Chapter 25

HEMISPATIAL NEGLECT: COGNITIVE NEUROPSYCHOLOGICAL ASPECTS

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This chapter reviews some of what has been learned about the cognitive neuropsychology of visual attention from the study of patients with neglect. The mutually supporting contributions of neurology and psychology have enriched both disciplines. Theories and methods for studying visual attention in normal people have contributed to our understanding of neglect; at the same time, a better understanding of neglect has helped illuminate some of the tougher theoretical issues in cognitive science.

DISENGAGING ATTENTION AND THE MECHANISM OF EXTINCTION

Does the phenomenon of extinction indicate that the parietal lobe is involved in controlling the orienting of attention? It had been argued[1,2] that an attentional explanation is not necessary to explain extinction. Instead, extinction could simply result from sensory competition. That is, although parietal lobe lesions do not produce hemianopia, they might nevertheless cause visual perceptions to be more weakly represented in the contralesional than in the ipsilesional field. Under conditions of sensory competition, the weakest sensory signal might not be perceived.

The most direct evidence for an attentional explanation of extinction was provided in an experiment in which it was shown that attending to the ipsilesional visual field could cause extinction, even under conditions where there was no competing visual target to be reported in the ipsilesional field.[3] Patients with lesions of the parietal lobe were asked to respond, by pressing a key, to the appearance of a target in the visual field either ipsilateral or contralateral to the lesion. The target was preceded by a cue that could summon attention to target location (valid cue) or to the wrong location (invalid cue). As illustrated in Fig. 25-1, the cue was either a brightening of one of the possible target locations or an arrow in the center of the display instructing the subject where to expect the forthcoming target signal. The results showed that patients with parietal lesions, even those who did not have neglect or show clinical extinction on conventional examination, demonstrated an "extinction-like reaction-time pattern": slow detection of targets in the contralesional field when attention had been summoned to the ipsilesional field. Detection reaction time (RT) in the field opposite to the lesion (contralesional field) was not much slowed (and in some patients not slowed at all compared to the ipsilesional field) if a valid cue was given. Therefore, the patients were able to use the cue to move their attention to the contralesional field; when they did so, their performance for contralesional targets was relatively unimpaired. When, however, a cue summoned attention toward the ipsilesional field and the target subsequently occurred in the opposite, contralesional field (invalid cue), detection RT slowed dramatically. This extinction-like RT pattern occurred even after the cue disappeared. That is, the extinction effect occurred when attention

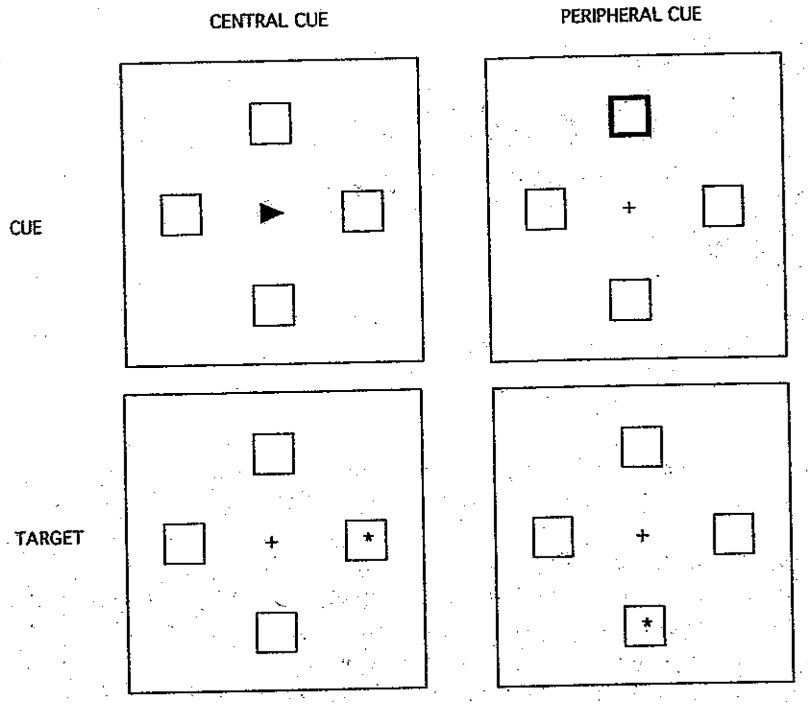


Figure 25-1
The experimental displays used to assess the orienting of spatial attention in a detection reaction time task. The subject's task is to press a button as soon as the target, an asterisk, appears in any of four locations. Preceding the presentation of the target is a cue that directs attention to one particular location. The cue can be central, in the form of an arrow (top left panel), *or peripheral, as when one box brightens* (top right panel). *When the cue directs attention to the location of the target, it is said to be a valid cue* (bottom left panel); *when it directs attention to a different location from the target, it is said to be invalid* (bottom right panel).

was directed ipsilesionally, even though there was no competing target signal to detect there. So it was not sensory competition that caused the extinction-like RT performance, but a difficulty in disengaging attention from the ipsilesional field.

