

CHAPTER EIGHT

The Neuropsychology of Spatial Attention

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The most basic finding in neuropsychology is that brain damage can dramatically impair some mental functions (e.g. disrupting just particular aspects of vision, or of language, or of memory) while leaving others relatively intact. By studying the patterns of spared and impaired functions after brain injury, neuropsychologists seek to learn which mental functions can operate independently in the brain, such that damage to one need not impair others. They may also hope to gain a privileged view of a single process when operating in isolation, in the absence of a second process that normally obscures the details of the first. By correlating the site of a lesion with its effects on performance, neuropsychologists can also try to relate particular mental functions to specific brain regions. Finally, identifying the spared and impaired functions in detail for particular patients may lead to more effective rehabilitation of their disorder.

As with any single method, there are many potential pitfalls for the neuropsychological approach. A damaged brain might reorganise itself to some extent, or patients might resort to idiosyncratic strategies in an attempt to circumvent their disorder. This could undermine attempts to derive models of normal function from studies of dysfunction after brain damage. A second problem is that damage to one area of the brain can have effects in other connected areas. As a result, even when damage to one particular area invariably impairs some process, it can be mistaken to conclude that this area is the sole substrate for that process.

Despite such potential problems, the neuropsychological approach has already proved highly fruitful in the study of vision, language, memory, and motor control, where it has succeeded in isolating numerous component processes that can each be associated with particular neural networks (e.g. McCarthy & Warrington, 1990). Research on these topics has illustrated that the potential pitfalls for neuropsychological methods can largely be avoided by combining neuropsychological analysis with other techniques (e.g. with the behavioral study of normal performance; or with functional neuroimaging of normal brain activity during particular tasks, etc.). The logic of this *convergent* approach is that while every method has its potential pitfalls, these are different for different methods. Hence any conclusion is considerably strengthened when results from several different methods all converge on it.

With this in mind, I shall review recent neuropsychological studies of spatial attention, examining whether the evidence from brain-damaged patients can shed further light on some of the major issues that have occupied the literature on normal attention (and conversely, whether these normal issues can be fruitfully applied to the patients). Although the neuropsychological study of attention has a short history in comparison with that for language or memory, current knowledge does suggest that a convergent approach to attention may prove equally fertile.

The various chapters in this book illustrate that "attention" is a broad term, encompassing many different mental and neural processes, with perhaps the only common factor being that all concern the selective processing of information. Some authors (e.g. Allport, 1993) have seen this broadness as a handicap to research, because when one theorist refers to "attention", they may not have the same referent in mind as another theorist. However, from the perspective of a neuropsychologist interested in attention, the situation may differ little from that when studying language or memory. Nobody disputes that an ability like language is made up of many component processes, each of which can lead to different forms of aphasia or dyslexia when disrupted by brain injury; and likewise for memory and the various forms of amnesia. Similarly, there may be numerous component processes behind our attentional abilities, and correspondingly many possible disorders of attention. For simplicity, the present chapter focuses only on neuropsychological deficits that have been attributed to disorders specifically in the *spatial orienting* of attention.

A normal person can readily turn their eyes, head, or body toward stimuli of interest, in order to process them in further detail. For instance, we may fixate a stimulus so that it now falls on the foveal region of the retina, where receptors have highest visual acuity; or we may feel it with the fingers of our preferred hand, which have highest tactile acuity. Such shifts in receptors are referred to as *overt* orienting. Experimental evidence from normals,

described later, shows that we can also direct our attention *covertly* toward particular stimuli, without shifting receptors (as when "looking out of the corner" of our eyes). Stimuli can be judged more efficiently when covertly attended in this way, even though they remain on the same part of the receptor surface.

At least three disorders after brain damage are thought to result from impairments in such overt and covert orienting abilities. Two of these, termed *extinction* and *neglect*, are fairly common following unilateral brain injury, especially to the right hemisphere (Vallar, 1993). The third disorder, *Balint's syndrome*, is associated with bilateral damage, particularly involving the parietal lobe (Balint, 1909; De Renzi, 1982). The hallmark of all three disorders is that the patient responds normally to stimuli in some restricted region, while appearing oblivious to equivalent stimuli in other regions, under circumstances where peripheral sensory or motoric losses (e.g. blindness or paralysis) can be ruled out as explanations for the impairment. In extinction and neglect, stimuli toward one particular side of space often go unacknowledged (in particular, toward the *contralesional* side, i.e. opposite the lesion). In Balint's syndrome, the patient seems spatially disorientated, and to be aware of only one object at any one moment, which may be on either side.

It is important to note from the outset that not all extinction patients are identical, and likewise for neglect and for Balint patients. Indeed, the differences between patients can often be as informative as the similarities. Nevertheless, patients usually must exhibit some defining characteristics to be labeled as suffering from one of these disorders. Although there is some dispute over which defining characteristics are most critical, I will briefly discuss those characteristics that are usually considered diagnostic. I will also introduce possible accounts for each generic disorder, in terms of impaired attention.

EXTINCTION

Extinction is a fairly common neurological sign following unilateral brain damage. It is classically associated with right-parietal damage, but can be seen in some form after various unilateral lesions (Driver, Mattingley, Rorden, & Davis, 1997; Vallar et al., 1994). Patients suffering from extinction are able to judge single stimuli presented on either side quite normally, but when presented with two concurrent stimuli they fail to judge the one further toward the contralesional side. This was first observed by Oppenheim (1885), and further investigated by Anton (1899). Extinction has since been regularly observed in vision, audition, and touch (e.g. Bender, 1952). It is often tested for in the clinic using stimuli produced by the clinician's own hands, an informal method called "confrontation".

For instance, vision might be tested by having the patient directly face and fixate the clinician's nose (so that the clinician can readily see where the patient's eyes are pointing). The clinician then stretches his or her own hands out on either side, so that one falls in the patient's left visual field and one in the patient's right visual field. The patient's task is to detect sudden movement (e.g. finger-wiggling) by either of the clinician's outstretched hands, while always looking straight ahead at the clinician's nose. A patient with right-hemisphere damage, and consequent left extinction, can detect an isolated hand movement in their right visual field (which anatomically projects initially to the intact left hemisphere); and likewise can detect an isolated hand movement in their left visual field (which projects initially to the damaged right hemisphere). However, if the clinician moves both hands at the same time, the left extinction patient will characteristically miss the movement in the left visual field, even though this event would have been detected in isolation. Tactile extinction can similarly be demonstrated by having the clinician touch the patient on either or both sides, and auditory extinction by the clinician making finger-snaps on either or both sides, in an unseen manner.

These informal confrontation measures of extinction provide a surprisingly reliable clinical test for unilateral brain damage (e.g. Vallar et al., 1994). However, they are unsatisfactory experimentally, as stimulus presentation is ill-controlled, fluctuating with the clinician's dexterity. Fortunately, the basic method of presenting stimuli on either or both sides, while requiring central fixation, can easily be adapted for use with computer-generated stimuli, so that the timing, salience, and location of events can be precisely controlled. The basic phenomenon of extinction (i.e. missing contralesional stimuli in just the double-stimulation condition) is readily observed with such computerised methods (e.g. Baylis, Driver, & Rafal, 1993; Di Pellegrino & De Renzi, 1995; Ward, Goodrich, & Driver, 1994), and can be measured more sensitively in this way.

For instance, patients who initially show extinction under the clinical procedure of confrontation often appear to recover over the initial months following their brain injury (especially if this was a stroke which, for metabolic reasons, initially produces a widespread disruption of brain activity that gradually resolves into a focus of abnormal tissue). Eventually extinction may no longer be observed when tested with hand movements. However, extinction can usually still be revealed using computer tests (Baylis et al., 1993; Ward et al., 1994); it is simply that the patient has now recovered to the extent that briefer displays are required to elicit extinction than can be produced by hand. Even with longer displays, contralesional stimuli might still be easier to detect when isolated than when paired with an ipsilesional event, but once performance becomes perfect ("reaches ceiling") in the double-stimulation condition, it then becomes impossible to observe

any greater ease for the isolated condition. These methodological shortcomings of ceiling effects are well known in the normal experimental literature. Unfortunately, they are often overlooked in the neurological literature on attention, a point to which I shall return. Ceiling effects can easily be avoided in computerized extinction tests, by reducing display duration until performance becomes imperfect.

Many authors (e.g. Baylis et al., 1993; Di Pellegrino & De Renzi, 1995), regard extinction as primarily a deficit in covert spatial attention, for several reasons. First, the intact performance for single contralesional events is often held to show that basic sensory processing is intact for the impaired side. The left-extinction patient is evidently not entirely blind, deaf, or insensitive on the left side, as they can report isolated sights, sounds, or touches there. These go undetected only when they must "compete for attention" with concurrent events toward the ipsilesional side.

Second, extinction can be dramatically reduced on double-stimulation trials if the patient is told to ignore any ipsilesional event, reporting only the contralesional events (Di Pellegrino & De Renzi, 1995; Karnath, 1988). This strengthens the idea that contralesional events suffer only when they must compete for attention with *relevant* ipsilesional events. Such competition is usually considered to affect covert rather than overt attention in extinction, as the patient must face and fixate centrally throughout the test, and the use of brief displays rules out any useful role for eye movements.

Finally, the phenomenon of extinction has a suggestive parallel with a robust finding in the normal attention literature, as originally pointed out by Ward et al. (1994). In a variety of tasks, healthy subjects are able to monitor for an occasional target event in two separate streams of information (e.g. rapid series of heard words, or seen characters) even when the streams come from two different locations. Moreover, they may do so as efficiently as when monitoring a single stream (Eriksen & Spencer, 1969; Ostry, Moray, & Marks, 1976; Shiffrin & Gardner, 1972), but with one important exception. Normal performance in monitoring two streams usually breaks down when two *targets* are presented at the same time, one in each stream (Duncan, 1980, 1985; Moray, 1975; see Pashler, 1995, for a concise review). Typically, one or other of two brief targets will be missed when presented concurrently. The usual interpretation is that, while normal subjects can divide their attention across incoming *nontargets* from two streams, and can thus detect a single target in either stream, they nevertheless have great difficulty in attending to two *targets* simultaneously (Duncan, 1980).

This seems analogous to the dilemma of extinction patients. They also exhibit a difficulty only with two concurrent target events, having no problem when a single target appears in just one stream (e.g. on the contralesional side) paired with a nontarget in the other stream/side (i.e.

with an entirely irrelevant item on the ipsilesional side, as in the Karnath, 1988, study; or with just a non-event on the ipsilesional side, as when only a contralesional target is presented in total isolation). Extinction may differ from the normal difficulty with multiple targets only in severity and spatial specificity. Extinction can be so severe that even a temporally extended salient event (such as a hand movement) can go quite undetected, whereas a normal subject would miss only one of two concurrent targets if they were very brief. Furthermore, one can reliably predict *which* of two concurrent targets will be missed by an extinction patient (i.e. the one further to the contralesional side), whereas this may be unpredictable in a normal subject. Nonetheless, it seems plausible to characterize extinction as a spatially specific exaggeration of the normal difficulty in attending to multiple targets, caused by a bias in attention toward the ipsilesional side.

