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## Object Recognition

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### INTRODUCTION

The ease with which we recognize objects in everyday life belies the underlying complexity of visual processing in the brain. However, insights into the intricacies of these processes can be drawn from the study of brain damaged subjects who have lost some of the abilities we take so much for granted. For instance, damage can result in selective impairments in the visual perception of form (Goodale, Milner, Jakobson, & Carey, 1991), color (Heywood, Cowey, & Newcombe, 1991), and motion (Zihl, Von Cramon, & Mai, 1983), suggesting that these properties are processed in separable neural pathways. We focus on selective impairments of visual form perception (or visual agnosia) in this chapter, though the other disorders are discussed. Since we have already published a number of reviews on agnosia (Humphreys & Riddoch, 1987a, 1993; Riddoch & Humphreys, 1988) we will not place so much emphasis on the different types of visual agnosia, but instead will focus our discussion on some of the current issues and controversies.

We start our review with an account of the transmission of visual information from the retina to the occipital cortex. Our discussion will focus particularly on the geniculo-striate pathway and the effects of lesions to this pathway at the level of the occipital lobes, which can lead to the disorder known as blindsight. Subsequently we discuss the deficits that can arise as a result of lesions to 'higher-level' visual areas, including those specialised for the processing of color and motion. We then address the issue of visual object recognition itself. In particular, we will discuss two different approaches to the understanding of perceptual deficits that result in agnosia: the hierarchical approach adopted by Humphreys and his colleagues (Humphreys & Riddoch, 1987a; Riddoch & Humphreys, 1988), and the hemisphere specialization approach suggested by Warrington and her co-workers (Davidoff & Warrington, 1989; Warrington, 1985; Warrington & Taylor, 1978). We also outline different forms of memorial deficit that lead to associative agnosia and will then spend some time discussing the fate of stored visual knowledge when perception is damaged. In a final section we will consider (a) the relations between the visual processing of objects, faces, and words, and (b) whether the processes involved in object recognition operate in a discrete or a more iterative manner, with 'higher-level' information sometimes influencing processing at lower levels. We suggest that the consequences of iterative processing are important for our understanding of vision.

## VISUAL PROCESSING FROM THE RETINA TO THE OCCIPITAL CORTEX

### The Retino-Striate Pathway

Detailed studies of visual processing in primates have revealed that there is substantial functional segregation in the visual pathways from the retina onwards (see Livingstone & Hubel, 1987; S. Zeki, 1990, 1993). Information about the visual world is transmitted from the retina for further processing via the optic nerve. While the majority of fibres from the optic nerve travel via the geniculo-striate pathway to the striate cortex (V1) in the occipital lobes, approximately 10% of the fibres terminate in the mid- and fore-brain (e.g., in the superior colliculus, see Weiskrantz, 1990). At the retinal level, there are two forms of ganglion cells (alpha and beta) which have distinctly different roles in visual processing. Fibres from these cells remain segregated in the optic nerve up to the visual cortex. Fibres from alpha cells project first to 'parvo cellular' cells of the lateral geniculate nucleus (LGN) and from there to 'blob' and 'interblob' regions in cortical area V1. Cortical area V2 receives inputs from the blobs and interblobs and in turn projects it outputs to cortical area V4. This 'P' channel provides color opponent information and has low luminance contrast gains. There are two separate inputs from the 'P' channel to the temporal lobes: the cells in the blob regions in V1 are wavelength but not orientation selective (responsible for the coding of color), while in the interblob regions the reverse is true (such cells are likely to be responsible for the coding of form). Fibres from beta cells in the retina project to 'magnocellular' cells in the LGN, the thick stripe regions in V1 and then to cortical areas V2, V3 and MT. This 'M' channel has characteristic features of high luminance contrast gain, orientation and direction selectivity, and sensitivity to binocular disparity. The 'M' channel is thought to convey motion, stereo depth, and coarse form information to the parietal lobes (Livingstone & Hubel, 1987). More recent work, however, suggests that the separation between these streams may be partial rather than all-or-none. For example, blob and interblob regions of the 'P' channel receive input from the magnocellular system (Nealey & Maunsell, 1994). At higher levels of cortex (e.g., within infero-temporal cortex) cells may also respond to specific conjunctions of visual attributes (e.g., color as well as form, see Tanaka, Saito, Fukuda, & Moriya, 1991). Nevertheless, the distinction between input streams for different visual dimensions such as color, form, stereo depth, and motion provides a framework for understanding the functional isolation of the streams following brain damage.

The general distinction between the cortical pathways projecting to visual processing areas in the temporal and parietal lobes is also supported by lesion studies with primates. Selective lesions to the pathways generate contrasting behavioral deficits. For instance, Ungerleider and Mishkin (1982) have shown that monkeys with lesions to the parietal cortex show little or no deficit in object recognition, but are profoundly impaired in visuospatial tasks requiring memory for location. On the other hand, monkeys with lesions to the temporal cortex may be impaired at recognizing objects visually but have no deficits in remembering location information. Results such as these have led to the argument that the temporal lobes contain cells that code 'what' an object is while the parietal lobes contain cells that code 'where' it is (Ungerleider & Mishkin, 1982). Lesion studies in humans too support the distinction between the 'what' and 'where' pathways (see Humphreys & Riddoch, in press for a review), as do studies using functional brain imaging. For example, Haxby et al. (1993) compared the areas activated when subjects indicated which of two faces matched a third face with the areas activated, in an analogous location matching task with the same stimuli. They found that identity judgements were associated with activation in the occipito-temporal region, while location judgements were associated with activation in occipito-parietal regions. Our review is concerned with neurological deficits of the 'what' system, including those affecting the coding of the basic dimensions of visual stimuli.

### Visual Processing in Striate Cortex: The Issue of 'Blind Sight'

Early writers, such as William James, argued that the occipital lobes were essential to human vision, hence the ablation of these areas would cause total blindness (James, 1890). Studies with human subjects with lesions of the striate cortex have indeed shown total blindness when assessed by visual field perimetry using static stimuli; however, other forms of assessment have shown that the loss of vision need not be total. George Riddoch first observed that such patients could detect motion in the field of view, although they appeared blind to everything else (G. Riddoch, 1917). Riddoch argued that movement may be recognized as a special visual perception, separate and in addition to perceptions of light, form, and color. George Riddoch's findings (1917, 1935) can be appreciated in the light of what is now known about the functional segregation of the visual processing pathways in the brain (see above), but at the time his findings were disputed (Holmes, 1918; Teuber, Batterby, & Bender, 1960). More recently however, using similar techniques to those originally described by G. Riddoch, several investigators have demonstrated perception of movement in an otherwise blind field (Barbur, Rudock, & Waterfield, 1980; Bridgeman & Stagers, 1982; Weiskrantz, 1990). Indeed, 'blindsight' can extend to include a number of residual visual abilities. For instance, such patients can move their eyes to the position at which a light is presented in the visual field (e.g., Barbur et al., 1980; Perenin & Jeannerod, 1985; Pöppel, Held, & Frost, 1973), and, through early evidence for shape discrimination was absent (Barbur et al., 1980) or weak (Perenin, 1978; Weiskrantz, 1990), more recent studies suggest that there can be high level processing of shape in some cases (Marcel, 1998). Cowey and Stoerig (1992) further demonstrated effects of wave length discrimination in the 'blind' field. These forms of blindsight are typically revealed by having patients make forced-choice responses between stimuli, even though the patient can deny 'seeing' any stimulus at all. Interestingly, some patients can report experiencing 'something,' but this experience is usually non-visual (e.g., a patient has described 'feeling' a moving stimulus in the blind field), although it can be visual (e.g., feeling that quite a bright light had been turned on; see Cowey & Stoerig, 1992). To some extent, the disparity between the visual properties that can be discriminated in blindsight, and those that cannot, is consistent with the physiological distinction between a visual route into the cortex via area V1 and a subcortical visual route (through the superior colliculus), with final projections into extra-striate regions. The subcortical route can support basic coding of position, motion and simple aspects of form and even wavelength (Weiskrantz, 1990), though the evidence for higher-level processing of form (Marcel, 1998) is less easy to account for in these terms unless it represents compensatory developments in some patients. Whatever account is offered for the stimulus compensatory developments in some patients, the evidence suggests that activity in primary visual cortex V1 is integral to conscious visual perception. We will return to the issue of consciousness later, in the final section of the chapter.

### ELEMENTARY VISUAL PROCESSING OF COLOR, MOTION, AND FORM Selective Deficit in Motion Perception—Akinetopsia

Damage to extrastriate areas of cortex can lead to problems in deriving some of the basic dimensions of visual stimuli, such as their color or their form, although such patients can perceive other nonimpaired properties. The most detailed study of impaired motion perception has been conducted with patient L.M. L.M. suffered a superior sagittal sinus thrombosis when aged 43 (originally reported by Zihl, Von Cramon, & Mai, 1983). A magnetic resonance scan (MR) showed severe bilateral damage to the middle temporal gyrus and the adjacent part of the occipital gyri together with subcortical damage affecting lateral occipital and occipito-parietal white matter (Zihl, Von Cramon, Mai, & Schmid, 1991). L.M. was profoundly disabled in

everyday life and found moving stimuli to be highly disturbing and unpleasant: moving objects appeared to jump from one position to the next, making busy streets or shops very frightening. As a result, she became wary of venturing from home, which led to an initial diagnosis of agoraphobia—an interpretation which could not account for some of her other difficulties, such as with understanding language (people's lips appeared to hop up and down), and meal preparation (she had difficulty in pouring and measuring out liquids because they appeared frozen like a glacier; see Heywood & Zihl, 1999). LM's visual recognition was intact: She had no visual field defect, acuity was unimpaired, and she performed normally on tests of visual identification and recognition of objects, faces, and places. In contrast, formal tests of movement vision revealed a number of specific impairments, such as a reduced sensitivity to motion and a reduced appreciation of subjective velocity. Not all movement perception was lost, however, LM was able to discriminate the direction of motion of high contrast stimuli and she could also perceive some aspects of higher order motion normally. For instance, she could discriminate various forms of biological motion formed when lights were placed on the joints of actors who were filmed in a dark room (McLeod, Dittich, Driver, Perrett, & Zihl, 1996). LM could tell whether the light dots were jumbled or consistent with walking figures, whether figures were walking or cycling, and the direction of motion. This dissociation, between impaired perception of some basic aspects of motion and an ability to perceive relatively complex patterns of biological motion, suggests that contrasting neural substrates may serve different forms of motion coding—in particular, there may be some neural areas specialized for processing biological motion, which are relatively preserved in LM. Converging physiological evidence for this proposal has been reported by Perrett and colleagues (Perrett, Harries, Benson, Chitty, & Mistlin, 1990), who have found cells in the superior temporal sulcus of primates that were specialized for processing biological motion.

