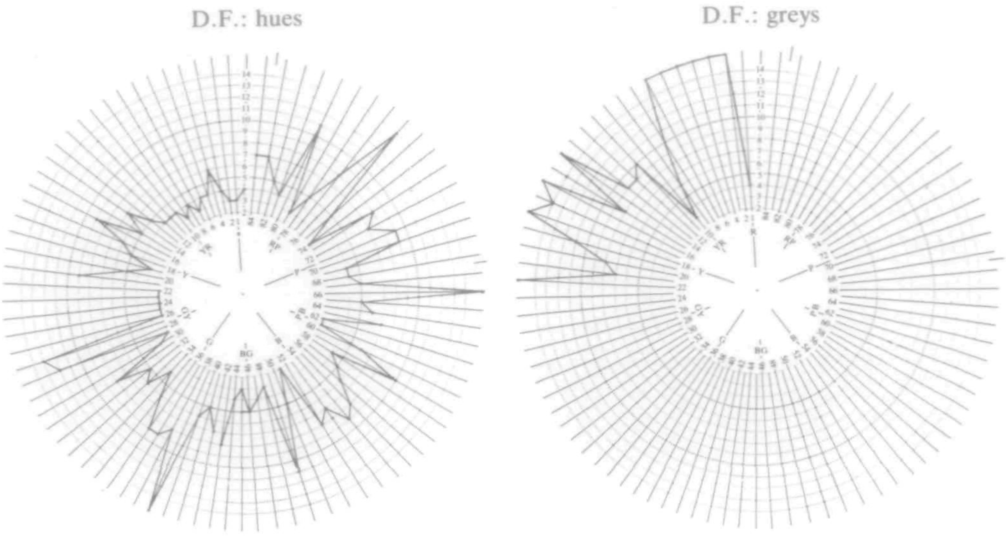

FIG. 4. The Farnsworth-Munsell tests. D.F.'s rank-ordering of sets of Munsell samples, the data being scored and presented in the standard fashion. Hue discrimination, which is relatively preserved, is contrasted with lightness discrimination, which is severely impaired.

D.F.'s identification performance (20/20 with red ink, 8/20 with black ink), even though she was unable to read the word triplets with 100% accuracy. Thus D.F. was unable to detect filled circles by use of achromatic cues, but could when additional chromatic cues were present. In a replication where triplets of circles were displayed on the screen of a graphics computer (Pluto 24i), a similar trend was observed, although it was less clear-cut: judgements were 90% correct with red lettering (37/41), and 66% with black (27/41). The difference remained significant ($\chi^2 = 5.77$, $P < 0.02$).

MOVEMENT PERCEPTION

D.F. reports great difficulty in estimating the speed of vehicles, making it impossible for her to cross a road. In initial laboratory tests it was found that she could accurately report the direction of movement of an achromatic random-dot shape against a static random-dot background, although she could not identify the shape (square or triangle) that moved. On the other hand she had an abnormality in the perception of apparent movement, such that 3 successively illuminated LEDs spaced 1° apart (flash duration 0.1 s) were seen as moving on only 75% of occasions; in these conditions normal subjects reliably saw compelling phi motion. When she did see movement, its direction was correctly identified. In a test where the 3 lights were cycled repeatedly (123123123 . . .) with a greater separation (20°), she either failed to see motion (reporting simultaneous flashes) or saw it inappropriately (e.g., as 'moving in to the centre', rather than rightward).

In more quantitative tests implemented on a Silicon Graphics IRIS 3130 computer, we used a procedure devised by Newsome and Paré (1988) in which the coherence of a moving dot pattern could be varied systematically. On each frame of an achromatic VDU screen (frame rate 50 Hz, noninterlaced) 100 dots were displayed: either 10, 25, 50 or 100% of these dots would then move in a coherent manner (up, down, left, or right), leaving the remainder (if any) to act as distractors appearing in random positions on each frame. The coherently-moving dots were displaced at a predetermined speed of 1 pixel per frame, and the dots were 5×5 pixels square (0.3° at the 80 cm viewing distance). The motion displays had a duration of 1 s and as a warning signal, the VDU flashed white 0.5 s before each display. As shown in fig. 5, at 9 mos postaccident D.F. identified the movement direction perfectly when all 100 dots moved in concert;

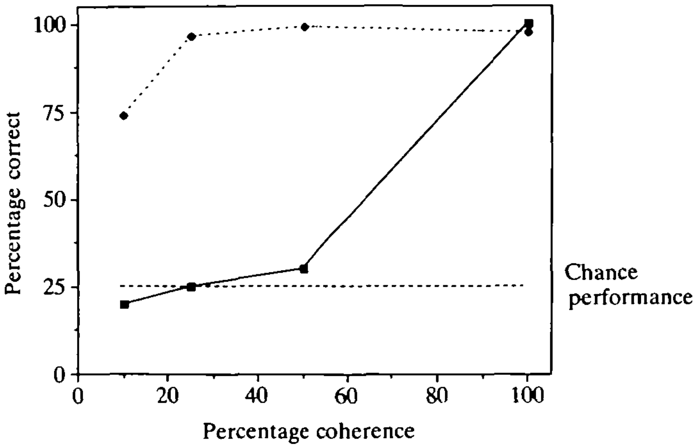

FIG. 5. Perception of motion direction. Performance in identifying the net direction of movement in a dot display in which a proportion of the elements move 'coherently' in a given direction, the remainder appearing at random locations in each frame. Squares = D.F.; diamonds = 5 controls.

however, her success rate fell to chance at 50% coherence and below. Her performance remained severely impaired relative to 5 age-matched normal controls, who performed the task almost perfectly except at the lowest coherence level.