Kinsbourne (1977, 1993) has suggested a simple neural mechanism for controlling the lateral direction of both overt and covert spatial attention, which could produce such a bias toward the ipsilesional side of space following unilateral injury. His account stems from basic anatomical and physiological facts which apply to many species, including humans. First, sensory pathways are typically "crossed", so that information from one side of space projects to the opposite hemisphere. As we have seen, the left visual field projects initially to the right hemisphere, and the right visual field to the left hemisphere. Similarly, touch information from the left and right sides of the body project to the right and left hemispheres respectively. Finally, while auditory sensory pathways are less fully crossed, the left and right ears do have stronger inputs to the right and left hemispheres respectively.

Motor pathways have analogous crossing. Thus, the right hand and left hand are primarily controlled by the left and right hemispheres respectively. Moreover, physiological stimulation studies in animals, together with lesions studies in animals and humans, demonstrate that left turns of the body, head, and eyes primarily involve activity in right-hemisphere structures, whereas right turns primarily involve left-hemisphere activity.

These basic facts led Kinsbourne (1977, 1993) to propose that the two hemispheres induce opposing contralateral orienting tendencies when activated. Stimuli on the left activate the right hemisphere, thus inducing a leftward turn toward them, while stimuli on the right activate the left hemisphere, inducing a right turn. To some extent, humans can also choose which way to turn, regardless of any stimulation. To account for this voluntary control, Kinsbourne must additionally propose that an intention to turn in one direction corresponds to a deliberate activation of regions in the appropriate (contralateral) hemisphere. Which way the person actually orients will then depend on the *relative* activation of regions in the two hemispheres, produced by stimuli and/or by intentions. The person will

orient toward the side opposite the more active hemisphere, and will do so further as the relative difference in activity increases.

Kinsbourne (1993) has further argued that similar opponent principles apply in the control of *covert* spatial attention, as well as for overt orienting (although different regions within the hemispheres may well be responsible in the covert case). Thus, the appropriate right-hemisphere lesion could bias covert as well as overt orienting toward the right side of space. Such an account can provide a natural explanation for the basic phenomenon of extinction, primarily because the account stresses the *relative* activity of the two hemispheres, as explained next.

Specifically, a lesion to one side of the brain may be expected to result in less activity than normal in response to the stimuli that project to that hemisphere; that is, stimuli toward the contralesional side of space. As a result, stimuli on this side should produce less (covert and overt) orienting than usual, on Kinsbourne's account. However, the crucial point is that this disadvantage will be largely immaterial when a contralesional event is presented *in isolation*, because it then has no rival stimulus to compete with. Although it may produce less activity than normal, any activity at all should result in some orienting toward it, as there is no stimulus to induce an opposing orienting tendency. By contrast, on a double-stimulation trial, the disadvantage for the contralesional side should thus become more apparent, and hence produce extinction, because in *relative* terms the ipsilesional event will now be strongly favored and the contralesional event correspondingly disadvantaged.

Extinction is not only found between events in different visual fields. If two events are presented *within* the "good" ipsilesional field, the stimulus that is further toward the contralesional direction may be extinguished (Kinsbourne, 1977). Kinsbourne (1993) explains this by proposing that more peripheral items produce a greater relative difference in activation between the hemispheres than more central items; in other words, the further that a stimulus is in one direction, the more it will activate the contralateral hemisphere over the ipsilateral. As a result, hemispheric competition will produce a dynamic *directional* bias, rather than a static impairment for fixed regions of the visual field. This directional bias will favor stimuli that are relatively ipsilesional over those that are relatively contralesional, within each visual field as well as between fields. This model provides a general account for the most basic phenomena of extinction. However, Kinsbourne's model needs considerable elaboration to account for the more detailed findings that we consider later.

UNILATERAL NEGLECT

Like extinction, neglect is relatively common following unilateral brain injury, especially after large lesions to the right parietal lobe (Vallar, 1993). The earliest clinical descriptions of neglect date from the nineteenth century (e.g. Hughlings Jackson, 1876), but detailed case-studies scarcely began until the 1940s (e.g. Paterson & Zangwill, 1944), and the possible relevance of neglect for models of normal attention was not widely appreciated until the 1980s (e.g. Posner, Walker, Friedrich, & Rafal, 1984).

As in extinction, neglect patients fail to acknowledge or respond appropriately for stimuli toward the contralesional side under the appropriate circumstances. However, neglect can be apparent on a wide range of measures in addition to the extinction test (although many of these measures also rely on ipsilesional events competing with contralesional events). Neglect patients are usually severely disabled by their disorder in everyday life; by contrast, a mild extinction patient may show little impairment to the casual observer in daily behavior, perhaps because the temporally extended nature of many real-world tasks allows them to circumvent their difficulty with concurrent discrete target events.

On casual observation, neglect patients may have their eyes, head, and/or body noticeably turned toward the ipsilesional side (although they may be capable of turning contralesionally when asked to do so). They may ignore people who approach or address them from the contralesional side; may fail to eat food toward the contralesional side of their plate; may omit contralesional words or letters when reading text; may fail to groom the contralesional side of their body; and if mobile, may collide with contralesional objects, and get lost when navigating because of a propensity to turn ipsilesionally at each junction (see Bisiach & Vallar, 1988, for review). Furthermore, they may be frustratingly unaware (so-called anosagnosia) of their contralesional deficits.

Common clinical tests for neglect in visual behavior include cancellation tasks (where the patient is given a page with various items distributed across it, asked to mark them all with a pen, and typically fails to mark items toward the contralesional side); bisection tasks (where the patient is given some stimulus, such as a horizontal line, and asked to mark its center, typically placing the mark well to the ipsilesional side); and drawing tasks (where the patient is asked either to draw an object (e.g. a clockface) from memory, or to copy a presented drawing, tending to omit contralesional elements in both cases). Examples of neglect in each of these informal tests are shown in Fig. 8.1.

Neglect, as defined by an impairment for more contralesional stimuli, has also been observed in auditory, tactile, and proprioceptive tasks. Patients may fail to respond to contralesional sounds, or may mislocate them

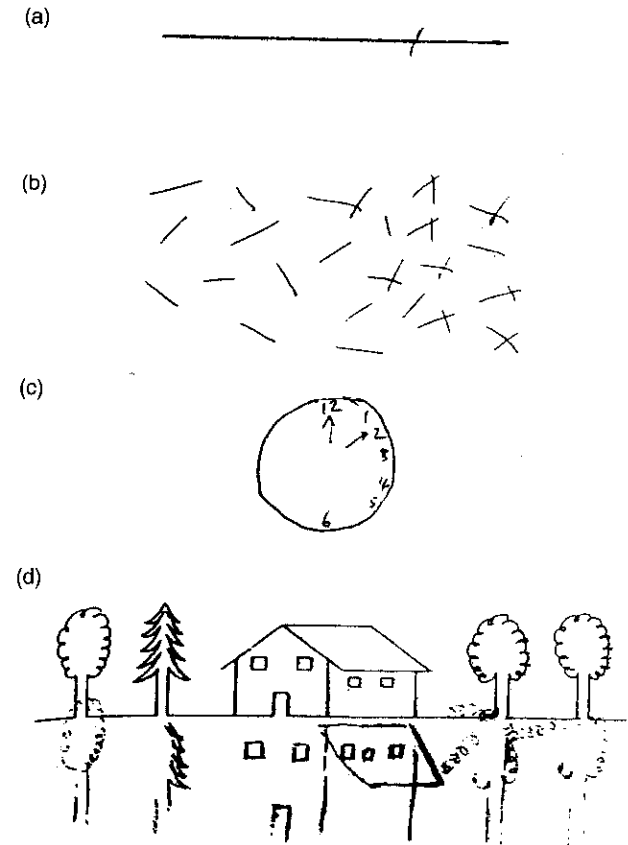


FIG. 8.1. Examples of left neglect after right-hemisphere damage in several informal paper-and-pencil tasks: (a) Line bisection; the patient marks well to the right of true center; (b) Line cancellation; the patient fails to mark lines toward the left of the page; (c) Drawing from memory; details on the left of the object are omitted; (d) Copying; the original drawing is shown above, with the patient's reproduction below (adapted from Gainotti et al., 1972). Note that details on the left of each object are miscopied, rather than just details to the left of the entire scene.

towards the ipsilesional side (so-called allochiria; Bisiach, Cornacchia, Sterzi, & Vallar, 1984); they may fail to explore contralesional space in the tactile modality (Bisiach, Capitani, & Porta, 1985) and they may misjudge the proprioceptively sensed position of their own limbs when these are towards the contralesional side of space (Vallar, Antonucci, Guariglia, & Pizzamiglio, 1993).

Many authors consider extinction to be just a mild form of neglect (see Driver et al., 1997), and clinical textbooks often suggest that extinction

persists as the patient gradually recovers from the more florid symptoms of neglect that can be apparent in the early weeks after their initial stroke or trauma (e.g. Heilman, Watson, & Valenstein, 1985). Others argue that extinction and neglect may be fundamentally distinct disorders (e.g. Di Pellegrino & De Renzi, 1995), citing observations that patients can show neglect on the tasks just described and yet no extinction, or vice versa. These two complimentary patterns of selective impairment provide what is known as a "double dissociation". Such a pattern is often taken by neuropsychologists as firm evidence that the dissociated tasks reflect distinct processes (e.g. Shallice, 1988).

However, the reported dissociations between neglect and extinction have not as yet ruled out the possible methodological problem of ceiling effects that was raised earlier. For instance, the patients who showed neglect on paper-and-pencil tests, yet no extinction on confrontation, might well have shown extinction if brief computerized displays had been employed instead. Equally, the paper-and-pencil tests for neglect can sometimes be insensitive, also due to ceiling effects. For instance, the relative difficulty of canceling contralesional items can be overlooked in a patient who eventually cancels all the items, but labors over the more contralesional ones. Their contralesional difficulty would be totally obscured in standard cancellation scores, which consider only how many items were marked on completion of the task, rather than the timing, accuracy, or effortfulness of each mark.

Nonetheless, it should be acknowledged that neglect patients typically exhibit strikingly abnormal performance in fairly naturalistic, temporally extended tasks (see examples in Fig. 8.1), whereas extinction patients may show an impairment only in one very constrained task (i.e. detecting two concurrent targets). This difference mirrors the differing degrees of impairment in everyday life for the two broad classes of patient, and suggests that more processes may be disrupted in those patients who show signs of neglect as well as extinction.

Naturalistic tasks like drawing, at which many neglect patients are impaired, are necessarily more complex and unconstrained than the more "artificial" measure of extinction. One consequence is that it can be hard to identify exactly which component processes are impaired in tasks like copying or cancellation, as compared with more restricted tasks like the extinction measure. One obvious way in which most neglect measures differ from the extinction test is that the patient is allowed (indeed, often required) to explore the stimulus in the neglect measures, often by moving their eyes, head, or hand across the scene. The neglect tests might therefore be more sensitive to any deficits in active exploration (be this overt or covert) toward one side of space (Karnath & Fetter, 1995). In general, the standard neglect tests have a more substantial motoric component than the extinction test (see Driver et al., 1997; Mattingley & Driver, 1977).