The disengaging of attention has been hypothesized to be one of a number of elementary operations underlying the orienting of spatial attention.[4] Support for this framework comes from a replication of the cued detection RT experiment comparing patients with lesions of the temporoparietal junction (TPJ) to patients with progressive supranuclear palsy (PSP) who have degeneration of the midbrain.[5] Figure 25-2 shows the results of this experiment. The effects of valid and invalid cues are measured by differences in RT between the affected visual hemifield and the more normal hemifield. For TPJ-lesioned patients, this is the difference between ipsilesional and contralesional fields; for patients with PSP, the difference is between vertical and horizontal attention shifts (because PSP affects vertical movements of the eyes and of attention more than horizontal). Patients with TPJ lesions show the extinction-like RT pattern, with no impairment for valid cues and an impairment for invalid cues only when attention is engaged ipsilesionally. This can be interpreted as an impairment of the *disengage* operation. In contrast, patients with midbrain lesions show a deficit in orienting only with valid cues, reflecting a difficulty in moving attention to its target location. This can be interpreted as an impairment in the *move* operation.

EXTINCTION AND NEGLECT: DISENGAGING ATTENTION DURING VISUAL SEARCH AND EXPLORATION

The foregoing experiments, and a number of others, examined the effect of parietal lesions on detection of a luminance change in a relatively uncluttered field.[6–9] The results show that the extinction phenomenon is caused by a deficit in at-

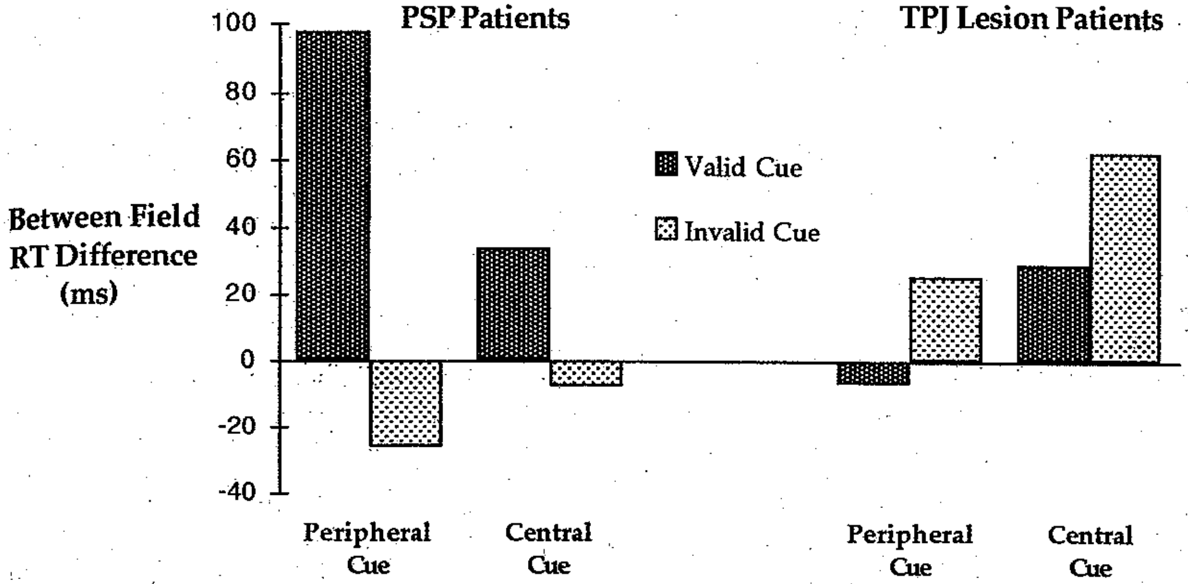


Figure 25-2
Covert orienting in patients with progressive supranuclear palsy and temperoparietal junction lesions. The results are depicted as the difference in detection RT between the more affected and the more normal visual fields. A greater difference in a given condition, thus, indicates a greater impairment in orienting in that condition. For the PSP patients (left) *and the TPJ lesion patients* (right) *the between field detection RT differences are shown (in ms) for valid and invalid peripheral and central cues. The PSP patients are more impaired in the valid cue condition, especially with peripheral cues; whereas the TPJ lesion patients are more impaired in the invalid cue conditon, especially for central cues.*

tention. Yet extinction is just one component of the neglect symptom complex. Other symptoms of neglect include defective exploratory behavior as revealed by tasks like line bisection, drawing, and cancellation. To understand how the deficit in disengaging attention can contribute to deficient exploration, we must examine attentional search in a cluttered field, where many objects are competing for attention. This is a more typical situation in the real world.