D.F. was also tested (8 mos postaccident) with videotape presentations of 'biological motion' (Johansson, 1973). The tape was prepared by first recording a person walking on a treadmill, and then frame-grabbing each of 24 successive frames constituting one step cycle and recording the x, y positions of 13 points on the body surface (head, ankles, knees, hips, shoulders, elbows and wrists). This procedure was repeated for front, left, right and back views. Using this database, walking sequences for the 4 views were generated as computer-animated dot displays (white dots on a black background). The sequences were displayed for 1 s starting at a random point in the walking cycle. D.F. could not distinguish these displays from moving jumbled arrays, created by displacing each dot in random directions at the start of the sequence by 30% of the head-to-toe height (21 correct out of 32: chance = 16/32). With a pattern exhibiting net translation as well as internal (limb) movement, however, she perceived the translation direction perfectly (16 out of 16) while remaining at chance on judgements of internal body form (normal vs jumbled, 7 out of 16).

SHAPE AND PATTERN PERCEPTION

Shape discrimination

Following Efron (1969), we used squares and rectangles matched for surface area: each stimulus was black with an area of 25 cm^2, mounted on a 21 cm×30 cm white background. As shown in fig. 6, naming performance using squares or rectangles each presented alone (in 20-trial blocks consisting of equal numbers of square and rectangle) only exceeded chance at an aspect ratio of 0.5 or less. Same/different matching of pairs of shapes (a block of trials consisted of 5 trials with 2 squares, 5 with 2 identical rectangles and 10 with 1 square and 1 rectangle) exceeded chance only at the easiest aspect ratio (0.17). Even the highest aspect ratio of 0.8 is easy for age-matched control subjects to discriminate from a square. These tests were done at 5 mos.

At a later stage (15 mos postaccident) the same/different matching task was repeated using red shapes mounted on a green background, to test whether D.F.'s relatively preserved colour capacities could help her to perceive form. In the event, her scores did not improve, as shown in fig. 6. Most recently, at 2 yrs postaccident, D.F.'s performance with black shapes still remained virtually unchanged (not shown in fig. 6). Performance was poorer still (a mean of 67% correct across the 3 easiest rectangles) when the shapes

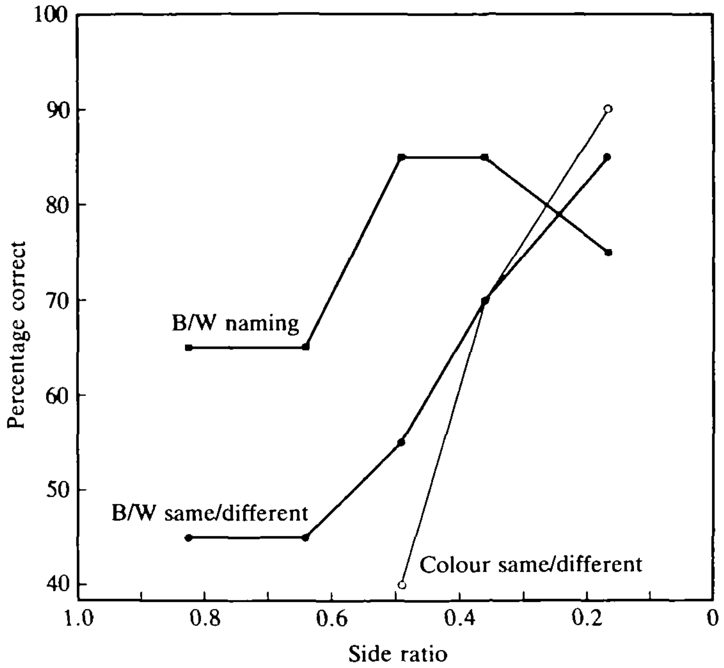

FIG. 6. Discrimination of shape: the Efron task. Percentage correct performance under 3 different test conditions: solid squares = naming of a single black shape (square or rectangle); solid circles = same/different judgements of 2 adjacent black shapes; open circles = same/different judgements of 2 adjacent coloured shapes. All data points are based on at least 20 trials.

consisted of square and rectangular patches of random dots (Letratone LT98 on white paper) moving over an identical random dot background.

Similar difficulties were apparent in matching-to-sample tests using 4 black filled shapes (either meaningful silhouettes of animals, or using the geometrical figures rectangle, trapezium, parallelogram and diamond; *see* fig. 7F); performance was at chance (25%). Consequently, there are impairments of shape discrimination where the shape is defined by luminance, colour or motion, as well as by binocular disparity, as noted earlier.

Shape detection

In an adaptation of the test devised by Warrington and Taylor (1973), simple figures (+, O, X) were presented either at 100% contrast against its background or noise-masked by reversing the contrast of 25% of the pixels (i.e., 75%/25% contrast, or vice versa). Examples are given in fig. 7A. D.F. reported the figure's presence (though not its identity) on all of the 100% contrast trials, but was at chance on the masked trials (12 correct out of 24).

Symmetry perception

Perception of the symmetry or asymmetry of abstract shapes was tested at 8 mos using figures composed of 3 or 4 geometric elements combined in vertical stacks which were then divided at the vertical midline and recombined in different ways (*see* fig. 7B). With stimuli subtending 10°×5° at a viewing distance of 40 cm, performance was at chance (8 out of 16). The test was then repeated using smaller patterns (3.5° in height), either black or red, on white backgrounds. Black patterns gave chance (50%) performance (11/24 and 6/12), while red ones gave a temporary hint of improvement (19/24 but then 6/12).