There is now abundant evidence for double dissociations between the various traditional measures of neglect themselves. That is, a patient can show severe neglect on one measure (e.g. cancellation), but not on another (e.g. line bisection; Halligan & Marshall, 1992). Such dissociations raise the possibility that neglect is a multi-component disorder (Rafal, 1994), as has previously been concluded for aphasia, amnesia, and most of the other neurological syndromes that had been closely analyzed prior to detailed studies of neglect. In other words, the majority of neglect patients may suffer from impairments to a large number of spatially selective processes, with only a minority of patients suffering from damage to restricted subsets of these multiple component processes.

However, it remains controversial whether some of the dissociations already reported for neglect (e.g. between cancellation and bisection tasks) reflect a distinction between two fundamentally separate aspects of spatial cognition. Instead, they may just reflect the different ways in which two crude measures of the same underlying deficit can become insensitive. An analogy with a very different area of psychology, namely the measurement of intelligence, may help to explain the methodological point here. The fact that bisection and cancellation tasks usually both reveal neglect can be considered analogous to IQ testers finding that two types of items on their test-battery (say, visual versus verbal problems) usually both provide a reasonable measure of general intelligence across most people. However, on closer inspection of individual performance, the IQ tester may then find that some people do better on visual problems than verbal, while others do the reverse. Ought they to conclude that there is no such thing as general intelligence (or in our case, neglect), but rather many different abilities? Or should they conclude instead that both types of question (or in our case, both measures of neglect) provide approximate measures of an underlying factor, with each measure being approximate for different reasons, because every measure involves some unique process in addition to the underlying factor of interest?

Such disputes continue over the correct interpretation for the various dissociations that have already been found within neglect patients (see the various opinions in Halligan & Marshall, 1994a). Nevertheless, there is an increasing consensus that various aspects of neglect may be attributable to deficits in corresponding aspects of attention (e.g. Rafal, 1994; Robertson & Marshall, 1993). The rationale for invoking attention is reminiscent of that for the case of extinction; primarily, that peripheral sensory or motoric losses do not provide a complete account of the contralesional deficit, for several reasons.

First, while many neglect patients do have sensory impairments, such as visual field losses ("hemianopia") for the affected side, florid neglect can nevertheless be observed in the complete absence of any such sensory

impairment (Halligan, Marshall, & Wade, 1990). Conversely, purely hemianopic patients rarely show neglect in everyday life, nor in paper-and-pencil tests, as they can compensate for their blind region simply by moving their eyes. Thus, peripheral sensory loss seems inadequate as an explanation for neglect.

Second, while many neglect patients are hemiplegic (paralysed on the contralesional side of their body), this is by no means true for all of them, and conversely hemiplegia need not lead to neglect. A hemiplegic patient can still move their ipsilesional limbs toward the contralesional side of space, likewise their body, head, and eyes. In principle, the same is true for most neglect patients, but unlike a purely hemiplegic patient they will often fail to make such movements spontaneously, and may exhibit preserved motor behavior toward contralesional items only when explicitly cued to do so. Thus, *peripheral* motor impairments on the contralesional side seem inadequate as a complete explanation for neglect, although raised thresholds for overt responding toward contralesional events seem likely.

Faced with the striking abnormalities in neglect patients' performance, and with the apparent inadequacy of purely sensory or motoric explanations, one is compelled to postulate a bias in some spatially selective process(es) which intervene between initial sensation and ultimate response. Processes of this kind seem very close to most existing definitions of spatial attention (although it must be admitted that such definitions are a little vague). The temptation to invoke an ipsilesional attentional bias becomes even stronger given findings that neglect can be temporarily ameliorated by manipulations that encourage the patient to attend toward the contralesional side (e.g. Riddoch & Humphreys, 1983, for line bisection). Much rehabilitative effort has been based on such observations, repeatedly encouraging the left neglect patient to look, scan, or attend leftward (e.g. Diller & Riley, 1993). Unfortunately, current findings suggest that such therapies tend to produce only limited improvements, which remain closely tied to the intervention setting (Robertson & Marshall, 1993). The essential problem in neglect may be that while the patient can, in principle, look or attend toward the contralesional side, they usually fail to do so spontaneously.

The neglect I have described thus far might be largely due to failures just in *overt* orienting toward the contralesional side, and ipsilesional biases in fixation scanning are indeed well documented in neglect patients (e.g. Karnath & Fetter, 1995; Walker, Findlay, Young, & Lincoln, 1996). However, two classic findings demonstrate that covert factors can also be involved. Bisiach and Luzatti (1978) observed that neglect can sometimes arise even in *imagery* tasks. Their patients had to describe verbally the buildings in a familiar cathedral square (from their home city), when first imagining themselves facing toward the cathedral. The patients, with left

neglect after right-hemisphere damage, named buildings on the right from this imagined perspective, but tended to omit buildings on the left. They were later asked to perform the same task, but now imagining themselves on the opposite side of the square, facing away from the cathedral. They tended to omit buildings on the left from this new perspective—that is, those that had previously fallen on the right and had then been recalled!

Such neglect in the imagination has since been confirmed with many other patients and tasks. However, in some cases imaginal neglect has been found without any ostensive neglect in visual behavior (Guariglia, Pado-vani, Pantano, & Pizzamiglio, 1993), or vice versa (Anderson, 1993), suggesting that imaginal neglect may be a separable problem from the other forms of neglect. Nevertheless, when observed, imaginal neglect clearly cannot be attributed solely to a failure in *overtly* orienting receptors toward contralesional target items, as no target items are physically present on any receptors during the imaginal task.

A final demonstration that covert factors can be involved in neglect provides perhaps the best rationale for considering it (at least partly) to be an attentional deficit. Neglect patients can show specific abnormalities in components of covert spatial attention, as operationally defined by performance measures. Posner (e.g. 1980) introduced one performance method for studying covert shifts of spatial attention in normal subjects, which has since been widely used. In basic form, the subject must detect or discriminate a visual target which can appear in various locations (say, on the left or on the right). The subject's attention is cued to one location or another (e.g. by an uninformative event at that location, or by an instruction that the target is most likely there), but central fixation must be maintained throughout. Even though the subject does not make any eye movement, the robust finding is that a variety of judgments is more efficient for targets at the cued location ("valid" trials) than for targets appearing elsewhere ("invalid" trials). This normal performance benefit on valid trials is usually attributed to a covert shift of spatial attention toward the cued locus.

Posner et al. (1984) administered variants on this cuing task to patients with unilateral parietal damage, suffering from various degrees of neglect and extinction. They found that these patients showed the normal pattern of facilitation following valid cues, for targets in either visual field. That is, the patients were able to shift their covert attention when cued to do so, even in the contralesional direction. However, the patients were abnormally slow to judge contralesional targets if these were preceded by an invalid cue to the ipsilesional side. Posner et al. attributed this result to a specific difficulty in "disengaging" attention from relatively ipsilesional locations once covert attention had been drawn there.

This basic pattern of abnormally poor performance for contralesional targets after invalid ipsilesional cues has since been replicated in further

unilateral parietal patients (e.g. Posner, Walker, Friedrich, & Rafal, 1987), and the extent of the abnormality has been shown to correlate with clinical measures of neglect severity (Morrow & Ratcliffe, 1987). However, the specific interpretation in terms of a "disengage" difficulty has been disputed (Cohen, Farah, Romero, & Servan-Schreiber, 1994; Rorden, Mattingley, Karnath, & Driver, 1997). Nevertheless, the result does demonstrate an abnormality in covert attention, as operationally defined, in neglect patients. Note that this abnormality has some striking parallels with extinction. In particular, the deficit for targets at contralesional locations is most pronounced when they must compete with ipsilesional locations (i.e. after an ipsilesional rather than contralesional cue). For this reason, the result can be given a similar explanation as for extinction, in terms of hemispheric competition based on relative activation (Kinsbourne, 1993; Cohen et al., 1994).

BALINT'S SYNDROME

This cluster of deficits was first described by Balint (1909), although similar cases have since been reported (e.g. Baylis, Driver, Baylis, & Rafal, 1994; Driver, Goodrich, Ward, & Rafal, 1996; Holmes & Horrax, 1919; Humphreys & Riddoch, 1993; Luria, 1959). It is associated with symmetrical bilateral lesions, involving the posterior parietal lobe or parieto-occipital junction. It is less common than the unilateral deficits discussed so far, if only because bilateral lesions are rarer. As originally described, Balint's syndrome is extraordinarily disabling, and involves three major deficits.

First, there may be severe difficulties in spatial localization; for example, as suggested by gross misreaching toward visual objects. Second, there may be "fixity of gaze"; that is, a difficulty in executing saccades or in tracking a moving event once a visible item has been fixated. Third, there is a characteristic tendency for visual experience to be dominated by just one object at a time (termed "simultanagnosia"). This can be apparent in the patients' descriptions of what they see (e.g. "When I see your spectacles I cannot see your face"); in their everyday behavior (e.g. failing to light a cigarette because when they see the match they reportedly cannot see the cigarette, and vice versa); and also in their psychophysical performance.

For instance, they may be able to judge whether a stimulus is square or rectangular (when each display comprises just one object) yet be quite unable to compare the length of equivalently extended but unconnected lines (because the display now comprises multiple objects; Holmes & Horrax, 1919). They may also be able to read individual words (presented in isolation as single objects), yet be unable to identify the component letters individually on a visual basis, even for words that are correctly read

(because when the letters must be considered individually, each word now comprises several objects; Baylis et al. 1994).

There are now grounds for suspecting that the three major characteristics of Balint's syndrome may be dissociable (De Renzi, 1982); for instance, patients may show just misreaching without the other two problems. It may be that the three deficits often co-occur simply because the brain regions involved in each deficit share some anatomical relation, which may have little to do with their cognitive function. For instance, three functionally separable brain regions or networks might in principle all be sustained metabolically by common blood vessels, in which case a major stroke would be likely to damage all three networks together even though they share no functional relation.

It is for this kind of reason that neuropsychologists often place more faith in *dissociations* (i.e. observations of which processes can be impaired independently) than in *associations* (i.e. which processes tend to be impaired together). Some anatomical factor, such as a common blood vessel, might also produce frequent but nevertheless non-functional associations in neglect, or in any other disorder for that matter. In practice, we often have some useful knowledge of the relevant blood vessels, and of other anatomical interconnections, and so may be able to assess the plausibility of any particular association being of this non-functional kind. Nevertheless, in principle one can always question the interpretation of a neuropsychological association. For instance, while most neglect patients apparently show both a difficulty in ignoring ipsilesional visual distractors (Robertson & Eglin, 1993) and a tendency to err in the ipsilesional direction when reaching for visual objects (Harvey, Milner & Roberts, 1994), there may be no functional relation between these two deficits. The misreaching might be a separate problem, as it may also be in the case of patients suffering from Balint's syndrome.