LM's lesions were in the region of visual area V5 in both hemispheres. In the macaque monkey, cells in this area have been shown to be sensitive to motion, the majority of cells being directionally sensitive (S. M. Zeki, 1974). Furthermore, again in the macaque monkey, neurons in V5 have been shown to be selective for binocular disparity and direction and speed of motion but not for color (Maunsell & Van Essen, 1983a, 1983b). LM's behavioral deficits in perceiving basic aspects of motion information are consistent with these physiological data. In normal human observers, the functions of V5 have been studied using both functional brain imaging (fMRI and PET) and transcranial magnetic stimulation (TMS). TMS provides a means of disrupting activity in regions of the cortex with millisecond accuracy. Walsh, Ellison, Battelli, and Cowey (1998) stimulated V5 using TMS and found this disruption improved search for a non-motion target amongst moving distractors. This interesting result suggests that inhibition of selective neural areas may play a functional role in many tasks, especially when areas selectively process distracting information. Functional imaging studies also reveal modulation of motion processing areas (V5) by attention. For instance, Rees, Frith, and Lavie, (1997) measured activity in V5 generated by a moving background using fMRI. When the primary task required reading a word at fixation, there was less activity in V5 than when subjects simply had to detect whether or not a target word was in lower case. Hence these areas of cortex specialized for processing various visual attributes do not seem to operate in a purely bottom-up mode but they may also be influenced in a top-down fashion, by how much attention is paid to the dimension of interest. The notion that emerges here is of a dynamically modulated visual system, tuned to task demands as well as to specific visual properties of the world—an argument we return to in the final sections of the chapter. It can even be speculated that one reason for the functional specialization of vision is to facilitate dynamic modulation of processing of specified properties. We note too that a patient such as LM will not only be impaired at processing motion, but also in attending and ignoring motion information selectively. LM's deficit is striking, but relatively rare. It is possible that akinetopsia only results from bilateral lesions and that a single area V5 may be sufficient for motion perception in cases with unilateral lesions.

## Loss of Color Perception (Achromatopsia)

The term achromatopsia is applied to the syndrome in which a patient loses the ability to see colors after cortical damage. The loss may be partial or complete, and it may or may not be accompanied by other visual defects. The patient often reports seeing the world in black and white and shades of grey (Humphreys & Riddoch, 1987b). The disorder is one of color perception and not just recognition (e.g., associating red with a mail box) or naming. Thus patients can perform poorly at perceptual ordering tasks (such as the Farnsworth Munsell 100-Hue Test), but they can arrange achromatic grey discs in terms of their lightness (Heywood, Wilson, & Cowey, 1987). Achromatopsia often occurs in association with prosopagnosia (failure to recognize familiar faces; Ratcliff & Newcombe, 1982; Riddoch & Humphreys, 1987a), but not always (Kölme, 1988; Sachs, Wasserman, Zeki, & Siegel, 1988) and is associated with lesions in the region of the lingual and fusiform gyri. This region in humans is probably analogous to visual area V4 in the macaque, which has been shown to be specialized in the processing of color (S. Zeki, 1990; S. M. Zeki, 1973, 1976, 1980). This supposition has been strengthened with data from PET studies (Corbetta, Meizin, Dorneyer, Shulman, & Petersen, 1991; Lueck et al., 1989; S. Zeki, 1993). When subjects view a multicolored abstract display (such as a 'Color Mondrian') there are regions of heightened activity in the lingual and fusiform gyri, relative to when the colors are replaced with grey shades matched in luminance (Lueck et al., 1989). Troscianko et al. (1996) reported forced-choice color-matching tasks in two achromatopsic patients. Despite failing to report conscious color perception, both patients matched isoluminant colors above chance (see also Heywood et al., 1991). Either static or dynamic (moving) luminance 'noise' was then added into the color stimuli. With one patient, performance was poor with static noise but improved with luminance noise. This is consistent with any residual color processing being based on the 'P'-pathway, which is sensitive to static but not motion cues. In contrast, the second patient showed the opposite pattern of performance, being more impaired with the dynamic than the static noise. Troscianko et al. (1996) suggest that another color-sensitive system may be involved in this case: possibly the 'M' channel, which is sensitive to red-green border information (Li, Martin, & Valberg, 1989) or to some further system that remains able to discriminate colors at isoluminance. In this second patient the dominant 'P'-pathway for color processing seemed to be abolished.

## Impaired Depth Perception

Impairments affecting all aspects of depth perception, including the use of monocular as well as binocular cues, have been reported in patients with bilateral occipital-parietal damage (Gloning, Gloning, & Hoff, 1968; Holmes & Horrax, 1919; Riddoch, 1935; Rizzo & Damasio, 1985; Valkenberg, 1908). Such patients describe the world as if it is two-dimensional; for instance, "... To the patient a chair is flat, though he knows from experience that his visual impressions are cheating him. ... A stair is a flat inclined plane with no protruding steps, and yet he knows from the light and shade that he ought to see the steps ..." (G. Riddoch, 1917, pp. 47-48). More specific impairments that affect stereo depth perception have been documented after unilateral lesions of the right versus the left hemisphere (Benton & Hecaen, 1970; Carmon & Bechtold, 1969; Harnsher, 1978), though problems of sampling bias here need to be taken into account (e.g., if patients with aphasia after left hemisphere lesions have been omitted; see Datta, Hilton, & O'Boyle, 1978). It is also unclear whether problems in global stereo depth perception are related to damage to the magnocellular stream in humans. For example, Pito and colleagues (Pito & Zatorre, 1988; Pito, Zatorre, Larson, & Tosini, 1991) have documented deficits in global stereopsis after temporal lobectomies. The precise relations between disorders of depth perception and the 'M' and 'P' streams need to be evaluated.

### Selective Deficits of Form Perception (Apperceptive Agnosia)

Perhaps equivalent to impairments affecting processing of basic visual dimensions of color, motion, and depth, are those affecting the basic processing of form. The neurologist Lissauer first distinguished visual recognition deficits consequent on damaged perceptual processes from those consequent on damaged access to stored memories giving these deficits the labels apperceptive and associative agnosia (Lissauer, 1890). Using this terminology, damage to the processes involved in extracting basic form information can be classed as a type of apperceptive (perceptual) agnosia.

Patients with impaired perception have been reported by Efron and Milner and his associates (Efron, 1968; Milner et al., 1991). Such patients are unable to identify or to copy line drawings of common objects or even simple geometric shapes; however, while figural properties such as size, orientation, and shape are lost, other abilities such as color, brightness, and movement discrimination may be preserved (Efron, 1968; Milner et al., 1991). In many instances, patients with these deficits have been exposed to carbon monoxide poisoning. Campanion and his coworkers have argued that the visual recognition problem in patients with carbon monoxide poisoning is due to many small scotomas produced by the multiple lesions. This could have the effect of causing the patient to view the world through a peppery mask. However, on this account, we might expect that patients could adapt to the presence of such a mask; in addition, some form of integration of the information should operate across the mask when patients move. Against this, recognition is severely disrupted in free vision in everyday life. Others have argued that the problem with visual recognition results from impaired grouping processes (Humphreys, Riddoch, Donnelly, et al., 1992; Humphreys, Riddoch, Quinlan, Donnelly, & Price, 1992). Cells in early visual areas can respond differentially when local grouping cues, such as collinear line segments, are present (see Von der Heydt & Peterhans, 1989, for evidence from area V2). Damage to such areas may prevent patients from linking edge elements into coherent perceptual structures disrupting object recognition.

Data contrasting the effects of peppery masks versus disruption of grouping have recently been reported by Vecera and Gilds (1998) with normal subjects. Vecera and Gilds had subjects respond to a spatially cued target. There were two viewing conditions to the experiment: either a peppery mask was present, or stimuli were degraded to mimic impaired grouping. They examined effects of spatial cueing on targets that appeared in the same object as the cue (both appeared with a rectangular box) relative to targets that fell in a similar object, but on the opposite side of fixation. Previous work by Egly had shown an 'object' benefit, with there being faster RTs to targets that appear in the same object as the cue relative to targets that appeared in the noncued object (Egly, Driver, & Rafal, 1994). Vecera and Gilds (1998) degraded the boxes by either removing their mid-sections or removing the corners. Removal of the mid-sections leaves cues such as collinearity and closure present, while removal of the corners would make it more difficult to group the parts into objects (see Biederman, 1987, for evidence in object recognition and Humphreys, Romani, Olson, Riddoch, & Duncan, 1994, for evidence with simultanagnosic patients). Vecera and Gilds found that removing the mid-sections left the object-cueing advantage intact, whilst the advantage was lost when corners were removed. In contrast, effects of object-cueing were additive with the effects of a peppery mask. Vecera and Gilds suggest that object coding is selectively impaired by disruption to grouping processes rather than degradation due to masking.