Circular dot arrays with an 8-fold pattern of radial symmetry (*see* fig. 7C) were also used: symmetry

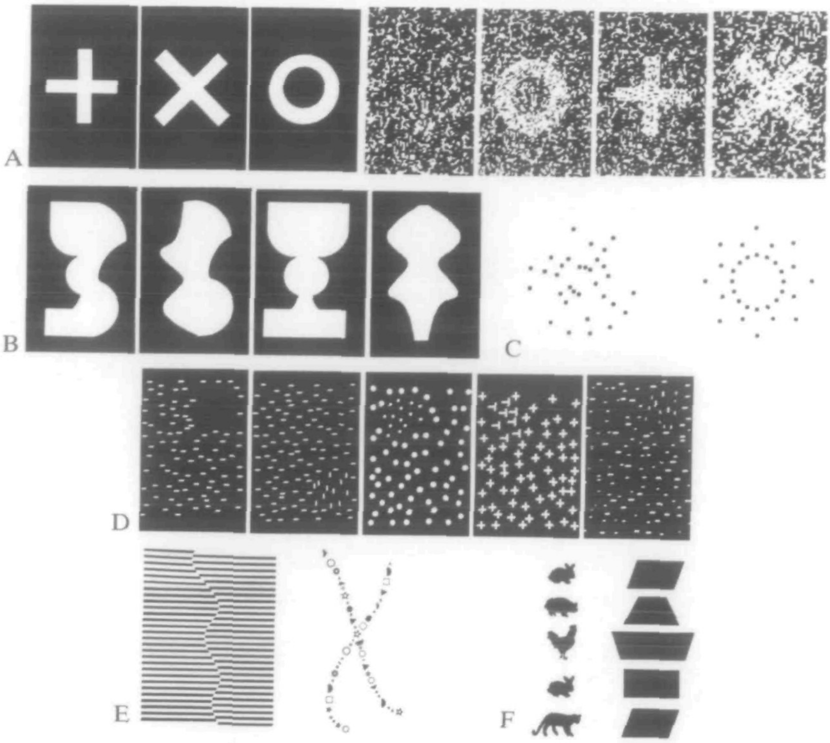

FIG. 7. Visual stimuli used for various perceptual tests. A, shape detection task. From left to right: target shapes at 100% contrast, and shapes (with a no-shape control) in which the direction of contrast of 25% of the pixels has been randomly complemented. Adapted from Warrington and Taylor (1973). B, C, stimuli for assessing symmetry perception. B, symmetry about a vertical axis. C, asymmetric pattern and radial pattern with eight-fold symmetry. D, stimuli for assessing texture perception. From left to right: texture differences defined by intensity, orientation, size, texton differences, and orientation with size as an irrelevant cue. E, stimuli used to test perception of continuity. Wavy lines defined by the continuity of vernier offset of grating elements (*left*) or pattern elements (*right*). F, shapes used in matching to sample tasks. *Left*: meaningful silhouettes (animals). *Right*: geometric shapes.

judgements were at chance (6/10 correct), as were judgements of attractiveness (more flower-like), giving no evidence for any 'implicit' appreciation of symmetry (6/10 correct).

Line orientation

In tests given at 4 mos postaccident, square-wave gratings of different spatial frequencies were presented at high contrast with either a horizontal or vertical orientation. D.F. scored close to chance both with the use of a coarse (0.14 cycle/deg) grating (7/16 correct) and with a 1.1 cycles/deg grating (5/12). Occasionally following a verbal error a check was made that she was using the words correctly, by asking her to signal the judgement by orienting her arm; this action always corresponded perfectly with the verbal report.

Since she was able to use the 'oddity' principle to demonstrate relatively good hue discrimination (Milner and Heywood, 1989), D.F. was given a similar test of orientation discrimination at 9 mos. On each trial 3 circles (4.5 cm diameter) were presented on the table, each containing an achromatic high-contrast square wave grating (0.5 cm bar width), 2 at the same and 1 at a different orientation. The orientation of the stimuli varied between 10° and 90°, and the difference between them on a given trial was either 45, 67.5, or 90°; 32 trials were given. Success at indicating the odd stimulus was significantly above-chance at 90°

(70% correct), but fell to chance for smaller angular differences (37% correct: chance = 33%).

D.F.'s ability to judge the orientation of a large open slot was also severely impaired (*see below*).

Dot numerosity

At 3 mos D.F. was asked to state the number of high-contrast spots presented on a sheet of paper. When only 1 was presented, performance was perfect, but with 2 it fell to 33% correct, and with 3–5 spots it fell to 0%. Although there was a significant correlation across the 25 trials ($r = +0.68$, $P < 0.01$) between the number presented and the number reported, D.F. never reported seeing more than 3. This failure held for arrays both of large (10 mm diameter) and of small dots (1 mm). The test was repeated at 22 mos postaccident, using 4 mm dots (either black or red) placed in a cluster spanning up to 10 cm on A4 sheets. Performance was now almost perfect for 0–3 dots, whether tested with black (19/20 correct) or with red dots (20/20), but between 4 and 6 dots, scores fell to a mean of 10% correct (3/30) for both colours. These difficulties cannot be attributed to an impairment in counting per se since D.F. was faultless at counting up to 6 auditory taps made out of sight at an irregular rate (0.2–1.0 Hz).

Texture differences

A number of photographs of 'random' patterns were made, some of which contained an area (approximately one-eighth of the total) where there was a change in the texture. The task was to say whether there was an area that was different from the rest of the photograph, and then to point to the area and describe how it differed. Unlimited time was given for each presentation. Texture differences included (1) an area of missing texture elements (therefore constituting a luminance difference), (2) a 90° orientation change, (3) a 2-fold linear size change, (4) a micropattern or texton difference (Julesz, 1981), and (5) an orientation difference where size was made an irrelevant and distracting cue. Examples are given in fig. 7D. Stimuli were presented as 15 cm high-contrast black/white prints or as back-lit 35 mm slides at a viewing distance of 30 cm. A follow-up test was given (14 mos postaccident) using video displays of equivalent patterns that were black on white, white on black, red on black, and red on white.