The grounds for considering components of Balint's syndrome as attentional deficits have been less articulated than for extinction and neglect. To my knowledge, no-one has argued that the misreaching and eye-movement difficulties are specifically attentional, even though both might be considered extreme deficits in overt orienting. However, the simultanagnosic tendency to lock onto individual visual objects has often been regarded as an attentional deficit (e.g. Baylis et al., 1994; Humphreys & Riddoch, 1993), primarily because this aspect of the disorder does not seem reducible to peripheral sensory loss. Particular regions of the visual field may be neglected or reported depending on whether they are linked by a common object to other regions (e.g. Humphreys & Riddoch, 1993; Luria, Pravdina-Vinarskaya, & Yarbuss, 1963). Moreover, the object-based simultanagnosia is not simply due to *overt* orienting factors, as it can be observed in displays too brief to permit eye-movements (Driver et al., 1996). Finally, Balint

patients can show specific abnormalities in Posner's cuing measure of covert orienting (Verfaellie, Rapcsak, & Heilman, 1990).

It has been suggested (e.g. Driver et al., 1996; Farah, 1990) that the object-based aspect of Balint's syndrome may just be a form of bilateral rather than unilateral neglect, consistent with the bilateral lesions. Balint patients may suffer from a difficulty in "disengaging" covert attention from one object in order to shift it in *any* other direction, rather than only in the contralesional direction as for the unilateral parietal patients studied by Posner et al. (1987). It should be noted, however, that Kinsbourne's (1977, 1993) account of orienting in terms of hemispheric competition is much less successful in explaining any such "disengage" deficit after bilateral damage than after unilateral damage, as the relative levels of activity in the two hemispheres might remain roughly balanced after symmetric bilateral lesions.

Having introduced the three general deficits of extinction, neglect, and Balint's syndrome, I now turn to consider what light experimental studies of these neurological disorders might shed on some major issues from the *normal* attention literature.

GROUPING EFFECTS ON SPATIAL SELECTIVITY

A recent debate in the normal literature on visual attention (e.g. Baylis & Driver, 1993; Driver & Baylis, 1989; Duncan, 1984; Kanwisher & Driver, 1992) has concerned whether covert attention is directed to unsegmented regions of space, or to segmented perceptual groups that are likely to constitute coherent objects. A common metaphor for covert attention invokes an attentional "spotlight" that "illuminates" relevant areas of space (e.g. Posner, 1980). If taken literally, this metaphor might imply that attention is directed to particular locations with little or no preprocessing of any stimulus structures there.

On the other hand, since the early days of Gestalt psychology it has been well established (Wertheimer, 1923; Pomerantz & Garner, 1973) that human perceptual systems *segment* their input, in order to group together those stimulus elements that are likely to belong to a common object (e.g. grouping together visual elements with common color, motion, or alignment). As our actions must ultimately be selectively directed toward individual objects, some theorists have proposed that it would be efficient for covert attention to operate on segmented objects rather than just on unstructured regions of space (e.g. Driver & Baylis, 1989; Duncan, 1984; Neisser, 1967).

In essence, the recent debate between space-based versus object-based accounts of normal covert attention is just a new variation on a very old question; namely, how much perceptual processing takes place unselectively,

before attention acts to boost processing for just a subset of the incoming information? The current version of this question focuses on how much grouping of the scene into distinct objects takes place before spatial selection is completed.

In the normal literature, space-based and object-based models of attention have often been presented as mutually exclusive alternatives (e.g. by Driver & Baylis, 1989). However, many hybrid views are possible. For instance, it may be that covert attention does operate within a spatial medium (as argued by Tsal & Lavie, 1993), but that grouping processes modulate the spatial extent of the attended region (Lavie & Driver, 1996). As we shall see, current neuropsychological evidence strongly supports this hybrid view.

To the extent that extinction and neglect are viewed as deficits in attention, their ostensibly spatial nature supports the view that there are space-based components to covert attention, which can be biased toward one side or the other by the appropriate unilateral lesion. However, recent evidence suggests that the extinguished or neglected region can depend strongly on Gestalt grouping factors, as well as on its location. These results imply that grouping still takes place on the extinguished or neglected side, and thus that grouping processes do not depend entirely on the components of spatial attention that are impaired by the brain damage.

Segmentation and Extinction

To my knowledge, at the time of writing, only a few studies have looked for effects of Gestalt grouping on extinction, and these come from my own laboratory. Ward, Goodrich, and Driver (1994) examined two right-hemisphere patients with left extinction, and found that left-sided misses on computerized double-stimulation trials were dramatically reduced if the two concurrent events formed a good perceptual group. For instance, there was less extinction between two horizontally aligned brackets (i.e. a display like "[+]") than between an adjacent bracket plus dot (i.e. "[+ o", or "o +]"). Several normal performance measures have previously shown (e.g. Pomerantz & Garner, 1973) that two aligned brackets tend to be grouped together as a single rectangular object by the visual system. Ward et al. therefore concluded that extinction is reduced when the two concurrent targets can be linked into a single group.

Driver, Goodrich, Ward, and Rafal (1996) similarly showed that visual extinction can be virtually eliminated when the two concurrent targets are literally linked together, using the "bar-bell" versus "two-circle" displays shown in Fig. 8.2. In further studies we have shown that extinction can be similarly modulated by more sophisticated grouping processes than mere

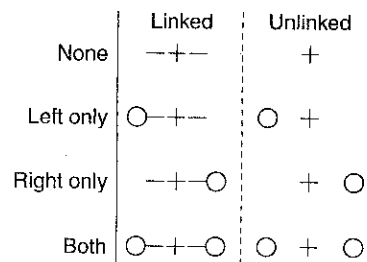


FIG. 8.2. Example stimuli from Driver et al.'s (submitted) study of grouping effects on extinction and on Balint's syndrome. Eight possible displays are illustrated, with the four linked possibilities separated from their four unlinked equivalents by the vertical dotted line. Linked and unlinked displays differed only in whether an uninformative horizontal line was presented together with the circular target events that had to be detected and localized. The patients fixated a central cross, whose position relative to each subsequent display is illustrated. They were then presented with either no circular target event on the two sides, a target on just the left side, on just the right, or on both sides. A right-parietal extinction patient tended to miss left targets only in the unlinked-both displays. Similarly, a bilateral parietal Balint case tended to miss circular targets only in the unlinked-both displays, being equally likely to report just one circle from either side. Both patients' deficit was dramatically reduced in the linked-both displays, presumably because these contain just one object (a bar-bell) rather than two competing objects (the unconnected circles).

visible connectedness or alignment. For instance, two horizontal visual bars produce less extinction when interpreted as the two ends of a single long stick jutting out from either side of a central occluder, rather than as two separate short sticks appearing in front of the same central object (Mattingley, Davis, & Driver, 1997). Equally, two events produce less extinction when together they form a Kanizsa (1979) illusion of a single subjective figure (Mattingley et al., 1997.) Both these effects imply that three-dimensional grouping processes, involved in generating depth interpretations from two-dimensional visual inputs, do not depend on the attentional components that are impaired in extinction patients. This accords with recent proposals that such grouping processes may also operate in a "pre-attentive" manner for normal subjects (Davis & Driver, 1994, in press; Enns & Rensink, 1994).

A further parallel with normal research concerns Duncan's (1984) work. He has found that the performance cost that healthy subjects usually show when they must divide attention across two concurrent targets (Duncan, 1980; Moray, 1975) can be eliminated if the concurrent targets are both attributes of a common object. A similar principle seems to apply for our extinction patients, who show little difficulty with concurrent targets when these are grouped into a single object.

Taken together, these findings suggest the following account. The normal difficulty with multiple concurrent targets is exacerbated in extinction. As in

normals, target objects compete for selection. The more ipsilesional of the two objects will usually win this competition in the patients, due to the spatial imbalance produced by their lesion. However, this imbalance has little effect when the two-target events are linked into a common object (e.g. the bar-bell at bottom left of Fig. 8.2), because the two events now become allies rather than competitors for selection. That is, selection of the ipsilesional event now tends to bring the contralesional event with it, because the two events are grouped together.

This general account of extinction is consistent with two broad types of model. First, grouping processes may entirely *precede* spatial attention (as originally proposed by Neisser, 1967), and may thus be totally unaffected by any pathological biases in spatial attention. Second, grouping might *interact* with spatially selective processes, so that both types of operation overlap in time, with each influencing the other (Farah, Wallace, & Vecera, 1993; Humphreys & Riddoch, 1993; Ward et al., 1994). In this way, relatively preserved grouping processes might aid relatively impaired spatial selection in extinction patients. The existing neuropsychological (and normal) evidence has not yet decisively distinguished between these two kinds of model. However, note that on either view the spatial extent of both normal and pathological attention is substantially modulated by grouping processes. Clearly, human covert attention is rather more sophisticated than a simple "spotlight" metaphor implies.

Segmentation and Neglect

As with extinction, the ostensibly spatial nature of neglect might seem consistent with purely space-based models of normal attention. Neglect invariably applies for information toward the contralesional side, and thus might be accounted for by an ipsilesional bias in space-based components of attention. However, as with extinction, recent results suggest that the particular area that is neglected can strongly depend on how the scene is grouped, consistent with models in which grouping processes precede or interact with the spatial selection that is disrupted in neglect.

Suggestive evidence for this comes from the errors in copying made by some neglect patients. In Fig. 8.1d, the left-neglect patient's copy omits details toward the left of each object, but faithfully reproduces the right side of objects that fall well to the left of the scene. One interpretation of such performance would be that the patient's visual system can still segment the scene into distinct objects across both visual fields, with neglect arising only at a later stage of attending to each object in turn to copy its details.

Driver, Baylis, and Rafal (1992) examined this possibility in a single case of left neglect, using a simplified visual-judgment task that was designed to eliminate the possible contributions that eye, head, or hand movements, plus

planning processes, might make to abnormal copying performance like that in Fig. 8.1d. As discussed earlier, copying is a naturalistic task that can demonstrate the serious consequences of neglect, and can suggest testable hypotheses, but which remains rather intractable for experimental purposes because of the large number of component processes that may be involved.