Eglin and coworkers[10] studied visual search in patients with neglect using a task developed by Treisman.[11] They varied the side of a predesignated conjunction target (one defined by a specific color and shape, requiring the conjunction of more than one feature to identify) among a variable number of distractors and measured the time to find the target. When distractors were present, they could occur in either the ipsilesional or contralesional field. As long as no distractors appeared on the ipsilesional side of the display, no differences were found in locating a target on the neglected and intact sides. In other words, in displays that were limited to the ipsilesional side of a page, there were no objects to attract attention to the intact side and therefore nothing from which to disengage attention. Under these circumstances, the patients searched the display on the left as readily as they searched displays on the right. In contrast, for bilateral displays, in which distractors were present in both fields, search times increased as a function of the number of distractors or objects in the ipsilesional field. Each distractor on the intact side tripled the search time to locate the contralesional target. That is, the difficulty in disengaging attention from the ipsilesional field of distractors to move attention to the contralesional field depended on the number of items in the display.

Mark and colleagues[12] provide an elegantly simple demonstration that patients with neglect have difficulty in disengaging attention when ipsilesional items are present. They used a line cancellation task, a conventional bedside method for demonstrating and measuring neglect. The patient is shown a page filled with lines and asked to "cross them all out." Typically, a patient with left hemineglect fails to cross out many of the items on the left side of the page. Mark and coworkers[12] compared this conventional cancellation task with another condition in which they asked the patient to erase all the lines. As each line was erased and thus no longer present, the patient no longer had to disengage from it before moving on. Performance was strikingly better in this erasure task than in the conventional line cancellation task.

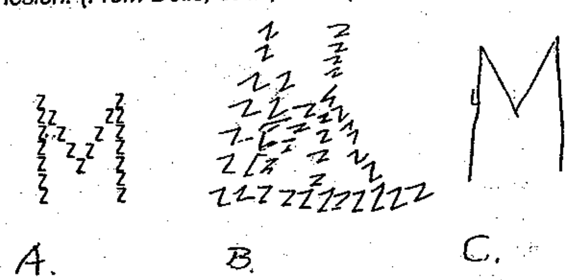
LOCAL PERCEPTUAL BIASES AFTER LESIONS OF THE RIGHT TEMPOROPARIETAL JUNCTION EXACERBATE VISUAL NEGLECT

Some patients with parietal lobe lesions may have extinction but not exhibit any of the exploratory deficits of neglect on drawing, copying, cancellation, or bisection tasks. In fact, extinction appears to be just as frequent after left as after right hemispheric lesions. However, other components of the syndrome, including deficits in exploration of contralesional space, are much more frequent after right hemispheric lesions, especially those that involve the right temporoparietal junction.[14] So while a deficit in disengaging attention may be a satisfactory explanation for extinction, it seems that other factors, perhaps specific to right hemispheric lesions, are at work in patients with the full-blown syndrome of neglect.

The observations of Eglin and coworkers[10] and Mark and colleagues,[12] discussed in the last section, show that the difficulty in disengaging attention is greater when attention is more actively engaged. Factors that cause attention to become more actively engaged in the ipsilesional field will exacerbate the problem of disengaging attention and, hence, will exacerbate visual neglect. One effect of a lesion of the right temporoparietal junction (TPJ)—but not the left TPJ—is that it causes attention to become locked onto local perceptual details.[14] Figure 25-3[15] shows the copying of a patient with a large stroke of the right hemisphere and that of a patient with a large stroke involving the left hemisphere. The right hemispheric lesion causes almost complete exclusion of the global organization of the figure, while the left hemispheric lesion causes the exclusion of local detail.