D.F. could not discriminate homogeneous textures from textures containing a distinct patch with any of the 5 available cues. This was true with 2-choice discrimination and with a single area to find in one stimulus. The same failure was observed on 2 occasions separated by 6 mos. Furthermore, the size and colour of the stimuli presented did not make any difference to performance. D.F. would often detect an area that appeared to her different in an inappropriate part of the display and would often describe the difference in texture wrongly, for example, claiming an orientation difference where a size difference or texture absence was displayed. (It may be noted that D.F.'s failure to perceive form from colour in the Ishihara plates may have been secondary to a segmentation deficit of the same kind as that apparent with these other textural qualities.)

Gestalt perception

As well as being unable to perceive Gestalt grouping by similarity in the texture stimuli just described, D.F. could not perceive grouping by contiguity; for example, she saw large letters composed of small (different) letters only as unstructured sets of small letters (usually themselves misidentified). Similarly, strings composed of nonverbal symbols (stars, dots, etc.) were never seen as strings, although individual elements could often be identified (fig. 7E, right).

Vernier offset and grating continuity

D.F. could not identify (verbally or by pointing) a vernier offset in a single line (0.7 mm wide) even at a maximum displacement of 0.35 mm. She was presented with a related task in which a break in parallel lines traced a curved contour (e.g., fig. 7E, left): this could be seen as testing also whether there was any perception of grouping by continuity. Whereas D.F. noted the presence of a break correctly in 5 out of 6 presentations, she was unable to point to or trace the correct line of breakage, in one instance tracking a line almost 90° to the vernier break. In a retest (13 mos postaccident) with similar stimuli created on a Pluto 24i graphics system in black on white, red on white or red on green, D.F. could not correctly identify the position or continuity of line breaks using either intensity or chromatic differences, or both.

Topographic imagery

D.F. was asked a number of questions that required her to visualize a particular area—her mother's kitchen and living room, and 1 of the 3 main streets in St Andrews (South Street). For the home rooms she was asked to say where items (e.g., TV, kettle, coffee) were kept. For the street she was asked what could be seen if looking East from a stated standpoint. D.F. gave responses quickly and confidently to these questions, and her accuracy was independently validated.

VISUOMOTOR TESTS OF ORIENTATION DISCRIMINATION

Despite D.F.'s poor performance on shape recognition tasks, she had little difficulty in everyday activity such as opening doors, shaking hands, walking around furniture, and eating meals. It was further observed in informal testing that she could accurately reach out and grasp a pencil orientated at different angles. These observations suggested that D.F. might have some residual visual contour and edge information available to her for the visuomotor guidance of action, even though it was not accessible to her perceptual awareness. In pursuing this possibility, we used a modified version of the technique devised by Perenin *et al.* (1979), in which the subject is required to reach out and place the hand into a rectangular slot held at different orientations.

Experiment 1

As shown in fig. 8, D.F. was presented with a 12.5 cm×3.8 cm slot cut into a white disc, which on different trials was orientated at 0° (vertical), 45°, 90°, or 135°. Raising the hand from the resting platform started a digital clock, which was video-recorded along with the movement of the hand towards and into the slot, by means of 2 cameras, 1 overhead and 1 at the side. Measurements of the horizontal and vertical extents of the hand across the palm were made from still frames of a split-screen videotape at 100 ms intervals, and hand orientation was calculated at each point of the trajectory. Both hands were tested for 8 trials at each orientation, at 5.5 mos postaccident. As shown in fig. 9, D.F. correctly matched her hand orientation to that of the slot during the course of the movement, well in advance of contacting the target (which was reached at about 750 ms). Yet verbal judgements in the absence of reaching, on an equivalent series of slot presentations, were made at only 55% correct (chance = 25%).

Experiment 2

In a second test session 1 wk later, reaching movements and orientation judgements were again both tested. For the former, an 8 cm×8 cm card was held in the right or left hand and 'posted' into the slot on each trial; this allowed more accurate measurements to be made from the videotapes. The judgements

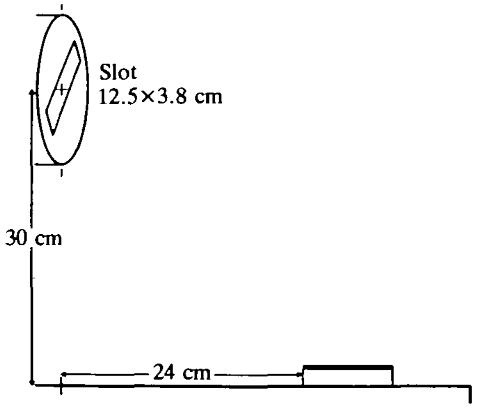

FIG. 8. Reaching task. The subject was asked to move the hand towards and into the slot, starting from the resting plate (holding down a microswitch) on each trial.

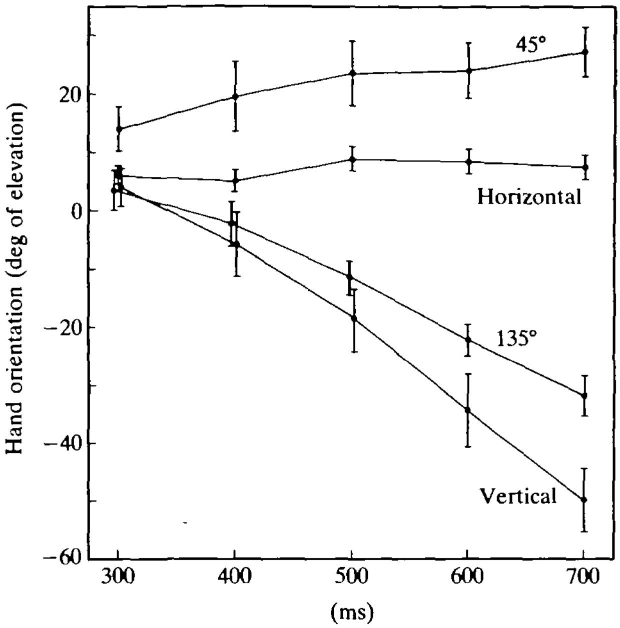

FIG. 9. Visuomotor coordination: Experiment 1. Hand inclination (averaged across left and right hands) during reaching towards the orientated slot. The error bars show the SEM.