In Driver et al.'s simplified task, the left-neglect patient was shown displays like those in Fig. 8.3a and b, comprising a horizontal rectangle divided by a random jagged contour towards its left (Fig. 8.3a) or right (Fig. 8.3b). The smaller of the two resulting areas was bright green, while the larger area was dark red, with the entire rectangle appearing on a black screen. Normal observers unambiguously see the smaller bright-green region in such dis-

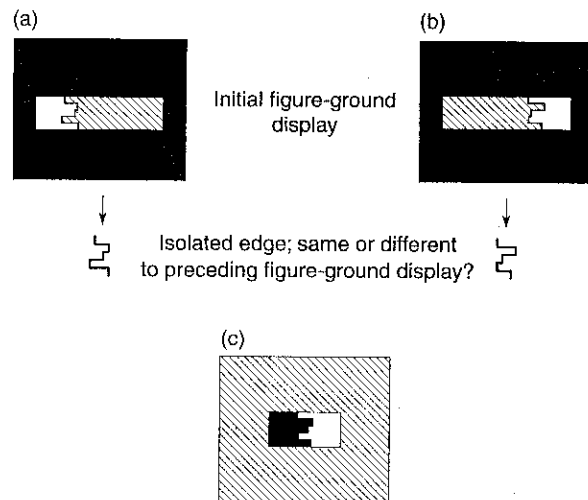


FIG. 8.3. (a) and (b) give a schematic depiction of two types of display from Driver, Baylis, and Rafal (1992). Each trial began with a figure-ground display against a black screen, comprising a rectangle divided by a random, jagged contour into a large red area (shown with diagonal shading) and a smaller bright green area (shown in white; on the left in a, and on the right in b). Normal observers saw a green figure against a red background in these displays, the jagged edge appearing to belong to just the green shape. The task for a left-neglect patient was to compare the jagged dividing edge in each figure-ground display to an isolated edge which appeared half a second later in the center of the screen (one is shown at the bottom of a, and of b). This isolated edge was equally likely to match (as illustrated) or to differ from the preceding figure-ground display. The left-neglect patient was more accurate at comparing the edges when the initial figure had appeared on the left (as in a) rather than on the right (as in b). This is because the critical jagged edge appears to the right of the green figure in a, but to the left of this figure in b. (c) An ambiguous figure-ground display, which can be seen as a white shape against black, or a black shape against white. Marshall and Halligan (1994) found that their left-neglect patient could reproduce the jagged dividing edge when asked to copy the shape on the left (in this case black), which has the edge on its right, but could not reproduce the very same edge when asked to copy the shape on the right, which has the critical edge on its left.

plays as a figure against a red background, with the dividing jagged contour appearing to belong just to the green shape. The patient's task was to face and fixate the center of each rectangle, while concentrating on the jagged dividing edge for comparison with another jagged edge that appeared immediately afterwards, in total isolation (see bottom of Fig. 8.3a or b) at the center of an otherwise empty black screen. In this way we could measure how well the patient represented edges at particular locations, without requiring him to draw anything, and without allowing him to make any eye-, head-, or hand-movements. All the patient had to do was say whether or not the jagged edge in the initial rectangle matched the subsequent isolated edge.

Our question was how the left-neglect patient's performance would vary as a function of whether the green figure was on the left (Fig. 8.3a) or right (Fig. 8.3b) of the original display. The most straightforward prediction might be for poorer performance when the figure was toward the left (Fig. 8.3a), as here the critical information (i.e. the jagged edge) fell further toward the contralesional (and thus "bad") side of the patient. However, note that in this situation the jagged contour falls toward the ipsilesional (right) side of the small green shape that would be figural for a normal observer. By contrast, when the green figure appeared at the ipsilesional end of the rectangle (and thus to the "good" side of the patient) the jagged edge now fell to the contralesional (left) side of the green figure (see Fig. 8.3b). Thus, if the patient were able to segment figures from ground in both the ipsilesional and contralesional visual fields, with his neglect subsequently applying just to the contralesional side of any figure, he should actually perform worse when judging the contours that originally fell on his "good" ipsilesional side (because these fell on the contralesional side of the figure, see Fig. 8.3b). The results clearly supported this figure-based prediction.

Further evidence consistent with such figure-based neglect has since been reported for another case of left neglect after right-hemisphere damage (Marshall & Halligan, 1994), in a copying task for ambiguous figure-ground displays like the one shown in Fig. 8.3c, which can be seen either as a white shape on a black background, or vice-versa. The patient could accurately copy the jagged edge at the center of each such display when asked to draw the shape on the left side of the display (which has the critical jagged edge on its right), but was quite unable to produce the very same edge when asked to copy the shape on the right (which has the critical edge on its left).

The results from these two studies suggest that, at least in some cases, neglect can apply to the contralesional side of segmented objects rather than just toward one side of unsegmented space. This implies that segmentation processes precede or interact with those stages of spatial selection at which the neglect arises. It remains to be seen whether this applies for the majority

of neglect patients, or for only a specific sub-group. Note that on any account of figure-based neglect in terms of imbalanced hemispheric competition (e.g. Kinsbourne, 1993), one side of a shape must activate a particular hemisphere more than the other side of that shape, even when both sides fall within a single visual field. This remains a physiological possibility, but has yet to be confirmed. Such an explanation would be similar to that proposed for visual extinction within one visual field, except that figure-ground segmentation processes would now also be involved.

The proposal that neglect can apply to one side of segmented shapes immediately raises the question of exactly what divides a shape into its two distinct sides. Driver and Halligan (1991) suggested one possibility, based on research into normal human perception and machine vision. Various authors (e.g. Marr & Nishihara, 1978) have proposed that the visual system describes shapes relative to their principal axis of symmetry and/or elongation, with this axis effectively splitting a shape into two sides. Driver and Halligan tested whether neglect can indeed apply to the contralesional side of a shape's principal axis, using displays like Fig. 8.4a or b, each comprising two nonsense shapes, with one above the other. For many such displays, their left-neglect patient had to judge verbally whether the two shapes were the same or different (this again eliminates the motoric and planning

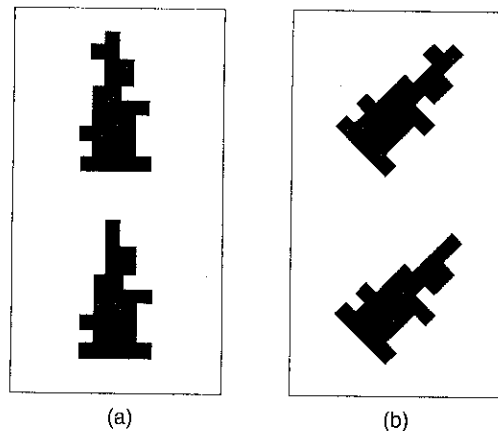


FIG. 8.4. (a) Typical upright display from Driver and Halligan (1991). Their left-neglect patient had to decide whether two black nonsense shapes, one above the other, were the same or different. When different, the discrepancy was only slight. For instance, there is just one additional square element on the left of the top shape in the example shown. The patient tended to miss such differences on the left, while detecting comparable differences on the right. (b) Typical tilted display from the same study. Importantly, the patient continued to miss differences (such as the one illustrated) which fell to the left of the elongated shape's principal axis, even though these differences now fell to the right of the patient.

components of tasks like copying). The shapes were identical on 2/3 of trials, but had a slight difference for the remaining trials, on either the left (as illustrated) or the right.

Unsurprisingly, when the two shapes were upright (Fig. 8.4a) the patient tended to miss differences on the left but not the right, consistent with her left neglect. The critical result was that the *same* differences tended to be neglected (or detected) even when the shapes were both tilted 45° clockwise, so that differences on the top left of the object now fell toward the patient's right (Fig. 8.4b), whereas differences on the bottom right of the shape now fell toward her left. This finding implies that neglect can apply toward the contralesional side of an axis of elongation within a segmented object.

I have since replicated this result in nine further left-neglect patients, and have yet to encounter an exceptional case. Caramazza (personal communication) has similarly corroborated the finding in a case of right-neglect after left-hemisphere damage. Moreover, a similar phenomenon can be observed in left-neglect patients' copying performance, when they omit details along the left of a tilted elongated shape (Halligan & Marshall, 1994b). Finally, Driver, Baylis, Goodrich, and Rafal (1994) have also observed axis-based neglect in a group of right-hemisphere patients, within a purely perceptual task designed to eliminate any possible contribution from eye-movements. Taken together, these findings suggest that axis-based neglect of segmented figures may be a quite general phenomenon, rather than a curio restricted to a few atypical cases. However, further work is needed to determine whether it applies for the majority of cases, or just for a specific subset.

In sum, as with extinction, the ostensibly spatial nature of neglect seems consistent with a bias in spatial components of attention. However, this need not entail that attention is a *purely* space-based phenomenon, as the common spotlight metaphor for normal attention implies. Neglect can be strongly affected by object-segmentation factors, suggesting that such segmentation precedes or interacts with the impaired spatial selection. Thus, the neuropsychological data support neither the purely space-based, nor the purely object-based, models of attention that exist in the normal literature. Instead, they suggest the compromise view that attention acts within a spatial medium, but on a segmented representation.

Segmentation and Balint's Syndrome

The simultanagnosic aspect of Balint's syndrome is almost by definition an impairment with respect to multiple objects, rather than multiple locations. Thus, any attentional account of it seems bound to invoke disrupted attention to objects, or to segmented regions of space, rather than to unsegmented positions in the visual field. A classic Balint patient will readily

detect the two circles in the bar-bell of Fig. 8.2 (as they belong to one connected object) but will detect only one circle when the two are unconnected; this was originally shown by Luria (1959), and has since been confirmed and extended by Humphreys and Riddoch (1993) and Driver et al. (1996). Moreover, this pattern of performance can be surprisingly insensitive to the actual spatial separation between the connected or unconnected elements (Humphreys & Riddoch, 1993), confirming the predominance of segmentation factors over spatial factors.

The object-based nature of the attentional deficit in Balint's syndrome has been apparent for some time; the new finding is really that extinction and neglect can be similarly sensitive to segmentation factors. For instance, Driver et al.'s (1996) extinction patient, with right parietal damage, showed an equivalent sensitivity to the bar-bell manipulation shown in Fig. 8.2 as the Balint patient with bilateral parietal damage whom they also tested. The only difference was that the extinction patient would invariably miss the leftmost of two unconnected circles, whereas the Balint patient was as likely to miss an unconnected circle on either side.

As noted earlier, such deficits in Balint patients after bilateral lesions are less readily explained in terms of Kinsbourne's (1993) imbalanced hemispheric competition than the apparently similar deficit in the unilateral extinction patient. I now turn away from the issue of segmentation to consider another area of potential common ground between normal and neuropsychological studies of attention.

MEASURING THE EXTENT OF UNATTENDED AND NEGLECTED PROCESSING

As discussed earlier, there is now abundant evidence in the normal literature (e.g. from the cuing paradigm of Posner, 1980) that covertly attended stimuli can be judged more efficiently than unattended events. This implies that at some stage or stages in the nervous system, attended stimuli are processed more thoroughly. The precise points at which this can happen have long been controversial, as has the fate of unattended stimuli beyond the point where attended stimuli are first favoured. Similar issues arise for the fate of neglected stimuli.

Assessing the extent of processing for unattended stimuli in normals poses a methodological challenge, which has received some quite sophisticated solutions in the normal literature (see the other chapters in this volume). The most basic problem is that if one directly asks a normal person about a stimulus they are requested to ignore, the likelihood is that they will no longer ignore it! Two general solutions have been provided to get around this problem. First, one can try to measure the extent of unattended processing indirectly, without ever asking the person about the information

they are meant to ignore, so that it remains irrelevant to them. Second, one can ask the subject a retrospective "surprise" question about events that were not specified as relevant at the time of presentation.