Interestingly, some patients with poor basic perception of form can use the same information to guide motor behavior. This was first reported by Milner and his colleagues (Milner et al., 1991). Patient DF suffered anoxia as a result of fumes leaking from a faulty gas water heater. Subsequently her visual object recognition was severely impaired, she could recognize few real objects and no line drawings. Her copying was poor, and she was at chance at making perceptual judgements even about the basic dimensions of form (see Milner et al., 1991).

Despite this, DF was able to reach appropriately to objects. Her grasp aperture and hand orientation were tuned to the size and orientation of stimuli and the kinematics of her movements were normal. Milner and Goodale (1995) propose that the dissociation between perceptual judgements and action in DF reflects the contrast between the ventral and dorsal streams of the visual system. They propose that DF's lesion affected the ventral rather than the dorsal visual system compromising perceptual judgements about even the basic dimensions of form. However, the dorsal visual stream remained intact. Milner and Goodale argue that the dorsal stream not only codes stimulus location (cf. Ungerleider & Mishkin, 1982), but also provides visual information for prehensile actions—such as reaching and grasping. Orientation and size information can be coded by the dorsal stream and used for action, even if coding of the same information in the ventral stream is impaired. On this view, the ventral stream (for object recognition) and the dorsal system (for location coding and action) are separated even from the early stages of cortical coding. Consequently, patients such as DF can have a deficit in early shape coding in the ventral system along with intact early shape coding in the dorsal system. An alternative possibility is that vision for action is not completely independent of vision for perceptual judgements and object recognition; rather that vision for action can bring into play feedback processes that do not operate in recognition. The dorsal system may mediate rapid feedback in visually-guided prehensile actions. According to this view, DF may be able to reach appropriately to objects by means of an intact feedback process (see Edwards & Humphreys, 1999, for evidence on visual feedback in the syndrome).

Interestingly, DF's ability to code orientation has been shown not only in action but also in perceptual judgement tasks where orientation information operates independently. The McCollough effect is a long-lasting instance of adaptation in which a negative color aftereffect is produced by a stimulus that has the same orientation as the adaptation pattern (McCollough, 1966). DF was unable to report the orientation of black and white test gratings which were either horizontally or vertically oriented. However, the orientation of these gratings affected the color aftereffect following adaptation to green and black horizontal gratings and red and black vertical gratings. For instance, if the adapting grating was green and horizontal, then a pink negative aftereffect was found on the subsequently viewed horizontal black and white grating. Thus, while she was unable to *explicitly* report the orientation of the test grating, the McCollough effect demonstrates that at some level in DF's visual system, orientation is being encoded (Humphrey, Goodale, & Gurnsey, 1991). This suggests either of two possibilities. One is that orientation is coded along with color within the color-sensitive part of the 'P' channel, so that DF manifests sensitivity to orientation when relying on that visual stream. She is impaired at using orientation only within the form-sensitive part of the 'P' channel. The second is that DF can use orientation information implicitly for perceptual judgements, but she does not have explicit access to that information unless it is used for action. In the final section of the chapter we return to consider differences between the implicit and explicit coding of visual information for recognition tasks.

### VISUAL OBJECT RECOGNITION

As we have noted, the deficits in form perception can be classed as a type of apperceptive agnosia, using Lissauer's (1890) distinction between apperceptive and associative agnosias. In addition to disorders of basic form perception, though, case studies over recent years have demonstrated that a variety of other types of object recognition deficits can occur, and that finer grain distinctions are required between contrasting forms of both apperceptive and associative agnosia. Thus, rather than there being a dichotomy between frank deficits of perception or memory access (apperception and association), there are sets of impairments reflecting particular operations involved in recognition. (Arguments for the finer-grained distinctions are provided in: Farah, 1990; Humphreys & Riddoch, 1987a, 1987b; Humphreys, Riddoch, & Boucart,

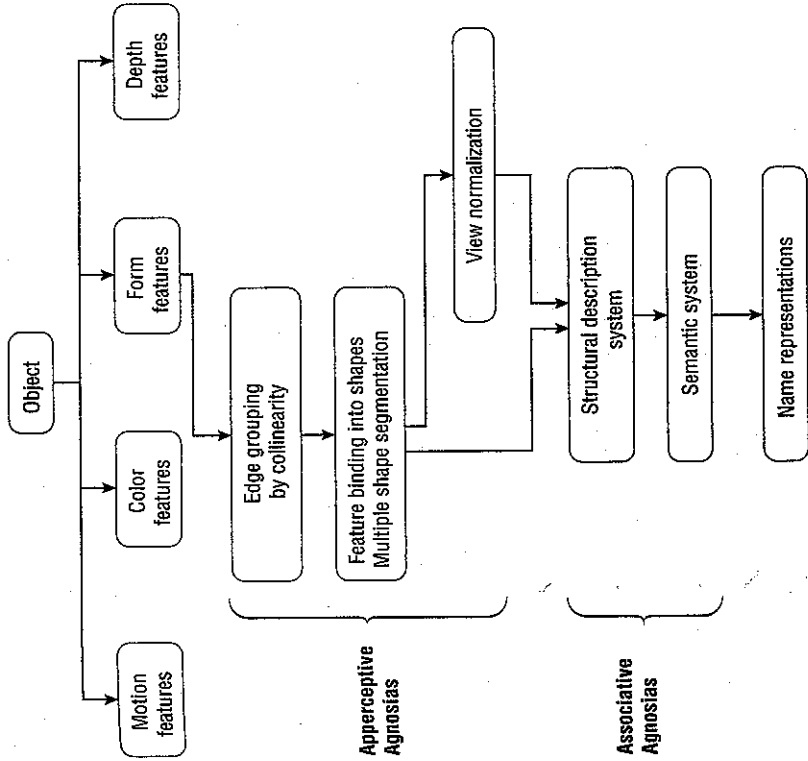


Figure 3.1. A hierarchical model of object recognition and naming, specifying different component processes which, when impaired, can produce varieties of apperceptive and associative agnosia.

coding the appropriate edges (perhaps in addition, requiring the assignment of edges to the shape). DF was also impaired at judgements about simple patterns grouped on the basis of properties such as proximity and collinearity (Milner et al., 1991).

**Feature Binding into Shapes and Multiple Shape Segmentation**

In other cases patients may be able to extract basic features and to perform some elementary feature-grouping, but they are still impaired at binding features into shapes. These problems are most clearly demonstrated under conditions in which multiple items are present in the field, when there may be competition in assigning elements between shapes. In a detailed study of one agnostic patient, HJA, we have shown the contrast between relatively good assignment of elements into shapes when only one item is present, and poor assignment elements to multiple shapes. HJA was profoundly agnostic and particularly impaired at recognizing line drawings.

1992a; Riddoch, 1999; Riddoch & Humphreys, 1988; Warrington, 1982, 1985). Here we present two contrasting ways of conceptualizing the distinctions in terms of two underlying frameworks for understanding visual processing: a hierarchical account of visual perception and object recognition, and a hemisphere-specific account.

**The Hierarchical Processing Account**

One of the most influential views of visual perception over the past 20 years was that proposed by David Marr and his colleagues (Marr, 1982; Marr & Hildreth, 1980; Marr & Nishihara, 1978). Marr suggested that vision results from processing via a number of modular subsystems, which, when combined in a hierarchical fashion, give rise to object recognition. For example, he proposed that early visual processes act to code edges in a retinal coordinate subsystem (the raw primal sketch). Subsequently, these edges are grouped and linked with surface information, again represented according to viewpoint (the 2½-D sketch). Finally, a viewpoint-independent representation is constructed in which the parts of the object are coded in relation to the object's main axis (the 3-D modal representation). Since this general hierarchical framework was proposed, many queries have been raised—for example whether a surface based representation is coded en route to recognition (Biederman & Gerhardstein, 1993 vs. Edelman & Duvdevant-Paf, 1997), and whether the processes leading up to object recognition operate in a purely bottom-up manner (see Humphreys, Riddoch, & Price, 1997). For our present purposes what matters is not whether Marr was right in the precise details (although we will discuss evidence where neuropsychological results are relevant), but whether the general principles of this approach apply: (a) that vision involves a set of separate processes, and (b) these processes are arranged in a hierarchical fashion. We have argued (Humphreys & Riddoch, 1987a, 1993; Riddoch & Humphreys, 1988) that neuropsychological data can be accounted for in terms of these two general principles. The quasi-modular decomposition of visual processing not only applies to the basic dimensions of form, color, depth, and motion, but to object recognition itself. A framework derived on the basis of observations of performance of patients with impaired visual recognition is shown in Figure 3.1.

**The Basic Coding of Color, Depth, and Motion**

As shown in Figure 3.1, the initial processing of an object is along the basic dimensions of color, depth, and form. We have already covered issues relating to such processing in Section 3.