of orientation were elicited nonverbally, instead of being spoken as before; it was hoped that this would reduce ambiguity, particularly in relation to the 45°/135° judgements. The task was to match the orientation of the target slot on a series of trials by manually rotating a second slot cut in a disc that was mounted inside a 20 cm × 20 cm box and had to be perceived tactually. The results for reaching are shown in fig. 10, which clearly demonstrates accurate orientation of the card during the reaching trajectory, well ahead of arrival at the slot (which occurred at about 930 ms). In contrast, as shown in fig. 11, D.F.'s manual matching of the slot's orientation was no better than chance ($P > 0.05$ for all 4 orientations tested). These judgemental data are presented as polar diagrams together with those of 2 normal age-matched subjects who both show a high level of matching accuracy.

Experiment 3

Fourteen mos postaccident (8 mos after Experiments 1 and 2), D.F. was retested on the hand-reaching task, first using the previous white disc and secondly using a grey disc (expected to reduce reaching accuracy by reducing the luminance contrast between the disc and the slot). Six trials were given at each orientation, using only the preferred right hand. Manual matching judgements were again tested, but now the subject adjusted a rotatable slot which was placed in full view in front of her on the table. Matching was tested separately for the white disc, the grey disc, and also with a green disc (as a possible way to improve matching performance, given D.F.'s spared colour discrimination ability). Performance in this visual matching task was now slightly better than chance ($P < 0.01$) with the white disc (either because of some recovery or because no cross-modal or tactile-discrimination element was now present in the task). However, it reverted to chance ($P > 0.05$) with both the grey and the green discs, presumably because in both cases there was a lower luminance contrast, and no benefit to be gained from a chromatic difference.

In contrast, hand orientation during reaching continued to anticipate the target orientation accurately for both target discs. Fig. 12 shows the judgemental settings for the grey disc, together with the corresponding final orientation of the hand in the reaching task (at the instant the hand arrived at the target). This method of analysis allows a quantitative comparison of performance accuracy in the 2 tasks: SDs are given

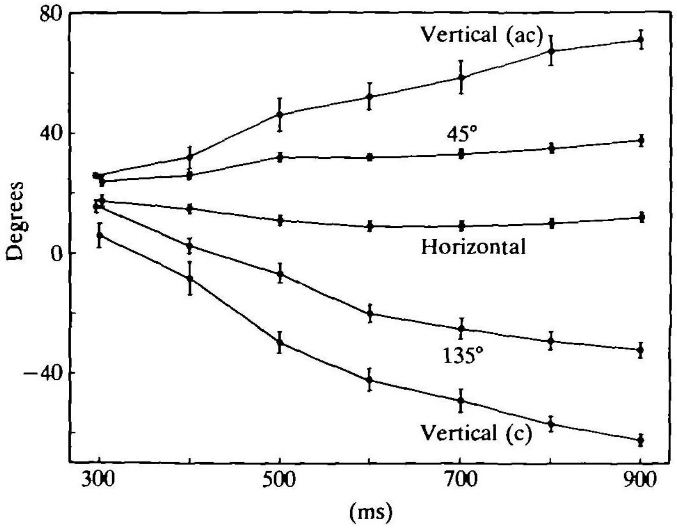

FIG. 10. Visuomotor coordination: Experiment 2. The inclination of a card as it was moved towards the slot to be 'posted'. The data are again averaged between left and right hand tests. Occasions when D.F. rotated the hand clockwise (c) and anticlockwise (ac) whilst approaching the vertical slot are presented separately.

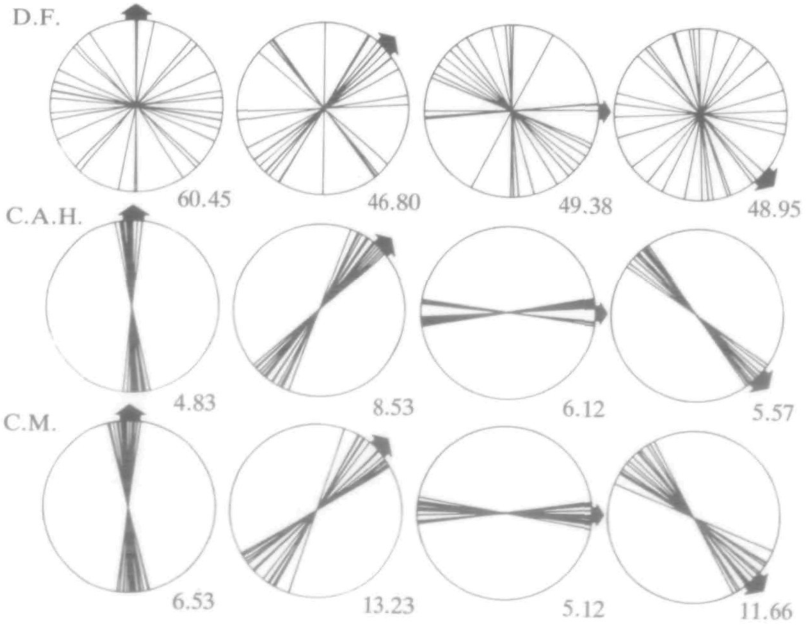

FIG. 11. Orientation judgements: Experiment 2. Polar diagrams representing the manual settings made to match a visible slot orientated at 0°, 45°, 90° or 135°, shown respectively from left to right. The data for D.F. are contrasted with those of 2 normal controls matched for age. SDs of the settings are given numerically; in calculating these it was assumed that all responses were within 90° of the true orientation.

numerically below the polar diagrams. Variance ratios between the corresponding tasks were in fact of a similar magnitude for the 2 discs, and were highly significant, vastly beyond the 0.001 level at all orientations except the vertical ($P < 0.01$ for both discs). Thus it is clear that with both discs there is a high level of accuracy in orienting the hand during reaching towards the slot, contrasting markedly with a low judgemental accuracy in the matching task.