The latter method was employed first in the normal literature, and provides clear results, although the interpretation of these straightforward findings still remains controversial. In the auditory case, if subjects are presented with two spoken messages at once from different locations, and told to concentrate on just one (e.g. to repeat it aloud) they will later recall very little of the irrelevant message when asked surprise questions about it (Cherry, 1953). Typically, they might know that there was another stream of sounds, where it was, and roughly what it sounded like (e.g. male versus female voice), but know nothing about its meaning. Similarly, if normal subjects are presented with multiple visual events, and asked to concentrate on just a subset, when later asked surprise questions about events that were considered irrelevant at the time, they will recall very little (e.g. Neisser & Becklen, 1975; Rock & Guttman, 1981). Typically, they might recall that there were some other events, and perhaps their location or color (Rock et al., 1992) yet be unable to identify them retrospectively. This poor memory can be demonstrated within seconds of initial presentation (Rock et al., 1992; Sperling, 1960).

Such results led to the "early-selection" view that unattended stimuli receive only cursory processing at very peripheral stages of perception (perhaps coding just apparently simple "features" like location, color, or pitch). On this view, unattended stimuli never reach the stages responsible for fully identifying visual objects, or for recognising spoken words. However, the memory findings alone might be reconciled with an alternative "late-selection" view, on which unattended stimuli proceed much further through the system. It can be suggested that unattended stimuli are fully perceived, yet forgotten; or fully processed, yet without reaching full awareness.

Indirect measures of unattended processing were developed to address such possibilities (see Allport, 1993; Kahneman & Treisman, 1984 for overviews). These methods examine the processing of unattended stimuli without requiring any deliberate response to them by the subject. This circumvents the potential problem that the "unattended" stimuli may become attended if specified as relevant. It may also sidestep the potential problem that if unattended stimuli are processed without awareness, deliberate responses to them will not reveal the true extent of this processing. Finally, most indirect measures can be applied at the time of presentation, avoiding the potential problem of forgetting. A wide range of indirect measures has now been employed with normals, ranging from physiological indices of response to irrelevant distractors (e.g. electrical activity measured at the scalp, or autonomic responses measured across the skin) through to

behavioral indices of priming or interference from distractors on the speed of deliberate responses to related targets.

The normal literature using these indirect measures of unattended processing is too extensive and complex to be reviewed in full here. However, two major conclusions from it can be stated. First, attention can modulate early sensory responses. For instance, scalp ERPs can be more pronounced for attended stimuli than equivalent irrelevant stimuli within 80 msec of stimulus presentation, and this is thought to reflect differential activity within early areas of visual cortex (Luck, this volume).

Second, despite such early modulation, there is clear evidence that processing of irrelevant stimuli can proceed beyond the stages where this modulation first arises, albeit at attenuated levels. Thus, while a person may have only restricted awareness and memory for events that they ignore, one can nonetheless demonstrate that substantial processing sometimes takes place for them, using interference or priming techniques. These techniques measure the processing of distractors by means of their effect on deliberate responses to targets. As an example of interference, subjects are slower to categorise a target shape when flanked by an irrelevant distractor if the latter shape is associated with an alternative categorization response (Eriksen & Eriksen, 1974). This effect demonstrates that the distractor shape was coded, and it can be found even when the subject is quite unaware of the response-associations of the effective distractors (Miller, 1987). As an example of priming, normal subjects are often slower to respond to a visual object if they have just ignored a related object (Tipper, 1985), even if the distractor and subsequent target were related only in meaning (e.g. after ignoring the word DOG, the subject may be slower to name a picture of a cat; Tipper & Driver, 1988). This implies that the category of the initial distractor was activated to some extent (and perhaps then suppressed, producing the delayed response to subsequent related items). The effect can be found even when subjects are unaware of the identity of the preceding distractor that produces it (Tipper, 1985).

Thus, indirect measures in normals suggest a compromise between extreme early-and late-selection views of unattended processing. Attention apparently can modulate perceptual coding (as early-selection theories emphasize), but nevertheless considerably more perceptual processing can take place for ignored stimuli than would be suggested by normal subjects' ostensive ignorance of them (as emphasized by late-selection theories). These normal findings raise similar possibilities for extinguished and neglected stimuli. To what extent do stimuli on the impaired side continue to be perceptually processed even when a patient is unable to respond to them, or remains quite unaware of them?

Only a few studies to date have used indirect *physiological* indices to examine contralesional processing in neglect. Vallar, Sandroni, Rusconi,

and Barbieri (1991) observed visual ERPs in response to contralesional stimuli that two left-neglect patients failed to detect. More recently, Spinelli, Burr, and Morone (1994) reported that while visual ERPs can be found to contralesional stimuli in neglect patients, they typically have a delayed latency relative to the ERPs for comparable ipsilesional stimuli. Such findings are consistent with the view that the deficit in neglect attenuates or delays processing for contralesional stimuli, but does not completely eliminate such processing. Further studies with ERPs and other neuroimaging techniques could be used to address exactly how far neglected stimuli can proceed through the system, by looking for physiological responses that indicate the activation of specific processes, such as visual object recognition, or face perception etc.

Recent behavioral studies suggest that residual processing can include a degree of unconscious object recognition for stimuli toward the contralesional side, in both neglect and extinction patients (see Driver, 1996, for a critical review). These behavioral studies have adapted indirect techniques from the normal attention literature, measuring the processing of contralesional stimuli by means of their impact on deliberate responses to ipsilesional stimuli. Several effects of this kind have now been reported, although it remains to be established how reliable they are across cases, and exactly how different lesions may constrain the degree of residual processing.

Audet, Bub, and Lecours (1991) adapted the interference paradigm of Eriksen and Eriksen (1974), requiring two left-neglect patients to name a target letter presented at fixation. A distractor letter was presented to its left, or above it, and its identity varied. Like normals, both patients were faster to name the fixated target if the distractor above it had the same rather than a different identity to the target (congruence effect). One of the two patients also showed a similar congruence effect when the distractor was on the left, even though he reportedly did not detect the presence of the effective left distractors, as measured by retrospective questioning. This study demonstrates that identification of contralesional stimuli (at least to a level sufficient to determine any congruence between the distractor and target letter) can take place in some but not all neglect patients. It also raises the possibility that this residual processing might be unconscious when found. However, the retrospective test for awareness of the effective contralesional events may have been insensitive, due to forgetting.

Berti and Rizzolatti (1992) also produced initial evidence for unconscious residual processing in the contralesional field. They required seven left-neglect patients to make a speeded animal/vegetable decision for target line-drawings presented in the right visual field, when preceded by a prime line-drawing in the left field. The drawings were presented briefly to preclude any role for overt eye movements during them. The contralesional prime could be identical to the ipsilesional target, from the same category, or from the opposite

category. Categorizations of the ipsilesional target were slower in the latter case, even though most patients did not spontaneously report seeing any contralesional event during 24 practice trials that preceded the experiment.

This study also suggests that a degree of object recognition can take place in the contralesional field, possibly without awareness. However, one can again criticize the informal measure of awareness as potentially insensitive. Moreover, while the data clearly show that contralesional objects could be classified to some degree as animal or vegetable, it remains unclear how much visual processing this would require, because the same 14 drawings were repeatedly presented, and thus may have come to be classified on the basis of quite limited information (e.g. just an eye-like feature might be sufficient to merit an animal classification after experience with the limited set of pictures).

A priming study by McGlinchey-Berroth et al. (1993) goes furthest to date in answering these criticisms. They required four patients with left neglect (but no hemianopia), and one patient with left hemianopia (but no neglect) to decide whether a central letter-string was a word or not. This was preceded by two concurrent drawings on either side of fixation, one depicting a common object, while the other was just scrambled lines (see Fig. 8.5a). The drawings were again presented briefly to preclude eye movements during them. The main finding for neglect patients was that judgments of a central word were faster when the preceding meaningful drawing depicted a semantically related object (e.g. a pictured baseball-bat followed by the letter-string BALL). This priming effect was equivalent in size regardless of whether the related picture had been in the ipsilesional or contralesional field. By contrast, no reliable priming was found from the blind field of the hemianopic patient.

The priming from pictures on the affected side in the neglect patients suggests considerable processing for contralesional stimuli, as each picture was shown only once, and could be related to the subsequent target word only in meaning. What about the issue of whether this extensive contralesional processing was truly unconscious? McGlinchey-Berroth et al. addressed this point with a further study. The same neglect patients were again presented with prime displays comprising a drawing of a common object on one side and scrambled lines on the other side, just as before. However, they now had to make an explicit judgment about the meaningful object in this prime display, whereas previously no response had been required to it. The task was to judge which of two subsequent pictures the meaningful prime matched, either the one above fixation or the one below (see Fig. 8.5b). As a group, the patients were above chance at matching when the meaningful prime had been on the right, but at chance when it was on the left, even though left objects had produced equivalent priming to right objects in the preceding experiment.

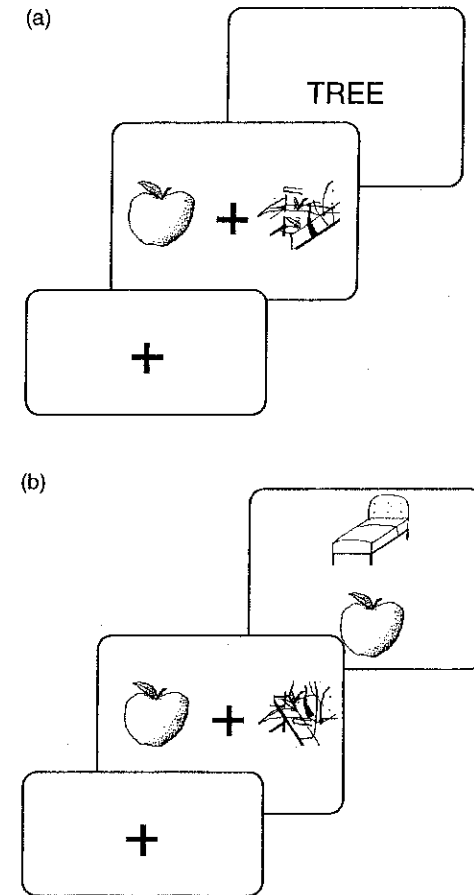


FIG. 8.5. Schematic depiction of a typical sequence of events in one trial from McGlinchey-Berroth et al.'s (1993) priming study (a), and from their matching study (b), with time running from front left to back right in each depicted sequence. In both experiments, the trial began with a fixation point for half a second, followed by a brief presentation of a meaningful drawing in one visual field (illustrated for the left visual field, or LVF) together with scrambled lines in the other field (on the right in the illustrated trials). After an empty 400 msec delay, this was followed by centralized targets which remained visible until a response to them was initiated. In the priming study (a), the drawings were irrelevant to the patients' specific task, which was to judge whether the central letter-string was a word or not. Neglect patients were faster to judge a word after a related drawing (as illustrated by the pictured apple preceding the word TREE), even if the drawing had fallen on the neglected side. In the matching task (b), the initial drawing was now relevant, as the patients had to decide which of the subsequent two targets matched it. They were at chance when the initial meaningful drawing was on the neglected side.