The conjoint effects of the local bias with a difficulty in disengaging attention combine in producing some classic constructional signs of neglect in paper-and-pencil tasks. Consider, for example, a patient writing a number on to a clock face. She will be more successful if, as she is writing each number, she remains oriented to her task with reference to the whole clock. If her attention becomes excessively focused on the number she is writing and she loses sight of the whole clock, she will have more difficulty in disengaging from that number to fill in the rest of the numbers in

Figure 25-3
Drawings of hierarchical stimuli by two patients. A. The figure which the patients were asked to copy is a hierarchical pattern in which the large letter at the global level is an M, constructed from small Z's at the local level. B. Global organization is lost in this drawing by a patient with a right hemispheric lesion. C. Only the global organization of the figure is preserved while the local details are lost in this copy by a patient with a left hemispheric lesion. (From Delis, et al.,[15] with permission.)



the correct location on the clock face. As she writes a number on the clock face, her attention becomes stuck there, and the difficulty in disengaging attention causes the numbers drawn subsequently to be bunched up together next to it. On the other hand, if the clock face remains uncluttered with other numbers, patients with neglect are better able to remain oriented to the whole clock face. Di Pellegrino[16] showed that neglect patients can put a single number in the appropriate location on a clock face as long as they are given a separate sheet for each number.

Halligan and Marshall[17] have shown the importance of the local bias as a contributor to neglect and how the local bias and the deficit in disengaging attention interact to determine neglect behavior. They asked their patient to bisect a horizontal line. In one condition, they also presented a vertical line at the right end of the line that was to be bisected. Before asking the patient to bisect the horizontal line, they gave their patient a task that required attending to the full extent of the vertical line. This obliged the patient to expand the "attentional spotlight" from the point at the end of the horizontal line, and this improved subsequent bisection performance on the horizontal line. By helping to overcome the tendency of the patient to become hyperengaged in a small focus of attention at the end of the line to be bisected, they were able to mitigate the neglect. Perhaps this expansion of attention to a more global level explains why patients with neglect make less bisection error when bisecting a rectangle than when bisecting a line, and why the higher the vertical extent of the rectangle, the less the bisection error.[19]

ORIENTING BIAS AND HEMISPHERIC RIVALRY

One model of the neurobiological basis of spatial attention postulates that each hemisphere, when activated, mediates an orienting response in the contralateral direction.[19–21] According to this account, neglect results from a unilateral lesion because of a breakdown in the balance of hemispheric rivalry such that the nonlesioned hemisphere generates an unopposed orienting response to the side of the lesion. Experimental observations in patients with hemineglect provide some support for this view. Ladavas and colleagues[22] showed that, in patients with neglect, detection performance was best for the most ipsilesional targets, and detection of these ipsilesional targets was even better than for normal control subjects. These results suggest that patients with neglect hyperorient toward the ipsilesional field.

One variant of the hemispheric rivalry account emphasizes putative mutually inhibitory callosal connections between the hemispheres. According to this account, when one hemisphere is lesioned, homologous regions of the opposite hemisphere, which normally receive inhibitory projections from the damaged region, become disinhibited and hyperorient attention to the ipsilesional side. A recent study[23] has obtained some support for this hypothesis by examining the effects of transcranial magnetic stimulation (TMS) on thresholds for tactile perception detection in normal subjects. A suprathreshold (i.e., sufficiently strong to activate a twitch in the contralateral thumb when applied over motor cortex) TMS stimulus transiently inactivates subjacent cortex. This study examined whether the hemisphere opposite the TMS stimulus would show signs of disinhibition, manifested as a reduced threshold to detect a tactile stimulus in the thumb *ipsilateral* to the TMS lesion. Results supported the attentional disinhibition account by showing a reduced ipsilateral tactile threshold after parietal (3 or 5 cm posterior to motor cortex) TMS but not when TMS was applied at control locations over the motor cortex or 5 cm anterior to it.

Another mechanism that has been suggested for ipsilesional hyperorienting postulates a corticosubcortical interaction. According to this account, the unlesioned parietal lobe becomes disinhibited tonically increasing activity in the superior colliculus ipsilateral to it; whereas the colliculus on the side of the lesion loses some normally present tonic activation. As a result, parietal lesions also produce an imbalance in the activity of subcortical structures involved in orienting, such as the superior colliculus. The contralesional superior colliculus becomes disinhibited, and this results in exaggerated reflexive orienting to signals in the ipsilesional field.