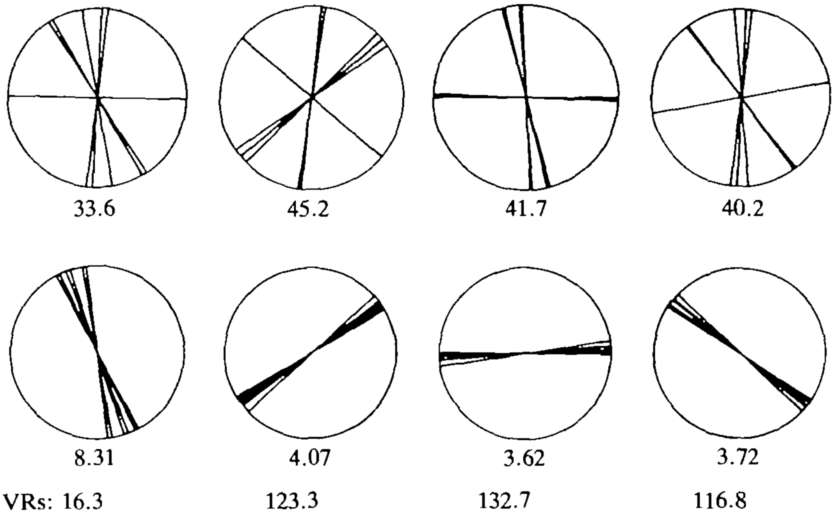

FIG. 12. Accuracy of reaching and judgement: Experiment 3. These polar diagrams compare the accuracy of judgements made manually by rotating a visible matching slot (*top*) against terminal hand orientation in reaching (*bottom*). The 4 target orientations used are shown across the figure (vertical, 45°, horizontal, and 135°, respectively). Data are shown for the grey target disc. Only the right hand was used throughout Experiment 3. VRs = Variance ratios.

Summary

These 3 experiments document a well-preserved capacity to coordinate motor behaviour in direct relation to the orientation of a visually presented object. Despite this, they also show that D.F. was unable to make accurate perceptual judgements of slot orientation, whether expressed as verbal descriptions or as manual matches with either tactile or visual feedback. The dissociation thus appears not to be between the use of verbal versus manual response channels; instead it seems to be between conscious perceptual judgements and the more 'automatic' visuomotor guidance of a skilled action.

DISCUSSION

The lesion

D.F. inevitably sustained diffuse brain damage as the result of the carbon monoxide poisoning that she suffered. This may be illustrated by her early amnesic difficulties, perhaps reflecting damage to medial temporal lobe structures, and also by a loss of spontaneity and verbal fluency, which may reflect frontal damage. Her acalculia and apparent decline in some aspects of verbal intelligence and short-term verbal memory (though there are no prelesion data for comparison) may reflect left parietal damage. The EEG showed bilateral abnormalities, in keeping with diffuse anoxic cerebral damage, though most prominent posteriorly and in the temporal regions.

It is striking, however, that the major abnormalities in the later MRI studies were restricted to the occipital poles bilaterally, the damage extending laterally in the ventral part of the occipital lobe (area 18) and dorsally in the posterior parasagittal occipitoparietal region. There was little indication of any abnormality in area 17 medially, except possibly for a small spot in the left calcarine sulcus. (It is notable that during the early stages of the disease process, when visual disability was most pronounced, neither CT scanning nor MRI clearly revealed the cortical damage, whereas SPECT did indicate an impairment of occipitotemporal function, at least on the left.)

The nature of visual form agnosia

The primary intention of the present report is to attempt an understanding of D.F.'s visual difficulties, especially the failure of shape perception which appears to be the root cause of her object recognition loss. It is clear that D.F.'s visual deficits are severe, and that they affect a wide range of sensory and perceptual functions, including brightness, motion, depth, and shape perception. This complex pattern of deficits is unlikely to be completely reducible to one or two readily enunciable factors. However, it is of less interest to catalogue all the possible effects that such devastating brain damage might have than to examine the dissociations seen between particular tasks that have much in common with each other. For example, it may be that D.F.'s visuospatial span of attention is reduced, causing difficulty in our tests of dot enumeration; but it is not clear that such an attentional disorder could affect performance differentially in oddity tasks, such that hue differences can be distinguished but reflectance differences or orientation differences can not. Nor could it explain the fact that words can be identified under conditions where the direction of their luminance contrast cannot be. In short, attentional and other generalized difficulties may be compounded with, but cannot explain, the perceptual losses we have documented.

In order to identify a particular shape, the brain must determine the orientation of the component boundaries. To do this it can use many different visual submodalities, including intensity, colour, saturation, stereopsis, and motion (through shear, occlusion, or coherence). It is therefore necessary to conceive of edge orientation, not just as a primary quality extracted by luminance-based 'edge detectors', but rather as a higher-level attribute. D.F. failed to perceive boundary shape or orientation accurately whether conveyed by colour, intensity, stereopsis, motion, proximity, good continuity, or similarity: thus edge perception may be disrupted at a high level. She was also unable to segment perceptually part of a pattern on the basis of common textural properties of size, orientation, intensity, or shape (e.g., + vs T) of its component elements. Such texture discrimination does not require judgements of boundary orientation or shape per se. Perceptual grouping based on similarity in size and intensity would thus seem to be deficient independent of deficits in orientation processing. There therefore seems to be a generalized inability to perceive shape and 'shape primitives', that is, basic figural qualities that would serve in the recognition of many different objects. These would include the Gestalt grouping principles (proximity, closure, similarity, good continuity and common fate) and also other descriptors such as parallelism (Biederman, 1987; Lowe, 1987).