The claim that the contralesional priming reflects unconscious processing thus rests on extrapolation across two separate experiments with slightly different tasks, and on a measure of awareness that concerns identification rather than mere detection of contralesional events. Nevertheless, the McGlinchey et al. (1993) study does show that considerable processing can take place in the contralesional field of neglect patients, as indexed by priming, while the matching task confirms that the extent of this residual processing can be at odds with the patients' very restricted ability to judge the same contralesional stimuli explicitly.

There has been less work on the extent of residual processing in Balint's syndrome than for extinction and neglect. However, some recent results hint that considerable processing may also take place for unreportable stimuli in this class of patients. Rafal and Robertson (1995) provide a preliminary report of congruence effects from undetectable objects on response to detected targets in a Balint case. Coslett and Saffran (1991) had previously reported a Balint case who was better at identifying both stimuli in a concurrent pair of words or in a pair of drawings when the two items were related in meaning.

The notion that considerable processing may still take place for pathologically unattended stimuli in extinction, neglect, and Balint's syndrome is entirely consistent with the evidence discussed earlier for the continued operation of segmentation processes in these disorders. Moreover, the recent work with priming and interference measures provides a further illustration of the potential for fruitful interplay between normal and pathological studies of attention, as these measures have been adapted from the normal literature, and then applied to neuropsychological issues with considerable success.

Although this is encouraging, such methodological adaptations from the normal literature do run the risk of extending past mistakes to the neuropsychological domain, as well as previous successes. Interference or priming effects from isolated distractors in the normal literature have in the past often been taken to support extreme late-selection claims that every single one of the numerous stimuli in very complex scenes will *always* be perceived to the same full extent, regardless of the direction of attention (e.g. Tipper & Driver, 1988). Such a claim clearly goes well beyond observations that a single distractor, presented on an otherwise empty background, can be processed to the extent that it exerts a small influence on response to a related target (Lavie & Tsal, 1994). Subsequent work has shown that the extent of processing for distractors by normals actually depends on a variety of complex factors, such as the number of events in the scene, their spatial proximity and grouping, the load imposed by the specified task, and so on (Baylis & Driver, 1992; Lavie, 1995; Yantis & Johnston, 1990).

We should therefore be wary of leaping to any conclusion that perceptual processing is absolutely full and unlimited in the contralesional field of a neglect patient, based just on observations that isolated stimuli in that field can produce priming or interference effects. The extent of residual processing in neglect seems likely to be subject to all the complex factors that influence the extent of unattended processing in normals. We should also recall that neglect and extinction are dynamic directional biases, rather than a static deficit that applies fixedly to an entire visual field (Kinsbourne, 1993). Finally, the extent of residual processing will surely depend on the precise lesion in each particular patient.

Neglect patients typically have relatively diffuse lesions. These tend to focus on right parietal cortex (Vallar, 1993), which is itself a large and heterogeneous region. However, the lesions typically include other areas as well, as the most common aetiology is a stroke involving the middle cerebral artery, which sustains numerous brain regions. Thus, while there is undoubtedly some systematicity to the lesions that produce neglect (Vallar, 1993), no two patients will have identical lesions. It seems very unlikely that the only effect of these diffuse and variable lesions could be to prevent awareness of otherwise fully processed stimuli! Presumably, the extent of residual processing in neglect patients will depend on the exact extent of their residual brain tissue, and thus on the precise details of their lesion.

This potential variability in the extent of residual processing may actually aid rather than hinder future research. We are now able to identify the lesioned areas in individual patients with considerable accuracy, based on techniques such as CT, MRI, PET, or SPECT scanning. We also have independent sources of evidence, other than human-lesion studies, concerning the function of particular brain regions. These come from techniques such as single-cell recording in animals, or functional neuroimaging in healthy people as they carry out various tasks. Such knowledge is particularly advanced for the functions of different components in the visual system (e.g. Zeki, 1993).

We should therefore be able to predict which visual functions will still operate residually for contralesional stimuli in particular neglect or extinction patients, based on the details of their lesion. Moreover, it may ultimately be possible to rehabilitate patients' impaired functions by means of their residual functions. As one example, Mattingley, Bradshaw, and Bradshaw (1994) have recently shown that visual neglect, as measured by line bisection, can be ameliorated in some patients by using visual motion to draw their attention to the contralesional side. Presumably, this is only possible in cases where some residual processing of motion exists.

The existing findings on residual object-recognition in the contralesional field by means of visual shape (Audet et al., 1991; Berti & Rizzolatti, 1992; McGlinchey-Berroth et al., 1993) may be broadly consistent with one coarse

anatomical distinction between those brain areas that are usually impaired, and those that are spared in most neglect patients. A distinction is often made between "dorsal" (anatomically higher within the skull) and "ventral" (lower) pathways in the primate visual system (Goodale & Milner, 1993; Mishkin, Ungerleider, & Macko, 1983; Ungerleider & Haxby, 1994). The dorsal pathway comprises a sequence of interconnected areas running forward from primary visual cortex in the occipital lobe into the parietal lobe. The ventral pathway also starts in primary visual cortex but runs lower into the temporal lobe. The two pathways were originally distinguished in terms of their anatomical connectivity (although it should be noted that there are some connections between the two). However, most interest has focused on possible differences in their function, as suggested by the effects of lesions in humans and monkeys, and by functional neuroimaging in the former subjects and single-cell recording in the latter subjects.

Such measures have identified the ventral pathway with functions concerning object segregation, and object recognition by shape (Ungerleider & Haxby, 1994). The dorsal pathway has been associated with spatial representation and attention (Mishkin et al. 1983) and/or with the spatial control of action (Goodale & Milner, 1993). Hence, given that the prototypical lesion that induces human neglect primarily involves dorsal areas (Vallar, 1993), one might expect that object segregation and recognition would be largely spared for contralesional stimuli in neglect patients, as the findings I have reviewed suggest. These functions should still take place within intact ventral pathways, with perhaps just spatial awareness and the control of deliberate responses being impaired for stimuli toward the neglected side by the dorsal damage. I return to this idea after considering neuropsychological studies of one final issue that has dominated the normal attention literature.

FEATURE INTEGRATION IN EXTINCTION, NEGLECT, AND BALINT'S SYNDROME

The most influential recent theory of normal visual attention has been Treisman's feature-integration account (e.g. Treisman & Gelade, 1980). In original form, this proposed that simple visual features (e.g. the orientation of edges, their direction of motion, their color etc.) can be coded across the visual field all at once, without any need for focal attention. By contrast, coding the particular combination of features that each object has in a field of many objects was held to require focal attention to the position of each object in turn. This model can be seen as a sophisticated form of early selection. In common with traditional early-selection models, unattended processing is considered restricted to simple physical features. The departure from traditional views is the idea that spatial attention performs one specific

function; namely, combining the various features within the attended region into a multidimensional percept.

Evidence initially consistent with this view was provided from a number of different tasks with normal subjects. For instance, in visual search, subjects may detect a target defined by a salient unique feature (e.g. a red item among green, or vertical among horizontal) as rapidly among many nontargets as among a few nontargets (so-called "parallel search", parallel in the sense that the search process can operate over all the items at the same time; see Wolfe, this volume). By contrast, when searching for a target that is unique only in its conjunction of features (e.g. a red vertical item among red horizontal and green vertical nontargets), subjects may be slowed when there are more nontargets, often in a linear fashion (Treisman & Gelade, 1980) implying that every extra item now adds another cycle around some process that takes a particular length of time (so-called "serial search", in which individual items are thought to be inspected one after the other). Such results seem consistent with the hypothesis that while simple features can be coded for all items at once (as in parallel feature search), combining the features of objects may require focal attention to the locus of each object in turn (as in serial conjunction search).

One independent source of initial support for this theory was that normal subjects can apparently miscombine briefly presented features, erroneously conjoining attributes from distinct objects together (so-called "illusory conjunctions"), when prevented from attending serially to the position of each object in turn (Treisman & Schmidt, 1982). Treisman's theory has since attracted considerable research interest, in part because of an apparent similarity between her idea that different visual features are coded independently in preattentive vision, and emerging neuroscience evidence that distinct areas of prestriate visual cortex specialise in coding different visual features (e.g. Cowey, 1985).

In subsequent years, the intense interest in Treisman's theory has led to extensive criticisms and revisions of it, in a substantial literature to which I cannot do full justice here (see Wolfe, this volume, for a review of the visual search evidence). Suffice to say that there have now been several demonstrations that covert attention can affect simple feature coding as well as conjunction coding (e.g. Briand & Klein, 1987; Posner, 1980; Prinzmetal, Presti, & Posner, 1986). There have also been numerous demonstrations that conjunction search can be parallel under some circumstances (see Wolfe, this volume). Moreover, the claim that shape features (such as the different orientations that together make up the occluding edges of an object) require attentional integration in just the same way as features from different dimensions (e.g. orientation plus color) has been particularly questioned (e.g. Davis & Driver, 1994; Enns & Rensink, 1990; Humphreys, Quinlan & Riddoch, 1989).

Despite these many criticisms, covert attention often does produce larger effects on conjunction tasks than on comparable feature tasks (e.g. Prinzmetal et al., 1986). Moreover, while several rival models now exist for the body of normal data generated by tests of feature-integration theory (e.g. Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Humphreys & Müller, 1993; Treisman & Sato, 1990), there are several points in common between these alternatives. First, distinct items in the visual field compete for attention (usually operationalized as some visual short-term memory stage, some inspection process, or control of responding). Second, features on different visual dimensions are initially coded independently. Third, grouping processes modulate the competition for attention (as required to accommodate results such as those discussed earlier in the sections on segmentation). Fourth, attentional competition is usually played out in a spatial medium; typically by means of activity in a "master map" of visual locations, intended to represent the current spatial distribution of attention (see Wolfe, this volume). Thus, there is some consensus in the normal literature, and apparently a substantial germ of truth behind feature-integration theory.

I turn now to consider the neuropsychological literature on this topic, which is scarcer. The most simple-minded prediction that might be derived from feature-integration theory as regards attention deficits is that these deficits should affect only conjunction tasks, not feature tasks. This is clearly not so in most cases; patients with extinction, neglect, and Balint's syndrome can all be impaired in the conscious detection of simple features, as when an extinction patient fails to detect the more contralesional of two wiggling fingers. On the other hand, covert attention is now known to affect coding of features as well as of conjunctions in normals (e.g. Prinzmetal et al., 1986), and thus attentional biases in patients would be expected to influence feature tasks also. The normal findings show only *larger* effects on conjunction than on feature tasks (Prinzmetal et al., 1986). Thus, a more subtle hypothesis can be proposed; attentional deficits might affect both feature and conjunction tasks, but should usually disrupt the latter more substantially.

Cohen and Rafal (1991) tested this possibility in several extinction patients with unilateral parietal injury, with a task of first naming a central digit (to ensure central fixation, and to occupy attention) and then the color and shape of a concurrent peripheral target letter, presented together with a nontarget letter that was always an O but could appear in various colors. The measure of interest was the number of feature errors (e.g. reporting a color that was not presented) and of conjunction errors (e.g. mistakenly ascribing the color of the nontarget O to the target letter) for letters on the ipsilesional versus contralesional side.