**Edge Grouping by Collinearity**

A first stage of visual processing involves organization of the input. Elements are grouped on the basis of their similarity to each other, allowing the derivation of edges. This grouping probably happens in early parts of the visual cortex, perhaps involving long range horizontal connections even within striate cortex (area V1; see Gilbert, 1992; Gilbert & Wiesel, 1989). Certainly within area V2 there is evidence of grouping by collinearity taking place (Von der Heydt, Peterhans, & Baumgartner, 1984). As we go on to discuss in the following section, there is also neuropsychological evidence that edge grouping by collinearity operates prior to the assignment of edges to shapes (Giersch, Humphreys, & Boucart, in press). This is consistent with edge grouping being a first stage in perceptual organization. It may well be that patients such as DF (see above) are impaired at this early stage since they are unable to perform simple shape matching tests. An example of this is the Efron (Efron, 1968) test. This involves discrimination between shapes varying in two dimensions which are matched for brightness, it is typically administered under conditions with no time limitations and with one or at the most two spatially separated shapes present, such a shape matching test is likely to be contingent on

Despite this, he performed well on the Efron shape matching task (Humphreys, Riddoch, Quinlan, et al., 1992). In contrast to this, HJA was impaired at search tasks that required that visual elements bind together in a spatially parallel manner across a field containing multiple stimuli. Targets were defined on the basis of a particular conjunction of form features (e.g., a horizontal and vertical line combining to form an inverted T), relative to homogeneous distractors containing the same features but in a different arrangement (e.g., upright T; see Figure 3.2).

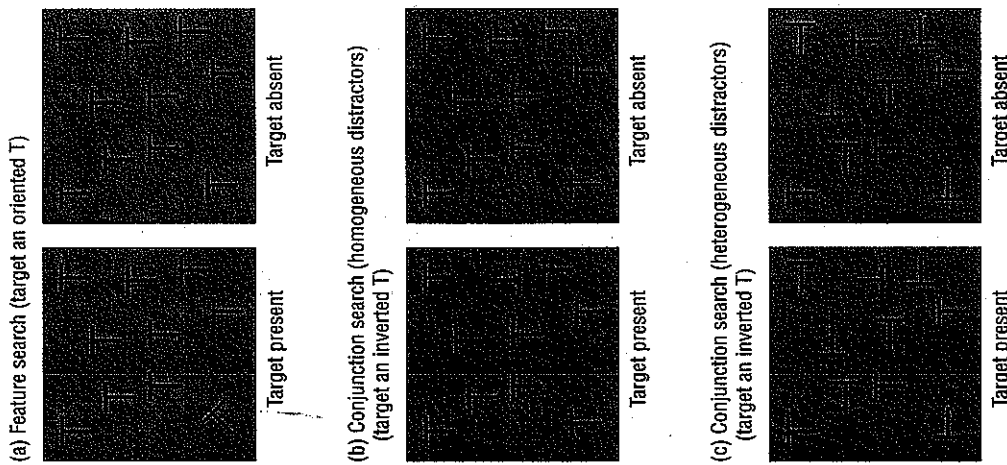


Figure 3.2. Examples of some of the visual search displays used with HJA: (a) illustrates a feature search (the 'feature' being orientation), (b) a conjunction search with homogeneous distractors, and (c) a conjunction search with heterogeneous distractors.

Normal subjects can detect such targets efficiently by binding elements in targets and distractors in parallel and by then grouping and then rejecting distractors on the basis of their 'bound' feature conjunctions (Duncan & Humphreys, 1989; Humphreys, Quinlan, & Riddoch, 1989). HJA was unable to do this and was significantly impaired relative to age-matched controls (see Figure 3.3). Nevertheless, he could detect targets in parallel when they were differentiated by a salient feature from distractors (e.g., a T having a contrasting orientation to distractors), so he was capable of processing elements in parallel when binding elements together was not crucial. He could also conduct efficient serial search for form-conjunction targets amongst heterogeneous distractors (e.g., upright and 90° rotated Ts). For normal subjects segmentation of targets and distractors by similarity at the level of feature conjunctions is disrupted when heterogeneous stimuli are presented, and subjects then adopt a serial search strategy (see Figure 3.4). HJA's deficit is not apparent under these circumstances, although it appears when parallel binding of elements is necessary (see Figure 3.4).

The distinction between intact coding of basic features and impaired binding into shape has been illustrated in recent experiments with HJA that use simple shape matching tasks. Giersch, Humphreys, and Boucart (in press) presented line drawings of three geometric shapes that could be spatially separated, superimposed, or occluding (see Figure 3.5a, b, c respectively). In addition, sets of occluding silhouettes were also presented. Subsequently, the target array was exposed again along with a distractor array in which the positions of the shapes were rearranged. HJA performed relatively well on this task with separated shapes and with silhouettes, but he performed poorly with superimposed and occluding shapes. Interestingly, the deficit with occluding shapes was most pronounced when the length of the occluded edge was small—the condition when the missing fragment should be easiest to compute based on collinearity between the non-occluded edges (see Figure 3.5c). Other studies showed that HJA sometimes

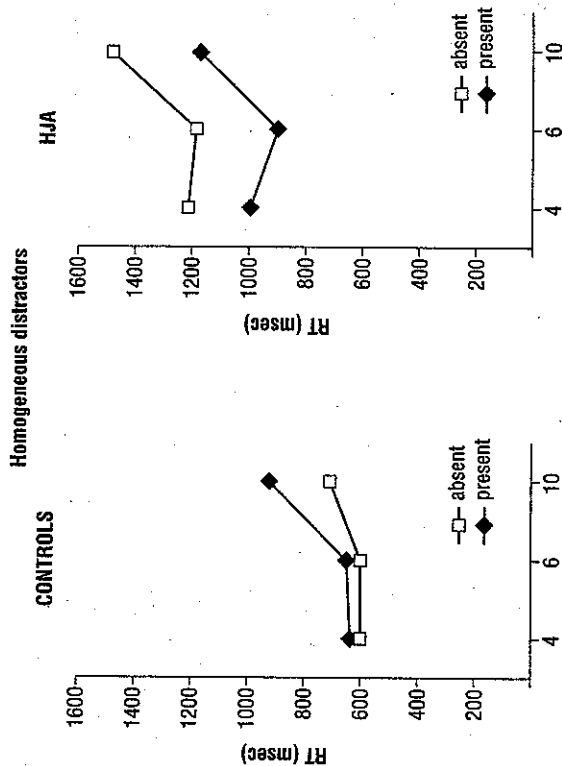


Figure 3.3. Data showing the contrast between HJA and controls in a conjunction search task with homogeneous distractors.

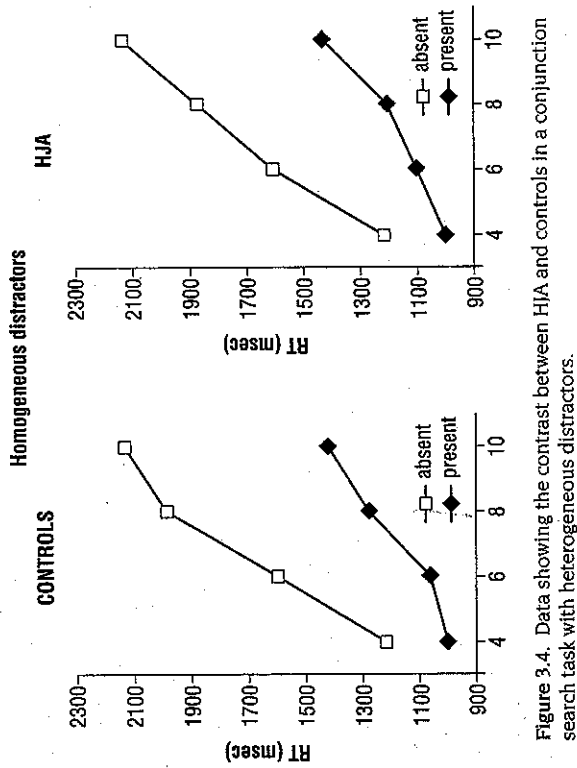


Figure 3.4. Data showing the contrast between HJA and controls in a conjunction search task with heterogeneous distractors.

used the occluded edge to segment the occluder, and sometimes he assigned the edge to the shapes as if it were visible. These results suggest that HJA could compute the occluded edge (using collinearity), but he was then impaired at assigning it to the correct shape and in using it in the process of segmenting the multiple shapes apart. Feature coding, including edge grouping by collinearity, precedes feature binding into shapes and multiple shape segmentation. The fact that HJA performed reasonably well with silhouettes here is also illuminating. Normal subjects tended to find the silhouettes more difficult than line drawings, presumably because local details that facilitate segmentation of shapes is lacking, and hence performance relies on more global descriptions of the overall configuration. HJA seemed able to use these global descriptions reasonably well, given his relatively good matching of silhouettes. However, the local detail present (e.g., the occluded edges) disrupted his performance, due to his impaired binding and segmentation of the shapes.

The contrast between HJA's good performance with silhouettes and his poor performance with line drawings extended beyond simple shape matching tasks. Riddoch and Humphreys (1987a), for example, first reported this in an object decision task with HJA (see also Lawson & Humphreys, 1999, for further recent evidence). With complex stimuli, the problem with line drawings can be demonstrated with even single items. With limited presentation times, the problem was even greater, and it was also exacerbated by overlapping figures (Riddoch & Humphreys, 1987a). A similar pattern, with strong effects of figural overlap and better performance with silhouettes was found by Butler and Trobe (1994) with their agnostic patient. Patients described by de Renzi and Lucchelli (1994) and Kartsounis and Warrington (1991) have also shown poor performance with overlapping figures despite good discrimination of simple Efron shapes. In more complex line drawings, edges provide cues for segmentation of objects into parts, and they must also be bound correctly to yield appropriate object descriptions. Some agnostic patients find this binding difficult and are prone to segment even single line drawings. This can lead to a piecemeal approach to object identification in which objects are identified from their parts (see Goldstein & Galb, 1918; Grossman, Galetta, & D'Esposito,

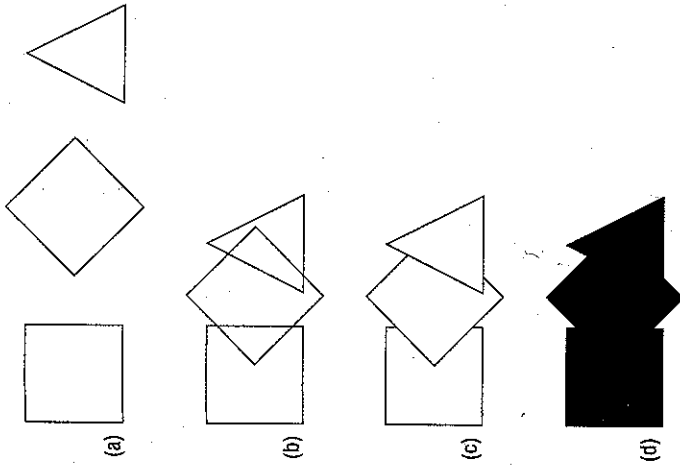


Figure 3.5. Examples of the stimuli used by Giersch, Humphreys, and Boucart (in press).