Sprague's experiments in the cat confirmed that this kind of corticosubcortical interaction is important in regulating visually guided orienting behavior.[24] Cats were first rendered blind in one visual field by removing occipital and parietal cortex. It was then shown that vision in this field improved if the *opposite* superior colliculus were removed. A similar result is obtained if the inhibitory connections are severed between the contralesional substantia nigra pars reticulata and the ipsilesional colliculus.[25,26]

This "Sprague effect" is thought to work in the following way. Parietooccipital projections to the ipsilateral superior colliculus normally exert a tonic facilitation on it. After parietal lesions, the colliculus looses this tonic activation, and at the same time the opposite (contralesional) colliculus is in fact hyperactive due to increased activation from its parietal lobe, which, as we saw earlier, is disinhibited. The unilateral parietal lesion therefore also produces a subcortical imbalance between the two hemispheres. Moreover, this imbalance is sustained and aggravated by the mutually inhibitory connections between the two colliculi themselves. The more active contralesional superior colliculus is released from inhibition. The disinhibited contralesional colliculus produces disinhibited reflexive orienting to ipsilesional signals. Once attention is reflexively drawn to the ipsilesional field, the disengage deficit causes attention to get stuck there—resulting in neglect. If the contralesional superior colliculus is then removed (or the fibers of passage from the substantial nigra pars compacta to the opposite colliculus), the hyperorienting, and hence neglect, is ameliorated.

The Sprague effect demonstrates (at least in cats) that neglect is aggravated by disinhibition of subcortical visual pathways on the side opposite the cortical lesions and that prevention of visual input to this colliculus can alleviate neglect. Are there any practical applications of this phenomenon in rehabilitation? It is obviously not an option to surgically remove the contralesional superior colliculus in humans who have suffered parietal lobe strokes. It is possible, however, to decrease contralesional collicular activation and reflexive orienting by occluding the ipsilesional eye with a patch.[27] Indeed, patching the eye on the side of the lesion has been shown to help reduce symptoms of neglect.[28]

It seems likely that both cortical and subcortical imbalances contribute to the rightward bias of attention in patients with neglect. The subcortical imbalance is presumably more pronounced during the period of extensive diaschisis in the acute stage following the ictus. This imbalance is thought to produce not just a turning bias but also a shift in the spatial frame of reference such that the contralesional space is more weakly represented.[20,29] The effect of the rightward bias on spatial representation can be reduced transiently by production of a countervailing orienting bias through vestibular activation using a caloric stimulus. Vestibular activation can transiently alleviate not only visual[30,31] and somatosensory[32] neglect, but also the lack of awareness of the deficit (anosognosia).[33] A shift in spatial representation by vibration of neck muscles[34] or by optokinetic stimulation[35] can also decrease neglect.

PERCEPTUAL AND MOTOR NEGLECT

As reviewed in Chap. 24, the neural circuitry controlling spatial attention is a distributed network involving cortical and subcortical structures (see also Ref. 36). Within this network, there appear to be several specialized if interconnected circuits for regulating different kinds of behavior. Consider the different kinds of representations of space that would be needed for performing some common, simple tasks. A representation of space for generating an eye movement to a visual signal requires retinotopic coordinates. One for controlling reaching requires an egocentric representation of space—a scene-based representation in which location in the environment is coded and remains constant even if the eyes move. In monkeys, areas of parietal lobe have been identified in which retinotopically mapped information is gated by eye position.[37] For reaching, moreover, this representation must be integrated with a reference frame mapped relative to hand position.[38] This kind of representation of near peripersonal space may not, however, be adequate for throwing, which may require a separate representation of distant space.[39] The representations of space that might be adequate for reaching to a stationary object may not suffice to reach for an object that is moving. For this, one wants an object-based representation that updates the changing location of parts of the object relative to an egocentric reference frame. Finally, consider the problem of remembering the location of a cache of food relative to some geographic landmark or the problem of remembering the locations of cities on a map. For this one wants an allocentric reference frame in which the relative locations of objects are represented in a frame of reference totally independent of the viewpoint of the individual. For navigating while moving in the environment, this allocentric map must be continually updated and integrated with some enduring record of changes in body position with regard to this allocentric reference frame—for example, the "place" cells that have been identified in rat hippocampus.[40]

Given that there may be many such independent circuits that might be affected by some lesions and spared in others, it is not surprising that the manifestations of visual neglect may vary from patient to patient. In some, neglect may be more perceptual; in others, more motor. While this distinction may be better appreciated as a continuum rather than a dichotomy, the distinction between disorders of attention and intention has been a useful one.[41] Some patients with a more pure attentional disorder (typically those with more posterior lesions sparing frontal lobes) may have visual extinction and other perceptual deficits but no motor bias against turning contralesionally, moving the limbs contralateral to the lesion, or reaching into the contralesional field (directional hypokinesia).[42,43] Other patients who do not show extinction or other signs of perceptual neglect may, nevertheless, have a motor bias causing neglect behavior in cancellation and construction tasks. Many patients with neglect have both perceptual and motor components affecting performance in these types of tasks. The relative contributions of these components may vary from patient to patient, depending on the size and location of the lesion in each patient and the task used to assess neglect.