We would argue that D.F.'s form-recognition deficit derives not from a loss of particular input channels ('edge detectors') but rather from a deficit arising at a higher level, at or beyond a general purpose mechanism for extracting shape primitives. Yet it seems that some information about boundaries and shape primitives must be available to certain other brain mechanisms in order for the patient to be able to perform tasks such as manual prehension and word recognition. Therefore it is proposed below that mechanisms of *object perception* (but not all processing systems) may be selectively disconnected from such an early shape processor. But in addition, D.F. has other deficits (e.g., a detection failure selective for low spatial frequencies) that it would seem implausible to attribute to a partial disconnection: hence an additional factor has to be postulated.

Loss of the 'magnocellular stream'?

It was speculated in a recent report (Milner and Heywood, 1989) that at least some of the deficits seen in D.F. could be understood in terms of a selective lesion to the *magnocellular visual pathway*. This refers to a subdivision of the visual system that originates in the alpha ganglion cells of the retina, includes the magnocellular layers of the dorsal LGN and layers 4C-alpha and 4B of the striate cortex (V1), and thence projects to the 'thick stripes' of the adjacent area V2 (Livingstone and Hubel, 1988; Zeki and Shipp, 1988). The properties of cells in this system suggest that it is involved in the analysis of low spatial frequency pattern processing and in depth and motion processing, and that it is spectrally broad-band or 'colour blind'. Damage to it might be expected to lead to several of the deficits seen in D.F.: specifically, to reduced depth and motion sensitivity, a loss of detection sensitivity at low spatial frequencies, to impaired figure/ground segregation, and perhaps also to impaired brightness discrimination (Livingstone and Hubel 1988). In contrast, higher spatial frequencies would not be expected to be affected, nor would colour perception.

It is not implausible to suppose that one or another part of this 'magnocellular' system might be selectively vulnerable to anoxia or toxic influence. However, it seems unlikely in the present case that the critical damage is at a level before V1, since measures of the occipital P100 component of the evoked potential to reversing chequerboard patterns recovered to normality. Particularly if the P100 wave is primarily mediated by the magnocellular pathway, as suggested by its spatial frequency response characteristics (Previc, 1988), then that system would appear to be intact in D.F., at least up to V1.

It is notable that the only previous patient of this type to be tested for psychophysical contrast thresholds also revealed a reduced sensitivity for lower spatial frequencies (Abadi *et al.*, 1981), consistent again with a loss of the 'magnocellular' system. The visual evoked potentials in that previous patient (R.C.), however, showed a reduced amplitude to a low spatial frequency (1 cpd) grating under pattern-reversal conditions. R.C. may therefore have suffered damage earlier in the system than did D.F.

It is proposed then that there is a selective lesion of the magnocellular stream at the early cortical level (e.g., a lamina-selective lesion in V1 and/or a thick stripe selective lesion in V2; *see* Livingstone and Hubel, 1988). However, this alone cannot provide a convincing account of D.F.'s shape discrimination loss, because her good acuity suggests that the 'parvocellular' processing stream, which runs in parallel to the magnocellular system, is relatively intact. This stream (more precisely its 'parvo-interblob' branch; Livingstone and Hubel, 1988) contains cells at the V1 level that are orientation-selective at high spatial frequencies. The problem therefore remains as to why shape discrimination should be lost, given that an intact 'parvocellular' system could potentially provide the necessary pattern information.

It should be noted in parenthesis that D.F.'s explicit awareness (and reasonably good discrimination) of colour may be attributed to a sparing of the *third* stream that passes through V1, the cytochrome oxidase-rich 'blob' stream. In this system cells are wavelength-coded but have virtually no orientation selectivity (Livingstone and Hubel, 1984).

A disconnection hypothesis

D.F. was able to modify the posture of her hand to match the orientation of a slot towards which she was reaching, yet she was unable to *perceive* the orientation of the slot. This appears to add a further instance of 'implicit' knowledge in the absence of 'explicit' knowledge, to those that have been documented for several other neurological conditions (Schacter *et al.*, 1988). She was impaired both in reporting the orientation verbally and in visually or tactually matching the orientation using a second slot. Moreover, her performance in other tests of orientation perception (e.g., oddity tasks) was consistently impaired. In more recent studies (Goodale *et al.*, 1991) we have extended this finding and shown that D.F. can also demonstrate implicit knowledge of the size and orientation of solid rectangular objects when asked to reach and grasp them.

Failures of orientation discrimination are not unusual following posterior right hemisphere damage (e.g., De Renzi *et al.*, 1971; Benton *et al.*, 1978), although they would be unlikely to cause an object or shape-recognition deficit. Undoubtedly it would be of great interest to test whether any such patients can, like D.F., demonstrate good implicit processing of contour orientation in visuomotor tasks. Likewise, it would be interesting to examine the visuomotor processing of orientation information in previously described 'dysmorphopsic' patients, some of whom are known to be able to reach accurately towards point targets in localization tasks (Warrington, 1985*b*).

It is proposed that D.F. can process many perceptual attributes (including luminance contours and brightness levels), but that the output routes to brain systems concerned specifically with recognition have been interrupted. Specifically, the disconnection might block the output from areas V1 (and perhaps V2) of the surviving form-related (parvo-interblob) system en route to higher processing systems in the temporal neocortex (presumably by way of the human equivalent of area V4: Maunsell and Newsome, 1987; Zeki and Shipp, 1988). But in D.F. this disconnection would be in addition to a hypothesized disruption within the cortical magnocellular system. Therefore, it must be assumed that other outputs of the cortical parvocellular system remain intact, making possible D.F.'s ability to orientate her hand in reaching towards an orientated visual slot, and her equally remarkable ability to identify many words.