1997; Sirigu, Duhamel, & Pöncelet, 1991; Wapner, Judd, & Gardner, 1978, for other examples). Interestingly, despite placing a good deal of weight on the parts of objects for identification, such agnostic patients typically do not report the whole object as if it were just the part (e.g., describing a bicycle as a wheel). Thus, they appear to have some information about the whole. This proposal is supported by the silhouette advantage that can occur. In an additional experimental test of the proposal with HJA, Humphreys, Riddoch, and Quinlan (1985) examined responses to compound stimuli in which the whole is composed of separately identifiable local parts (e.g., a large letter made up of smaller letters; cf. Navon, 1977). They found that HJA responded normally to the global form but, unusually, he showed no effect of the global form on the identification of the local parts (see also Lamb, Robertson, & Knight, 1990, for a similar result with patients with unilateral lesions to the superior temporal gyrus).

Riddoch and Humphreys (1987a) used the term 'integrative agnosia' to describe patients such as HJA. They argued that the deficit was not in early feature extraction but in integrating together both local features and local and global aspects of form. According to Riddoch and Humphreys, shape integration is a second dissociable process in the hierarchy leading to object recognition.

### View Normalization

Following shape integration and segmentation of figural shape from ground, theories differ in terms of whether object recognition proceeds directly or whether there is a form of 'normalization' to enable a viewpoint-invariant representation to be derived. Normalization here refers to

the fact that objects can be seen as having the same shape despite differences in viewing conditions. An upright chair, and same chair knocked over will be perceived as being the same object despite the different patterns of retinal stimulation. There are a number of different theories regarding view normalization, and detailed discussion of these is outside the scope of this chapter. Warrington and colleagues (e.g., Warrington & James, 1978, 1979) first described patients with damage to the right hemisphere who were poor at matching prototypical views of objects with 'unusual' views. Warrington and James (1986) suggested that patients had difficulty in extracting critical features that would enable objects to be matched across viewpoints. Humphreys and Riddoch (1984) reported a further double dissociation between patients who were either affected by alteration of critical features across the viewpoints or by changes in the principal axis of the object. They manipulated whether the 'unusual' view reduced the saliency of the critical features of object (the minimal feature condition) or whether it maintained these features but foreshortened the main axis of the object (the foreshortened condition; see Figure 3.6). They found one patient whose performance was impaired in the minimal feature condition but not the foreshortened condition, whereas other patients were disrupted in the foreshortened but not the minimal feature condition. Converging evidence that foreshortening the axis is important was provided by the further finding that depicting foreshortened objects against a background with strong linear perspective cues to depth improved the performance of this last group of patients. The depth cues aligned with the principal axis of the object. These results are consistent with proposals that recognition depends on the derivation of viewpoint invariant representations. For example, Marr (1982) suggested that recognition involved derivation of a 3-D model representation in which the parts of objects were described in relation to the principal axis. Humphreys and Riddoch's evidence indicates that some patients find it difficult to encode such representa-

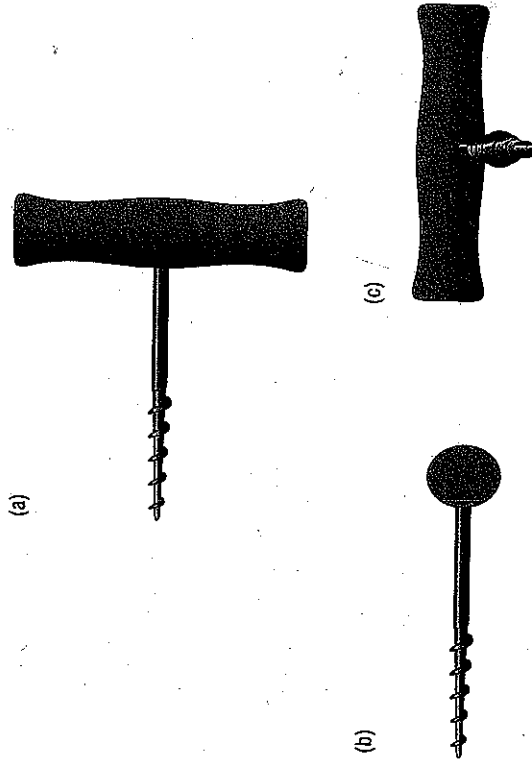


Figure 3.6. Examples of the stimuli used by Humphreys and Riddoch (1984) in their unusual view tests: (a) is a prototypical view of a corkscrew, (b) is a minimal feature view (the handle of the corkscrew is not so readily apparent), (c) is a foreshortened view (the main axis of the corkscrew has been reduced in length).

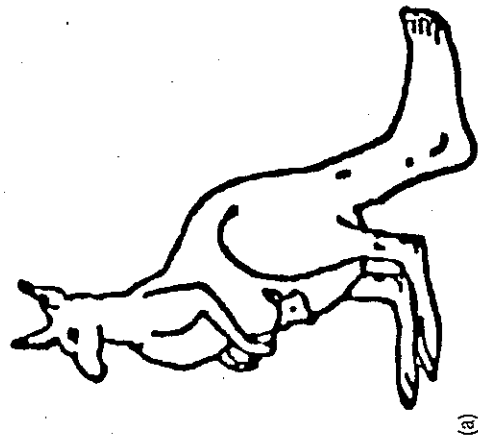
tions when the principal axis is obscured. However, it remains unclear whether this 'normalization' process is a necessary part of object recognition. It could be that problems with 'unusual views' reflect impaired procedures for coping with particular forms of object degradation, but these procedures are not needed when objects are not degraded. Indeed, many of the patients reported with deficits with 'unusual views' do not have problems in recognizing prototypical views of objects (see also Davidoff & De Bleser, 1994; Davidoff & Warrington, 1999). Thus, evidence from such patients does not impact on the issue of how objects in familiar viewpoints are recognized. We return to these issues in the next section when we discuss the hemisphere-specialization approach to object recognition.

### Access to Stored Knowledge (Structural descriptions)

Neuropsychological evidence also indicates that the process of accessing stored knowledge for object recognition can be fractionated. This is shown most clearly by patterns of sparing and deficits on 'object-decision' tasks. In these tasks patients have to discriminate between depictions of real objects and depictions of non-objects. Non-objects can vary in their similarity to real objects, in some cases being equally perceptually good (e.g., where non-objects are constructed by joining together parts of real objects, see Figure 7). With such non-objects, object decisions appear to rely on access to stored knowledge rather than being based on perceptual information alone. Several patients have been reported who can succeed on difficult object decision tasks but who still seem unable to recognize objects (Hillis & Caramazza, 1996; Riddoch & Humphreys, 1987b; Sheridan & Humphreys, 1993; Stewart, Parkin, & Hunkin, 1992). For instance, patient JB (Riddoch & Humphreys, 1987b) performed object decisions at a normal level but was impaired at judging from vision which two of three objects would be used together (e.g., hammer, nail, spanner). This problem with matching objects based on their functional associations was modality specific; when given the name of the objects JB carried out the same task with ease. Thus JB was impaired at accessing functional-associative knowledge from vision but could access forms of visual knowledge to perform the difficult object decision task. Riddoch and Humphreys (1987b) proposed that this reflected a distinction between access to stored structural descriptions for objects and access to stored semantic information (specifying functional and associative knowledge). The former, but not the latter, was intact in JB. Note that access to both forms of knowledge conform to what Lissauer (1890) originally termed the association process. We suggest that this association process is composed of separable hierarchically arranged stages including access to stored structural descriptions followed by access to semantic knowledge (see Figure 3.1).

Other patients have been shown to be impaired at performing object-decision tasks even though they succeed on tests stressing earlier perceptual processes (up to and including unusual view matching; Forde, Francis, Riddoch, Rumiati, & Humphreys, 1997; Rumiati & Humphreys, 1998; Rumiati, Humphreys, Riddoch, & Bateman, 1994; Sartori & Job, 1988). These patients are typically poor at retrieving stored perceptual knowledge about objects from auditory questions which may be measured in tasks such as drawing from memory or imaging the shape and dimensions of stimuli (e.g., does an elephant have a long tail relative to its body?). This suggests that stored structural descriptions may be accessed not only in order to recognize objects visually but also in the retrieval of visual knowledge to non-visual input. This process of mapping from structural to semantic knowledge may be particularly problematic for stimuli belonging to classes that are both visually and semantically close. This appears to be the case for stimuli from living categories, relative to objects from non-living categories that are perceptually more heterogeneous (see Humphreys, Riddoch, & Quinlan, 1988, for evidence on perceptual similarity differences between object categories). For example, JB (Riddoch & Humphreys, 1987b) showed worse identification for living than non-living things. Humphreys et al. (1988) attributed this to the greater overlap between both structural and semantic





(a)



(b)

Figure 3.7. Examples of nonobjects: (a) illustrates a nonobject constructed from parts of objects from different categories. (b) illustrates a nonobject constructed from parts of objects from the same category.

representations for living things, which renders identification more difficult for a patient with a deficit mapping between the representations. A similar argument has been made by Arguin, Bub, and colleagues (Arguin, Bub, & Dudek, 1996; Dixon, Bub, & Arguin, 1997). They examined the ability of an agnosic patient to learn relationships between visual shapes and names. The shapes could vary either along one or along two dimensions (e.g., elongation and bending, to describe a banana-like shape). The performance of the patient was disrupted when stimuli varied along two rather than one dimensions, and when the paired names came from a semantically close set. Semantic proximity had little effect when the stimuli varied along a single dimension, and the number of dimensions involved had little effect when the names referred to semantically dissimilar items. Arguin et al. (1996) argued that the patient could attend, and make discriminations along, a single visual dimension but failed to discriminate more complex visual information (varying along two rather than one dimension). This led to particular difficulties when the visual descriptions had to be related to close rather than more distant semantic representations. Outside the laboratory these difficulties may occur for visually complex and semantically similar living things. Other accounts of differences between the recogni-

tion of living and non-living things have been summarized recently by Humphreys and Forde (Forde & Humphreys, 1999; Humphreys & Forde, in press), and they are taken up in the chapter by Shelton and Caramazza (this volume).