Performance on many of the tests used clinically to diagnose neglect and measure its severity can be influenced by both motor and perceptual factors. Errors in line bisection or missed items in a cancellation task could be caused by perceptual neglect, motor neglect, or a combination of the two. Failure to cross out the leftmost items on a cancellation task, for example, could be due to failure to see the leftmost items or to a motor bias against moving toward the left.

Several ingenious studies have recently dissociated perceptual and motor components of neglect to measure their effects independently. Bisiach[44] first demonstrated this dissociation between perceptual and motor neglect by using a pulley device in a bisection task. Patients with neglect bisected lines under two conditions. In one, movement of the pencil toward the left (contralesional) direction required movement of the hand to the left. In this standard version of the task, a deficit in bisection could be due to perceptual neglect, motor neglect, or a combination of both. In the other version of the task, the pulley device required rightward movement of the hand to move the pencil to the left. Patients in whom neglect was exclusively due to a motor bias against moving the hand toward the left could be expected to improve their bisection performance in this version of the task. Some patients, those in whom neglect was dominantly perceptual, showed an equal amount of neglect in both versions of the task. Some patients showed some improvement in bisection with the pulley, and some, those in whom neglect was dominantly a motor bias, had no neglect under the pulley condition. These patients with more pure motor neglect tended to have more frontal lesions. Similar dissociations between perceptual and motor neglect have been also demonstrated using other devices, such as TV cameras[42] and mirrors[45] to separate out motor bias contributions to neglect. While there are clear tendencies for motor neglect to be more associated with more frontal lesions, the anatomic substrates relating to perceptual and motor neglect remain to be more precisely specified.[46]

Some simple bedside tests have recently been introduced to separate motor bias from perceptual neglect. Gold and colleagues[47] used a fixed-aperture technique in a cancellation task in which an opaque sheet with an aperture is placed over the page. The task can be done in one of two ways. In the standard task, the top sheet with the aperture is moved leftward by the patient during the cancellation task. In this task, both motor and perceptual neglect can influence performance. In the other condition, the bottom sheet is moved to the right by the patient in order to expose items on the left side of the page. In this version of the task, motor bias to the left cannot contribute to neglect performance, allowing for a purer assessment of perceptual contributions to neglect.

An elegant companion test to line bisection has been introduced[48] to determine whether motor neglect is contributing to bisection errors in an individual patient. Patients who manifest bisection errors are shown prebisected lines that may be bisected in the middle or to the left or right of midline. The patients are asked to point to the end of the line that is *closest* to the bisection mark. The critical condition is that in which the line is bisected in the middle. Patients in whom bisection error is due exclusively to a motor bias to the right would be expected to point to the right end of the line in this condition. In fact, several of the patients who were studied pointed to the left end of the line. This result indicates that, in these patients, their bisection errors were not due to a motor bias toward the right. These important observations suggest, in fact, that patients with perceptual neglect perceive the left side of the line as being shorter.

A more recent study has confirmed that neglect reduces perceived length. Milner and coworkers[49] showed patients with neglect two horizontal bars on a sheet of paper, one in each visual field, and asked them to judge which bar was shorter. On the critical trial in which the bars were equal in length, the patients indicated the bars in the left field to be shorter. In a control test in which vertical bars were shown, no such asymmetry in length judgment was evident. These findings indicate that patients with perceptual neglect experience compression of the left side of space.

This result may seem to be contradicted by a recent study of oculomotor behavior in patients with visual neglect.[50] Patients with left hemineglect, when asked to look straight ahead in the dark, deviated their eyes to the right of objective midline. This observation is consistent with the rightward hyperorienting described earlier, when we considered the hemispheric rivalry account of neglect. However, these patients did not show any asymmetry of oculomotor exploration around their subjective midline. That is, although they deviated their eyes rightward of true midline, eye movements to the left of their subjective midline were as great as eye movements to the right of it. This result would seem to indicate that there is a shift in perceived center of the egocentric world but no compression of spatial representation to the left of this center. However, the study of Karnath and associates[50] measured eye movements in the dark, presumably in relation to far extrapersonal space. That of Milner and coworkers[49] examined attention in relation to objects being manipulated in near peripersonal space. In the next section, we will see that neglect can be greatly influenced by the frame of reference in which it is examined and that the operations of visual attention are contingent on the requirements made of it for perception and action.