The majority of extinction patients simply could not perform this task (Cohen & Rafal, personal communication). They made so many errors for

the contralesional target letter (seeing none, and therefore refusing to respond, or just guessing) that the relative proportion of feature and conjunction errors could not be sensibly measured. This poses a methodological problem (the opposite of the ceiling effect discussed earlier) known as a "floor effect". When performance on the feature task (i.e. identifying any color on the contralesional side) is already at chance, no greater difficulty in the conjunction task (i.e. reporting the correct combination of color and shape for just the target letter) can possibly be measured. Such floor effects may obscure greater difficulties with conjunction tasks than feature tasks for many neglect patients.

Cohen and Rafal (1991) also tested one patient who showed only very mild extinction, no longer detectable by confrontation methods but evident in computer tests. Their report concentrated on just this left-hemisphere case. She showed disproportionately many more conjunction errors than feature errors in the contralesional field as compared with the ipsilesional field, after naming the central digit. Cohen and Rafal therefore concluded that her parietal damage had especially impaired feature conjunction for stimuli toward the affected side. This impairment was eliminated when she was presented with the very same displays, but now allowed to ignore the central digit and concentrate just on the peripheral letters. These findings therefore provide another example of extinction (in this case for conjunctions) depending on competition with a *relevant* ipsilesional event (cf. Karnath, 1988).

Riddoch and Humphreys (1987) gave feature and conjunction search tasks to several left-neglect patients, always presenting nontarget stimuli in both visual fields. Reaction times to detect feature targets were scarcely affected by the number of nontargets presented concurrently (as in normals), and there was little difference in the speed of response for contralesional versus ipsilesional feature targets. By contrast, search was slowed by additional nontargets in the conjunction task (as in normals), and contralesional targets were now detected much more slowly than ipsilesional targets. These latency data appear consistent with the strong prediction that only conjunction tasks should be impaired by the attentional deficit. However, the error rates revealed that the patients missed many contralesional targets, but few ipsilesional targets, in both conjunction *and* feature tasks; thus feature performance was not entirely normal toward the affected side.

Eglin, Robertson, and Knight (1989) gave seven neglect patients modified versions of conjunction search and feature search. There was now always one target in each display, with the patient having to locate it by pointing, rather than judging its presence or absence as in the usual task. This modification was intended to circumvent the numerous misses observed by Riddoch and Humphreys (1987), which can complicate the interpretation of

reaction-time data. Each display presented stimuli either on just the ipsilesional side of the patient, just the contralesional, or on both sides; although as the patients could move their eyes, and some had hemianopia, every stimulus may ultimately have entered the ipsilesional visual field.

Increasing the number of nontargets delayed the conjunction task more than the feature task, as in normals. This effect was equivalent within ipsilesional displays and contralesional displays (perhaps, as noted, because eye movements took place). Finally, in bilateral displays, responses to contralesional targets were substantially delayed by the addition of nontargets on the ipsilesional side, whereas the addition of contralesional nontargets did not delay responses to ipsilesional targets. This abnormality was much more marked in the conjunction task than in the feature task.

Finally, Arguin, Joannette, and Cavanagh (1993) studied a group of patients with left-hemisphere damage who showed attentional abnormalities in a variant of Posner's (1980) cuing task. They examined feature-and conjunction-search performance for brief displays while ensuring that central fixation was maintained. The patients showed slower search rates in the contralesional field than the ipsilesional field for the conjunction task, but there was no such effect on feature search.

Thus several studies have now shown that spatially specific attention deficits can be more pronounced in conjunction tasks than in feature tasks. However, these studies have not yet established that such an exaggeration of the deficit applies only when feature *conjunction* in particular is required; it might be produced by any manipulation that makes the task more demanding. Indeed, Humphreys and Riddoch (1993) report that search by neglect patients can be impaired disproportionately for contralesional targets by feature-based manipulations that make search harder in normals (e.g. increased target-nontarget similarity, or nontarget heterogeneity; Duncan & Humphreys, 1989). Similarly, Robertson and Eglin (1993) report that contralesional search difficulties in neglect patients are exaggerated when the target is defined only by the absence of a feature (e.g. an O among Qs) rather than by the presence of a unique feature (e.g. a Q among Os). This accords with the greater difficulty of feature-absent searches in normals (Treisman & Gormican, 1988).

There has been little study of visual search or feature integration in Balint's patients. Rafal and Robertson (1995) provide a preliminary report of a Balint patient who detects feature targets more readily than conjunction targets, and can detect a Q among Os, but not an O among Qs. This suggests that which object the Balint patient first locks onto may be determined by some of the same factors that influence attentional capture in normals. As for the possibility of illusory conjunctions, most case reports have stressed that Balint patients correctly integrate the features of the individual objects they experience (e.g. Farah, 1990). However, this conclusion has usually

been based on descriptions or judgments concerning the *shape* of particular objects (i.e. their specific conjunction of oriented lines etc.) rather than on assessments of feature conjunction across different dimensions (e.g. linking shapes together with the appropriate colors). Recall that in the normal literature, the hypothesis that attention is required to conjoin the various features of an object within the shape dimension (such as the oriented lines that comprise it) has been particularly criticized (Davis & Driver, 1994; Enns & Rensink, 1990; Humphreys et al., 1989).

Friedman-Hill, Robertson, and Treisman (1995) recently examined the across-dimension conjunction of colours with shapes in a Balint case. The patient made an extraordinarily high rate of illusory conjunctions. When presented with two colored shapes, he was very likely to miscombine the color of one stimulus with the shape of the other in his report, even with quite lengthy exposures. This may be consistent with Treisman's proposal that location plays a special role in attentional feature integration across dimensions. Severe Balint patients are typically unable to locate stimuli accurately, both in their conscious judgments, and in their motor behavior (e.g. grossly misreaching for visual objects). Such loss of location information may preclude knowledge of which color goes with which shape. It will be interesting to examine whether such impairments apply only for conscious knowledge, or also to the residual processing that might be revealed by interference and priming measures.

CONCLUSIONS

I have reviewed recent neuropsychological work relating to three main issues that have dominated the normal literature on visual attention; the relation between segmentation and spatial attention, the extent of unattended processing, and the nature of feature integration. Restrictions on the available space have precluded coverage of a host of further issues thrown up by neuropsychological research, which might usefully broaden the agenda of normal research. These include: possible hemisphere differences in attentional control, which might explain the predominance of left over right neglect; separate attentional systems for different spatial domains; the role of motor programming in producing shifts of attention; and the interactions between multiple sensory modalities in attentional control (see Driver & Mattingley, 1995; Robertson & Marshall, 1993, for reviews of these further issues). Nevertheless, I hope I have covered sufficient material here to indicate the potential fruitfulness of a combined normal and neuropsychological approach to attention.

On the first issue of segmentation, the neuropsychological data strongly suggest that some compromise must be reached between the purely space-based and purely object-based models of attention that have dominated

recent normal work. The patient evidence implies that spatial attention is directed within a segmented representation of the visual scene, with at least some of this segmentation taking place preattentively. Recent normal data converge on this conclusion (e.g. Lavie & Driver, 1996).

On the second issue, concerning the extent of processing for unattended/neglected stimuli, the neuropsychological studies have borrowed usefully from methods in the normal literature, and have provided some compelling examples of thorough implicit processing for stimuli that apparently cannot be reported explicitly. Much further work is required on this topic, however. On the third issue of feature integration, several studies have confirmed that the neurological deficits are more severe in tasks that are more attention demanding, consistent with the initial characterisation of these deficits as attentional in nature.

Can any overarching perspective be presented to accommodate the neuropsychological evidence on all three issues? It may be premature to attempt this. Nonetheless, the current data may be broadly consistent with, on the one hand, the special role often suggested for location in the direction of attention, and in feature integration (both thought to operate in a spatial medium); and on the other hand, the dorsal lesion that is typically involved in the disorders I have reviewed. As discussed earlier, dorsal visual pathways have long been associated with spatial representation, and more recently with the spatial control of action. By contrast, ventral visual pathways have been associated with visual segmentation, with the extraction of visual features such as color, and with recognition of visual objects by means of shape-based access to long-term memory representations.

Against this anatomical background, it may be less surprising to find that implicit segmentation, feature coding, and shape-based recognition (presumed to be ventral functions) can be relatively spared in patients with attentional deficits (due to dorsal lesions). However, this still leaves a striking gap between the extent of such residual processing for contralesional stimuli, and the patients' frequent inability to become aware of these stimuli, or respond overtly to them. This might perhaps be explained if some linkage between ventral properties (e.g. the shape-based identity of an object) and dorsal properties (e.g. the current position, size, and orientation of the ventrally identified object) is required for a person to become fully aware of an object, or to make a deliberate response toward it. Baylis, Driver, and Rafal (1993) have proposed exactly this. Such linkage between dorsal and ventral properties might be seen as an anatomical extension of Treisman's feature-integration idea.

Without the coherent spatial framework that the dorsal pathway normally provides to code the current disposition of objects in the scene, our awareness might be restricted to individual, disembodied objects that cannot be related to each other. This is apparently the dilemma faced by Balint

cases. Moreover, if our awareness of the distinction between separate objects is normally based primarily on their differing spatial locations, as argued by the philosopher Leibniz, then we may begin to understand the difficulty that Balint cases have in shifting their attention to new objects, away from the current focus of attention. Essentially, they may have lost the primary spatial means of differentiating new objects from those already attended within a scene. In the case of neglect and extinction patients, such deficits in spatial representation would apply only for items toward the contralesional side, restricting awareness of these objects however full their residual ventral processing might be.

Whatever the truth of such speculations, further study of extinction, neglect, and Balint patients may allow unique insights into the complex interactions between neural subsystems, such as the ventral and dorsal pathways, which take place so profusely and efficiently within the normal system that they are often extremely difficult to unravel.

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CHAPTER NINE

Computational modeling of spatial attention

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INTRODUCTION

If we had really huge brains, say the size of watermelons, attention would play a much smaller role in our behavior. Its significance stems primarily from limitations in our processing hardware. We simply do not have sufficient brain capacity to analyze all information that passes through our sense organs, to reason exhaustively about all possible courses of action, and to maintain multiple interpretations of the world. Attentional selection is needed to determine what information will be processed by the available hardware.

Consider the task of recognizing objects in a visual scene. What sort of processing resources would be required to identify all objects in parallel, regardless of their positions, orientations, and size in the scene? If we are familiar with o different objects, and any object can appear in any of p horizontal or vertical positions and r orientations and s scales, the number of different object instantiations is op^2rs . This number would be far larger still if the objects are not rigid. Regardless of the nature of the recognition process, the number of possible object instantiations roughly determines the amount of processing resources required. You can plug in reasonable guesses as to how many object instantiations are possible; 100 million might be a reasonable ballpark figure. If we limit ourselves to one object at a time, however, and the object's position, orientation, and scale are computed first, then the number of object instantiations that have to be considered at once