### Access to Stored Knowledge (Semantics) and Phonology

In addition to patients failing to recognize objects because of a difficulty in mapping from structural descriptions to semantics, recognition problems can be caused by a semantic deficit. In such patients naming and recognition problems may be expected even with verbal descriptions of the functional properties of objects, as well as when objects are presented visually. Nevertheless, access to stored structural descriptions, assessed via object decision tasks, can be intact (see Sheridan & Humphreys, 1993; Stewart et al., 1992).

The model outlined in Figure 3.1 has, as its final step, the process of name retrieval for objects. According to this model, name retrieval operates following access to semantic knowledge. This is not a commitment to the view that all one's semantic knowledge must be retrieved before name retrieval can occur, since each stage in the model may operate based on partial activation at earlier stages ('in cascade'; see Humphreys et al., 1988). Nevertheless, access to some forms of semantic information is deemed necessary. The evidence that object naming can proceed non-semanticly is weak (Hodges & Greene, 1998, though see Brennen, Danielle, Fluchaire, & Pellat, 1996).

### Optic Aphasia

For this model, the syndrome of optic aphasia is something of a puzzle. In optic aphasia patients may misname visually presented objects while (sometimes) being able to gesture how to use the object. Good gestures suggest that semantic access is achieved (see Lhermitte & Beauvois, 1973). Is there then a problem in accessing names from semantic information? The answer here is no, because the same patients can name objects to verbal definitions. The syndrome is problematic for accounts that assume that object naming is achieved via access to a semantic system that is common across modalities, given that visual access to semantics and semantically-based naming from verbal definitions both appear to be intact. Based on such reasoning, some authors have argued that optic aphasia is consistent with modality specific semantic systems. According to this view, the syndrome arises because access from visual semantics to name information is impaired. Naming to definition, on the other hand, is supported by an intact route from verbal semantics to names (Beauvois, 1982; Shallice, 1987). Another proposal accounts for optic aphasia in terms of hemispheric differences in access to name information. Coslett and Saffron (1989b, 1992), for example, suggest that optic aphasic patients can access intact semantics in the right hemisphere but are impaired at accessing name information in the left hemisphere due to hemispheric disconnection. A problem for this account though, is in explaining why accurate gestures can arise in optic aphasia when there is a left hemisphere dominance for gesturing as well as naming (see De Renzi & Faglioni, 1999) for a recent review. In addition, when detailed tests of semantic access have been carried out in patients with optic aphasia, then deficits have been shown (De Renzi & Faglioni, 1999; Hillis & Caramazza, 1995; Riddoch & Humphreys, 1987b). We have already discussed the case of JB who was able to carry out object decisions but was impaired at making functional/associative judgments to visually presented objects. JB also showed a good ability to make gestures to visually presented objects, sometimes making responses that were not only object-specific but also hand-specific (e.g., using his left hand to gesture to a fork, and his right hand to gesture to a knife). Riddoch and Humphreys (1987b) argued that JB's gestures did not indicate access to semantics but rather a direct association between stored structural descriptions and learned actions. These object-action associations may extend beyond single object usage to include

familiar action routines, where objects are used sequentially. Lauro-Grotto, Piccini, and Shallice (1997) reported a patient, RM, with dementia that involved loss of semantic (functional and associative) knowledge about objects. Despite this, RM was able to perform routine cooking tasks, with objects being used appropriately in the correct order.

In other instances, patients appear to make actions based on the parts of objects without even necessarily gaining access to stored knowledge of the whole objects. Sirigu, Duhamel, and Poncet (1991), for example, described an agnosic patient, FB, with bilateral temporal lobe lesions who was unable to match visually presented objects using functional or contextual information. Nevertheless, FB demonstrated the use of objects and described how this was done based on the parts present. The parts of objects may be said to 'afford' actions without the objects being recognized—either in terms of accessing stored perceptual or stored functional knowledge (cf. Gibson, 1979).

Hillis and Caramazza (1996) take a similar view to that of Riddoch and Humphreys (1987b) but suggest that partial semantic knowledge may also be used by patients to support gesturing, but that this is insufficient to generate correct naming. The framework offered in Figure 3.1 is consistent with these latter views of optic aphasia.

### The Hemisphere Specialization Approach to Object Recognition and Naming

Warrington and colleagues (Rudge & Warrington, 1991; Warrington & James, 1986; Warrington & Taylor, 1973, 1978) have proposed that disorders of object recognition and naming can be understood in terms of hemisphere specialization for the processes of perceptual and semantic classification (see Figure 3.8). They propose that perceptual classification involves assigning objects with different image structures to a common higher-level perceptual category if they have the same underlying shape. This perceptual classification process is probed by the unusual-views matching task that we discussed in the last section. On this view, the process of view normalization (see Figure 3.1) is achieved by perceptual classification. An impaired ability to perform unusual view matches has been found in patients with posterior right hemisphere damage (though see Bulla Helwig, Ettlinger, Dommasch, Ebel, & Shrezeck, 1992; Mulder, Bouma, & Ansinck, 1995, for counter evidence), and consequently Warrington and colleagues (Rudge & Warrington, 1991; Warrington & James, 1986; Warrington & Taylor, 1973) have argued that perceptual classification is achieved in the right hemisphere. The means by which perceptual classification is achieved remains unclear, however. Warrington and James (Warrington & James, 1986) suggested that classification was based on the extraction of critical features from objects (though see Humphreys & Riddoch, 1984, for evidence for axis-based coding). Whether access to stored knowledge is also involved, though, is unspecified. This account further proposes that following perceptual classification, information is fed forward to semantic categorization processes performed by the left hemisphere. Consequently patients with left hemisphere damage are impaired at making functional/associative judgements to objects though perceptual classification can be achieved (assessed by means of unusual view matches). Semantic categorization is a necessary precursor to object naming.

This hemispheric specialization account has many similarities to the hierarchical model outlined in Figure 3.1, with one difference being that the hemispheric account is less clear concerning the role of stored structural descriptions in the recognition process. For instance, Rudge and Warrington (1991) found that patients with impaired unusual view matching were not agnosic for prototypical views of objects. From this they argued that prototypical views may be recognized by the left hemisphere. For the hemisphere specialization account this would appear to involve mapping early representation of objects through to left-hemisphere semantic classification processes. How this can be achieved without access to stored structural knowledge is unclear. In addition, functional imaging studies of object recognition suggest that

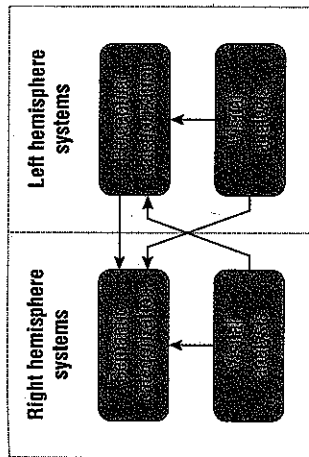


Figure 3.8. Illustrating the hemisphere specialization approach to object recognition and naming (adapted from "Selective impairment of memory and visual perception in splenial tumours," by P. Rudge & E. K. Warrington, 1991, *Brain*, 114, 349-360).

perceptual descriptions for objects are at least as strongly represented within the left as in the right hemisphere. For instance, when brain activations associated with objects or with structurally plausible non-objects are compared with visual noise of meaningless shape baselines, there is bilateral activity in posterior areas of the ventral cortex (lateral and middle occipital regions, fusiform gyrus and inferior, posterior temporal areas; see Kanwisher, Woods, Jacoboni, & Mazzioffa, 1997; Martin, Wiggs, Ungeleider, & Haxby, 1996; C. J. Price, Moore, Humphreys, Frackowiak, & Friston, 1996; Schacter et al., 1995). Access to structural representations does not seem to be the sole province of the right hemisphere. In one functional imaging study that assessed the processing of objects in unusual views there was evidence for activation in the inferior parietal cortex but this was present in both hemispheres (Kosslyn et al., 1994). In addition there was evidence for dorsolateral frontal activity (again in both hemispheres) which Kosslyn et al. attribute to problem solving processes needed when objects are distorted from their familiar views. Such problem solving strategies are unlikely to be part of a perceptual classification system used in everyday object recognition.