WHAT IS NEGLECTED IN NEGLECT?

It is now clear that visual neglect is not simply blindness in one visual field or even a lack of attention restricted to one visual field. Although neglect is greater for objects to the left (for right hemineglect) of fixation, it does not have the sharp retinotopic boundaries of hemianopia. Rather, it seems to operate over a gradient.[22] Using the cueing task described earlier, it has been shown, for example, that an extinction-like RT deficit can occur for detecting the leftmost of two stimuli in the right visual field,[7] even though this event is in the "good" field (and is in fact closer to the fovea). In this sense neglect seems to operate as a directional bias independent of visual field. However, neglect does, also, differentially affect the two visual fields. Baynes and coworkers[6] showed that vertical shifts of attention from an invalid cue were slower in the contralesional than the ipsilesional visual field.

So while it is clear that neglect is a deficit in attending to visual information, we still need to consider what it is that is neglected. We have seen that several different representations of space are maintained in the brain. Neglect could result from a degradation of any of these representations or of the ability to attend to any of them. Thus, what is neglected in neglect may differ from patient to patient, depending on which representations of space are involved by the lesion; in any given patient, what is neglected may depend on the requirements of the task at hand.

Reference Frames of Visual Neglect

Extrapersonal space exists independent of the viewpoint of the observer. Even when we are lying down (or standing on our heads), "up" and "down" remain the same, determined by the gravitational field. Ladavas[51] first showed that when patients with neglect tilted their heads, neglect was manifest not in terms of visual field but in terms of "gravitational" coordinates.

However, Fig. 25-4 shows a striking demonstration, using a test devised by Lynn Robertson, that neglect is not always manifest in terms of simple environmental (gravitational) coordinates. The examiner tests for extinction by wiggling a finger on each of his hands. In one condition, the examiner's body and face are rotated to the left (that is, the reference frame is rotated counterclockwise). In this condition the patient detects the upper finger wiggle and extinguishes the lower; that is, there is extinction of the left side of the reference frame. In contrast, when the examiner's body and face are rotated to the right (that is the reference frame is rotated clockwise), the patient now detects the lower finger wiggle and extinguishes the upper. That is, there is now extinction of the opposite spatial location, but this again is on the left side of the reference frame. In this case, then, neglect is not manifest with reference to gravitational coordinates but with reference to the principal axis of the attended object.

It seems that visual neglect does not simply affect a visual field mapped in retinotopic coordinates nor even simply one side of egocentric space. It can be manifest in object-based coordinates. To understand how neglect can operate in object-based coordinates for objects that are neglected—an apparent contradiction—we must first consider to what degree visual objects can be represented in the neglected field outside of the focus of attention.

Figure-Ground Segregation and Grouping in Visual Neglect

When we look at the two drawings on the left (*A*) and right (*B*) of Fig. 25-5,[52] we normally see bright-green objects on a dim red background (both because the green is brighter and because its area is smaller than that of the dim red). Driver and colleagues[53] showed a patient with left hemineglect figures like these; they asked him to remember the shape of the dividing line between red and green and to then match this line with the probe shapes (shown under the study shapes in Fig. 25-5). Notice that the boundary to be remembered is on the left side of the page in *A* and on the right in *B*; yet for *A*, the boundary to be remembered lies on the right side of the green object, while in *B* it lies on the left side of the green object. The patient's task did not require any judgment about either the perceived object (green) or its ground (red). His task was only to attend to the shape of the line bordering the two colored areas. Were neglect manifest strictly with respect to egocentric space, more errors would have been expected for *A* than for *B*. The results showed the exact opposite pattern. The patient was much more accurate in condition *A*, where the contour to be remembered was on the right side of the object but on the left side of the page, than in condition *B*, where

Figure 25-4
Reference frames and neglect. This patient detected a single finger wiggling in his contralesional field but did not see it when a finger was also wiggled simultaneously in the ipsilesional (right) *field (extinction). The test illustrated here demonstrates the dependence of extinction on the reference frame of the patient. When the examiner rotates clockwise* (A), *there is extinction of the lower stimulus, which is still the left side of the object, and the patient looks up. When the examiner rotates counterclockwise* (B), *there is extinction of the upper stimulus, which is still the left side of the object, and the patient looks down. (From Rafal,[75] with permission.)*

the contour to be remembered was on the left side of the object but on the right side of the page. Although the green shape on the left side in *A* was in the neglected field and while judgments about the object were not relevant to the task at hand, the patient's attention was nevertheless summoned to it.