A striking double dissociation may be noted between D.F. and the patients with optic ataxia recently described by Perenin and Vighetto (1988). Those subjects showed a converse impairment, in being able to judge the orientation of a visual slot but not to use such orientation information to guide their hand movements towards and into the slot. Their lesions, predominantly in the parietal lobe, evidently did not interfere with the *perception* of orientation, and none of the patients had agnosic problems; but the lesions severely disrupted visuomotor coordination in respect of stimulus orientation and spatial location. It may be surmised that the parietal mechanisms disrupted in optic ataxia, and their visual inputs, are largely intact in D.F. The MRI localization evidence that her lesion spares the dorsolateral parietal area, and most of V1, would be consistent with this view; and it is known that there is a direct input from V1 to the parietal cortex in the monkey (Colby *et al.*, 1988).

A different disconnection might explain the unusually clear dissociation between D.F.'s failure to name or match letters and her relatively good word recognition. While this type of dissociation is not uncommon in patients exhibiting the symptom complex of deep dyslexia (e.g., Howard, 1987), it is unusual outside that complex. Indeed, we have found no evidence that D.F.'s difficulty in reading is anything other than perceptual in nature. She is unable to perceive individual letters, just like other simple visual shapes. Yet remarkably, visual information is able to access mechanisms for the recognition of word form. This dissociation clearly contrasts with those patients with pure alexia who can only read letter-by-letter (and who often have no disorder of object or face recognition (Damasio and Damasio, 1983). Our preliminary speculation would therefore be that although visual pattern information is extensively processed in D.F., it is disconnected from the process of letter recognition. The information must, however, retain access to a word-form recognition process that is apparently inaccessible in letter-by-letter readers. It is interesting that this word-form access seems, like D.F.'s visuomotor performance, to be achieved without conscious mediation: she says that she is 'guessing' the words. A more detailed discussion of D.F.'s letter and word recognition is beyond the scope of the present paper, and will be published elsewhere.

D.F.'s impaired ability to discriminate lightness differences while able to discriminate hue differences has been discussed previously (Milner and Heywood, 1989), and led in part to the hypothesized loss of 'magnocellular' processing in D.F. These findings have been extended here by our finding that D.F. can detect small differences in luminance despite being unable to assign the correct contrast direction. Furthermore D.F. can use luminance information for reading, even when unable to discriminate the contrast direction of the words against their background. Although the disconnections postulated above would apply most readily to the perceptual disorders of form and pattern, it is possible that the arguments could be extended to suggest that outputs from the central mechanisms for brightness processing are also differentially spared in D.F. Alternatively, however, it is possible that her ability to detect and use brightness differences but not to judge their direction, could stem from a reliance upon an intact subcortical (tecto-pulvinar-parietal) route to the cortex. This route may permit difference detection but not directional discrimination.

Although the generality of our findings may be limited, it is interesting that a preservation of visuomotor skills was reported in two earlier accounts in the literature. The patients studied by Goldstein and Gelb (1918) and by Landis *et al.* (1982) were both unable to perceive visual form, and therefore would probably fall into the category of 'visual form agnosia'. Both patients were, however, able to trace the contours of letters and forms by moving their finger or head in a trajectory matched to the target outline. Indeed, the patients were so successful at this tracing that they could introspectively monitor the proprioceptive feedback from the tracing movements and thus infer the identity of a form, letter, or word. When tracing movements were disallowed by the experimenters, visual recognition of shapes, letters and words became impossible.

This dissociation in the patients of Goldstein and Gelb and of Landis *et al.* might be interpreted in much the same way as those observed in patient D.F.: direct routes from visual boundary analysis to pattern recognition mechanisms may have been blocked. The preserved visuomotor coordination required for tracing may be postulated to depend on routes from the analysis of visual contours in the occipital lobe to parietally-located systems controlling finger and head movements. Nonetheless, it should be noted that D.F. differs from the cases of Goldstein and Gelb and of Landis *et al.* in being unable to trace manually the visual shape of letters or shapes, and in any case not needing to trace the shape of letters in order to read words.

Previous models of visual form agnosia

Two previous proposals were mentioned in the Introduction: a generalized failure of 2-D form analysis (Warrington, 1985*a*; Humphreys and Riddoch, 1987*b*), and the hypothesis of Campion and Latto (1985) involving 'peppered scotomata'. We would agree with the former authors that a failure of '2-D sketch' formation could explain the failure of some 'form agnosic' patients on shape discrimination tasks like that of Efron. However, such a failure should disrupt all form processing. It is therefore difficult to see how it could account for the dissociations reported here between successful rotation of the hand in reaching towards a slot versus unsuccessful explicit report of its orientation; or between adequate word reading versus failure in letter identification. We would argue therefore that the impaired shape perception of our particular patient cannot be understood in this way.

Campion and Latto's hypothesized 'peppered scotomata' would likewise disrupt all shape processing, and other visual processing too. However, it fails to account for the dissociations we have found between the hue and the lightness versions of the Farnsworth-Munsell test or the Heywood *et al.* oddity task, and between detecting or using luminance differences and assigning contrast direction to them. It also has several other problems. It would predict that visual impairments should be related to the size of the stimuli, with stimuli small enough to remain within an intact region of visual space, or large enough to span several, being relatively spared. There was no evidence of such a size effect, for example, in our tests of dot enumeration, orientation, or texture perception. Nor was there any evidence that the use of scanning eye movements was especially beneficial to D.F. (she was given unlimited time in most tests). Yet on Campion and Latto's hypothesis, scanning movements should be of great benefit, since stimuli could be brought onto intact areas of the field by this means. It might also be noted that there is no sign on MRI of any disseminated lesion either in the calcarine cortex or in adjacent cortex (where the lesion seems rather continuous) in our patient; however, it could no doubt be argued that the images are of insufficient resolution to show this hypothetical pattern.

It must be freely confessed that our own suggestions do not satisfactorily explain all the intriguing dissociations that have emerged from our investigations of D.F.; they are offered merely as a beginning in unravelling the previously unsuspected complexities that exist in at least one patient with 'visual form agnosia'.

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