In some cases recently described by Turnbull and colleagues (Turnbull, 1997; Turnbull, Breschin, & Della Sala, 1997; Turnbull, Laws, & McCarthy, 1995), damage to the right parietal lobe has been associated with a further problem—namely impaired judgements of whether objects are in an upright orientation or not. Typically such patients believe that objects rotated in the plane are upright, and in copying the objects such patients may depict rotated objects as upright. It may be that damage to the parietal lobes impairs the ability to encode object orientation, making performance reliant on a ventral visual system that is insensitive to features, perhaps because ventral representations are viewpoint invariant. Rotated versions of objects may be mapped onto these viewpoint invariant representations by having matching features. However, without parietal information specifying the retinal or environmental orientation of the object, patients may then be unable to judge whether or not the object is upright. Being sensitive to orientation, the parietal lobes may play a useful role in identifying objects when they are depicted from unusual viewpoints—in deriving a principle axis, in encoding features across the orientation change, or even in mental rotation conducted as an explicit problem-solving strategy. On this view, hemispheric differences in object processing may be less crucial than differences between ventral and dorsal visual areas.

### The Role of Perception in Maintaining Visual Knowledge

Agnosic patients may have intact stored knowledge about the visual appearance and functions of objects, but may not be able to access this knowledge from vision. For instance, HJA, when originally tested, was able to draw items from memory and to provide detailed descriptions of the same items despite having a profound problem in perceptual processing (see section above;

Riddoch & Humphreys, 1987a). The fact that HJA was able to perform such tasks is germane to debates about the relationship between stored visual knowledge and visual imagery. There is some evidence for a shared substrate between perceptual and imagery processes from studies of functional brain activation and from studies of patients with cortical blindness. For instance, there have been a number of reports of activation of even the primary visual cortex during imagery tasks, measured by means of SPECT (Goldenberg et al., 1989), PET (Kosslyn et al., 1993), fMRI (Le Bihan, Turner, Zeffiro, Cuenod, & Bonnerot, 1993), and EEG (Farah, Peronnet, Gonon, & Giard, 1988). However, data obtained in other PET studies has shown activation in occipitoparietal and temporoparietal regions rather than early visual areas in visual imagery tasks (Decey, Kawashima, Gulyás, & Roland, 1992; Roland & Gulyás, 1994). It has been argued that this may be due to differences in the visual imagery tasks (see Pollicardi et al., 1996).

If primary visual cortex is critical in visual imagery, then loss of it (as in cases of cortical blindness) should result in a similar loss or severe impairment to visual imagery. Support for this proposal comes from Pollicardi et al. (1996) who describe a patient, TC, who became cortically blind following a road traffic accident. Neuroimaging studies showed bilateral metabolic reduction in calcarine and associative occipital areas, and extending to mesial and temporal cortex. TC demonstrated a severe impairment of visual imagery which was tested extensively in a number of different ways (including measures of topographical imagery, symbol imagery, animal and object imagery, and color imagery). The impaired visual imagery did not result from a degradation of stored knowledge, as TC performed well on tests of stored associative/functional information.

However, while the case of TC can be used to support the contention that there is a common substrate for imagery and perception, other cases of cortical blindness do not fit this pattern. Chatterjee and Southwood (1995) report *in vivo* visual imagery in a case of a patient with cortical blindness. The patient suffered a subarachnoid hemorrhage as a result of a right frontal arteriovenous malformation, which caused infarctions of the posterior cerebral arteries. Her imagery abilities were assessed in some detail and she was shown to perform at (or above) control levels in all tests bar one (a test of spatial imagery). A similar case of preserved visual imagery in a case of cortical blindness has been described by Goldenberg, Müllbacher, and Nowak (1995). The patient, HS, suffered a bilateral posterior cerebral infarction resulting in destruction of Brodmann's areas 18 and 19, and atrophy of areas 28, 35, 36, and 37. There was bilateral damage of area 17. HS was blind, although she denied this (this was also true of patient TC, above). Goldenberg et al. (1995) argued that TC had a lack of awareness because she confused her mental visual images with real percepts. Assessment of HS's imagery included tests of her ability to access knowledge of the shapes of letters and the shapes and colors of objects. In all instances, she performed well (see Goldenberg & Artner, 1991).

A number of patients have been reported with relatively preserved visual imagery following visual agnosia, and of these, four have been described in some depth (see Behrmann, Winocur, & Moscovitch, 1992; Behrmann, Moscovitch, & Winocur, 1994; Jankowiak, Kinsbourne, Shalvey, & Bachman, 1992; Riddoch & Humphreys, 1987a; Servos & Goodale, 1996; Servos, Goodale, & Humphrey, 1993; Young, Humphreys, Riddoch, Hellawell, & de Haan, 1994). CK (Behrmann, Winocur, et al., 1992, 1994) was thought to have sustained bilateral thinning of the occipital lobes as a result of a head injury. MD (Jankowiak et al., 1992), DF, and HJA suffered bilateral occipito-temporal lesions.

The four patients showed different degrees of severity of visual agnosia, with MD (Jankowiak et al., 1992) showing the greatest sparing of visual recognition (91%, 75%, 62%, and 48% correct for naming visually presented real objects, for MD, DF, HJA, and CK, respectively). All four patients were also more impaired at naming line drawings than at naming real objects. When initially tested, all four patients were able to draw from memory objects that they were no longer able to recognize. However, in a long-term follow-up of HJA, Riddoch et al. (1999) found

that there was a deterioration in performance over time (and relative to control performance) which was most pronounced for objects from categories with visually similar exemplars (natural kinds). This drop in drawing performance was mirrored by HJA's verbal definitions of objects. In the first years post lesion, HJA's verbal definitions contained many visual as well as nonvisual (functional and associative) details about objects. In the follow-up examination, the number of nonvisual properties had increased, while the number of visual properties had decreased. Since there was an increase in the number of nonvisual properties listed, there was no evidence for a general decline in his abilities; rather, there was a shift away from being able to recall the visual properties of objects. These findings are consistent with there being some interaction between visual perception and memory (and with the consequent expression of memory in imagery). In particular, perceptual processing of objects may lead to a consistent updating of visual memories over time, so that these memories remain tuned to the visual properties of objects in the world. Such consistent tuning of memorial processes to vision fits with connectionist accounts of cognition, in which recognition systems change adaptively to the inputs they receive over time (Ellis & Humphreys, 1999). When perceptual inputs are impaired, as in forms of agnosia, visual memorial processes may gradually show some decline, with there being less fine tuning of the system to the visual properties of objects. In cases where imagery appears to be preserved, either in agnosia or in patients with cortical blindness, testing needs to be conducted over a longer time period to evaluate the sustained effect of perceptual degradation on memory.

These results on the relation between perception and memory can be related to recent studies using PET studies on visual perceptual learning. An object in a degraded image which appears meaningless when seen for the first time can be easily recognized when an undegraded image of the object is presented first (when the recognition system is 'primed'). Dolan, Frith, and colleagues (Dolan et al., 1997; Frith & Dolan, 1997) have found that changes between the first (naive) and second (primed) state were associated with enhanced processing of inferior temporal regions involved in visual object processing (particularly the fusiform gyrus). Effects were differentially lateralized for objects and faces suggesting that item-specific learning takes place in these regions. The data match results on learning-related tuning of temporal lobe activity in the monkey (Sakai & Miyashita, 1994, 1996; Tovee, Rolls, & Ramachandran, 1996). In addition, Dolan and Frith (1997) reported enhanced activity in medial and lateral parietal cortex that was specific to perceptual learning (the change between the naive and primed state). They suggested that the parietal activity could reflect the involvement of imagery in reconstructing degraded stimuli and in binding the parts of these stimuli together. The critical lesions in forms of apperceptive (perceptual) agnosia involve the inferior occipito-temporal regions, consistent with the site of item-specific learning in PET studies. It is possible that this brain area is intimately involved in the updating of visual knowledge about specific objects in everyday life, a process that can be impaired after the occurrence of brain lesions (see Riddoch et al., 1999).

## OBJECTS, FACES, AND WORDS

The visual system is presented with many different perceptual forms—including faces and words as well as other object types. Are all visually presented forms processed in the same way, or is there specialization for different stimuli? It can be argued that some of the computational requirements of object recognition differ from those of, say, face and word recognition; hence different routines and neural structures may be involved. For instance, face recognition requires the identification of a specific exemplar within a visually homogeneous category, while object recognition generally only requires categorization at a base level (Henke, Schweinberger, Grigo, Kios, & Sommer, 1998).

Have special processes evolved for object recognition? Some of the computational require-

ments for object recognition differ from those of, say, face and word recognition; hence different routines and neural structures may be involved. There are a number of pieces of evidence which point to face processing being 'special'. Face recognition has been shown to be selectively impaired relative to objects of equivalent difficulty (Farah, Tanaka, & Drain, 1995). Single unit recordings in the temporal cortex of the monkey show selective responses to faces (some responding differentially to particular characteristics (Desimone, 1991). Developmentally, face recognition appears to have an innate component (Johnson, Dzurawiec, Ellis, & Morton, 1991). Furthermore, unlike most other stimuli, faces are particularly hard to recognize when they have been inverted (Valentine, 1988). Farah and her colleagues have argued that faces, the whole level representation is particularly important (Farah, Wilson, Drain, & Tanaka, 1998). As concerns neuropsychological disorders, Farah (1990) has argued that there are particular relations between agnosia, prosopagnosia (deficits in recognizing faces), and alexia (difficulties in reading), that are informative about the nature of the visual information used to recognize the different classes of stimulus. In a review of historical cases, she noted that there were patients with 'pure' alexia and 'pure' prosopagnosia (i.e., without concomitant deficits with other classes of stimulus), and cases of mixed deficits where patients had agnosia and alexia, agnosia and prosopagnosia, and also all three deficits. However, there were no convincing cases with 'pure' agnosia (i.e., without problems in reading or face recognition) and no cases with a 'mixed' impairment including alexia and prosopagnosia without agnosia. From this she concluded that there were two underlying visual processes that could be affected and lead to recognition deficits in patients: one concerned with processing holistic<sup>1</sup> visual representations (needed for face recognition), and one was concerned with processing multiple parts in parallel (e.g., the letters in words). These two processes would each contribute to object recognition, to different degrees, depending on the properties of the object. She argued that lesions to the process dealing with holistic representations would disrupt face recognition and possibly also object recognition (if the lesions are more severe), while lesions to processes dealing with multiple parts would disrupt word recognition and again object recognition to some degree (for those objects dependent on these part-based processes, with joint impairments found with more severe damage). Pure object agnosia, on the other hand, should not occur because there is not a unique process used for object recognition. Similarly, it should not be possible to damage both face and word recognition without there also being some disruption to object recognition, which will depend on the same processes. However, recent neuropsychological data contradict the view that all visual recognition impairments can be accounted for in terms of disruption to either holistic or parts-based perceptual processes. For example, Rumiati, Humphreys, and colleagues (Humphreys & Rumiati, 1998; Rumiati et al., 1994) have reported two cases of 'pure' agnosia, where the patients seemed to have good face and word recognition (reading words at a normal rate rather than letter-by-letter), but impaired object recognition. Both patients suffered degenerative impairments and had some problems in retrieving semantic information about objects even from words, but the problems were more serious with objects. Both were impaired at object decision tasks and one made primarily visual errors. This pattern of impairment is consistent with the patients having damage to stored visual memories for objects, and both performed well on a range of perceptual tests (including unusual view matching). The pattern would not be expected if all recognition impairments were due to perceptual impairments affecting either holistic or parts-based representations. If such perceptual impairments were important here, patients should always have associated deficits with

<sup>1</sup>By 'holistic processing' we mean that the processing of individual features is significantly influenced by the configuration of the complete stimulus (e.g., a face). Thus, while subjects may be able to identify people even when only half the face is presented (the face split down the middle), they have extreme difficulty in identifying the component halves in chimeric faces (faces composed of halves of faces of two different individuals; Young, Hellawell, & Hay, 1987).

either faces or words in addition to any problems in object recognition. The second pattern of deficit that goes against a simple two-process account has also been documented recently by Euxbaum, Glosner, and Coslett (1999) and by De Renzi and Di Pellegrino (1998). These investigators have reported patients with alexia and prosopagnosia but with relatively preserved object recognition. The data suggest that memory representations for faces, objects, and words can differ, so that there can be selective degeneration of visual memories for objects rather than for words or faces (and perhaps also vice versa). These last results also emphasize that not all recognition deficits are perceptual in nature, and that some reflect memorial rather than perceptual impairments—as we have suggested by both hierarchical and hemispheric specialization accounts of recognition disorders. It may be the case that the dichotomy between holistic and parts-based descriptions accounts for many of the perceptual differences between face, object, and word recognition, but memorial differences need to be considered. In addition, we need to distinguish between parts-based descriptions that are coded independently for individual parts (e.g., the letters in words) and those that are grouped to form a larger perceptual unit (e.g., supraletter codes in words). We suggest that a full account of face, object, and word processing will need to accommodate effects of grouped features in recognition (see also De Haan, this volume).

### INTERACTIVE EFFECTS IN OBJECT PROCESSING

The hierarchical and hemispheric specialization approaches to visual recognition have been discussed in terms of strict bottom-up activation processes. For instance, there is a stage of visual grouping prior to access to stored structural descriptions, and we have suggested that structural descriptions can be accessed prior to (and in the face of impairments to) semantic knowledge. However, other evidence indicates that visual processing may be more interactive, with later forms of information influencing earlier processes. For top-down effects to operate during on-line object recognition, partial activation would need to be transmitted between processing stages rather than each stage being discrete. Evidence for partial transmission of information can be drawn from a number of sources. One piece of evidence concerns the errors made by normal subjects in object naming. When forced to respond to a fast response deadline. Normal subjects make errors that are both visually and semantically close to target objects (Vikvitch, Humphreys, & Lloyd-Jones, 1993). Naming to a deadline seems to comprise the process of name retrieval (Vikvitch & Humphreys, 1991). If visual access to semantics is complete by the time name retrieval starts, then naming errors should only be semantic in nature. That errors are both visual and semantic suggests that visual access to semantics is not fully complete before name retrieval gets underway.

There are also data consistent with top-down feedback during early stages of visual coding. Peterson and colleagues (e.g., Peterson & Gibson, 1994) have had normal subjects make figure-ground judgements to stimuli with ambiguous figure-ground relationships. With such displays, judgements to perceptual figures are biased to familiar forms. Information about the familiarity of objects can be activated whilst figure-ground coding takes place. Top-down activation may further help explain some of the evidence on functional brain imaging which has shown selective activation of particular neural areas for particular objects (e.g., artifacts vs. natural kinds; see Martin et al., 1996; Moore & Price, 1997, 1999; Perani et al., 1995). The identification of particular object types may involve top-down activation of forms of knowledge that differentiate between members of the relevant object class. Hence, there is enhanced activation of perceptual information in the inferior occipito-temporal cortex for the regions identification of living things, since living things are typically defined in terms of their perceptual attributes (Farah & McClelland, 1991). There is activation of knowledge about action and movement in more middle temporal and inferior frontal regions for the identification of artifacts, since these objects are defined in terms of this information. Price, Moore, Humphreys,

Frackowiak, and Friston (1996) further showed that enhanced activation of posterior, inferior temporal regions was found when naming rather than recognition was stressed. This is consistent with top-down activation particularly coming into play when activation needs to be sufficiently precise to enable a unique name to be derived (see Humphreys et al., 1997, for this argument). If object naming is indeed interactive (top-down as well as bottom-up), then this is likely to impact on the performance of patients. For instance, object naming may be selectively impaired by lesions affecting the ability to activate early forms of knowledge in a top-down fashion, although basic recognition may be achieved in a bottom-up manner. Data that fit with this have been reported by Forde et al. (1997) and Humphreys et al. (1997). They documented evidence on patients with unilateral (left) medial extrastriate lesions whose problem was much more pronounced in naming than in recognition. They suggested that the posterior lesion disrupted top-down reactivation of perceptual knowledge, required to name rather than to recognize (particularly) living things.

### COVERT PROCESSING

At various junctures throughout this chapter we have discussed findings in which patients have shown an ability to process information when tested covertly but not when tested overtly. We refer to a covert procedure as requiring either: (a) the patient does not have to respond directly to the stimulus property of interest, but the effect of processing that property is shown through its effect on another stimulus; or (b) the patient is made to guess when they cannot discriminate the stimulus property directly. An example of (a) is the finding that the agnostic patient DF showed the McCollough aftereffect for color which was contingent on another property (orientation) that the patient could not discriminate in an explicit orientation discrimination task. An example of (b) is the above chance performance shown by patients with blindsight when asked to guess about the location of a stimulus that they are unaware of (see section on visual processing earlier in the chapter). In addition to the covert abilities we have mentioned, several others have been shown in patients with a variety of visual disorders. To cite but three: (a) achromatopsic patients can show above chance discrimination in same-different matching with isoluminant stimuli (Heywood et al., 1991; Troscianko et al., 1996); (b) prosopagnosic patients can show better face-name learning for familiar but unrecognized faces than for unfamiliar faces (De Haan, Young, & Newcombe, 1987); and, (c) alexic patients can be above chance at discriminating the categories of words presented so briefly that the patients claim not to be able to read them (Coslett & Saffran, 1989a). McNeil and Warrington (1991) have gone so far as to argue that tests of covert recognition in prosopagnosic patients can provide a means to separate patients with a deficit in stored visual knowledge for faces and patients with a deficit after this stage. Tests of covert processing then provide at least an important source of convergent evidence for diagnosing the locus of functional deficit in a patient. They may even throw new light on the functional diagnosis.

Several different accounts of covert processing can be offered. One is that covert abilities reflect visual processing in visual pathways that do not lead to conscious awareness. This form of account can be offered to explain blindsight, where the residual abilities in blindsight patients can be related to processing in a residual collicular pathway (Covey & Stoerig, 1992). Another account of covert processing is that it is produced by partial activation of visual processes to a subthreshold level. This can be sufficient to generate above-chance guessing and even to affect the processing of other stimuli, but not to produce overt discrimination (see Burton, Bruce, & Johnson, 1990; Farah, 1994, for simulations; also Farah, this volume). Another possibility is that covert processing is contingent on transitory activation that cannot be sustained long enough to generate overt behavior. Whatever the case, the evidence demonstrates that it is important to test for covert processing abilities in patients to help document the functional nature of the disorder.

### SUMMARY

We have reviewed evidence that visual processing can break down in a variety of ways after brain damage. Damage to striate and extra-striate cortical areas can lead to selective disorders in coding basic properties of images, such as color, elementary form, depth, and motion. In instances of blindsight, there can be coding of these properties without any perceptual awareness on the part of the subject. In addition to these disorders of early vision, contrasting impairments can also arise in higher-level processes that lead to object recognition. Here we have distinguished disorders of feature binding and shape segmentation, view-normalization, access to stored structural descriptions, access to semantic knowledge, and access to names. These different disorders can be conceptualized in several ways and we have discussed the hierarchical and hemispheric specialization views. We have also noted evidence indicating that failures in object recognition can coincide with patients being able to use the information for action both for prehensile reaching and grasping and also for learned actions in cases of optic aphasia. Finally, evidence on the relations between visual perception and imagery, and on top-down as well as bottom-up factors in vision, indicates that vision is interactive in at least two ways: (a) it is constantly updating our visual memories of the world, and (b) even in on-line naming tasks, top-down processes may play a role in differentiating objects with their categories. The evidence we have considered not only throws light on different neurological conditions, but also on the processes underlying normal visual recognition and naming.

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