In this example, neglect operated with regard to the reference frame of the object. These observations tell us two important things: (1) the processes for segregating figure from ground can operate preattentively in the neglected field and (2) attention operates at a later stage on candidate objects generated by these preattentive processes.

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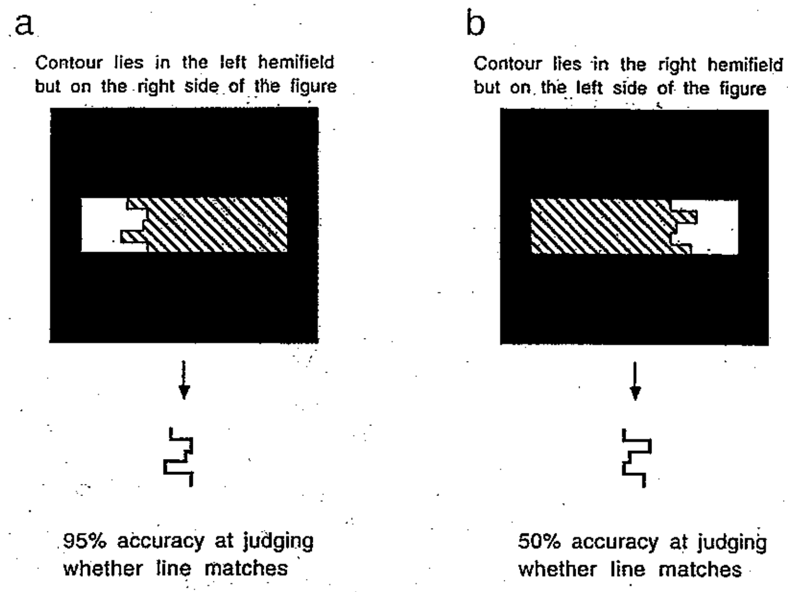
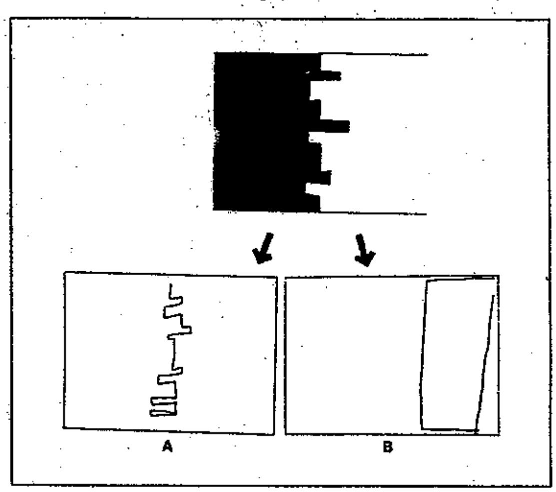


Figure 25-5
A patient with left hemispatial neglect was shown figures like those shown here and asked to report verbally whether the contour dividing red (hatched) *and bright-green* (white) *areas of a rectangle matched the probe line presented immediately below the rectangle following its offset. Normally the small bright-green region is seen as figure against the dim red background. Although not required to identify figure or ground, the patient showed more neglect for the left side of the figure* (B), *even though this figure was in the right visual field. (Adapated from Driver et al.,[53] with permission.)*

The object-based neglect of objects segregated from ground is nicely shown by the drawings of similar shapes shown in Fig. 25-6.[54]

Another preattentive process that is preserved in patients with unilateral neglect is the segregation of figure from ground based on symmetry. The effect of symmetry in preattentively generating candidate objects was first demonstrated by showing a patient with visual neglect pictures in which isoluminant red and green areas were alternated across a page. Either the red or the green areas on each page were symmetrical. The patient was asked to report simply whether the red or green areas appeared to be "in front." Normal individuals see symmetrical regions as being the figure and report them to be in front of the ground. Like any normal individual, the patient reported symmetrical regions to be in front, indicating that he had perceived the symmetrical objects as the figure. When he was asked to judge whether the shapes were symmetrical or not, he performed at chance. That is, even though his neglect prevented him from reporting whether or not shapes were symmetrical, he nevertheless per-

Figure 25-6
Object-based neglect is demonstrated by the copying performance of a patient with left hemispatial neglect. When asked to copy the black object, the patient did well, since the jagged contour is on the right side of the black object. When asked to copy the white object, the patient was unable to copy the jagged contour, since it is on the left side of the object being attended. (From Marshall and Halligan,[54] with permission.)



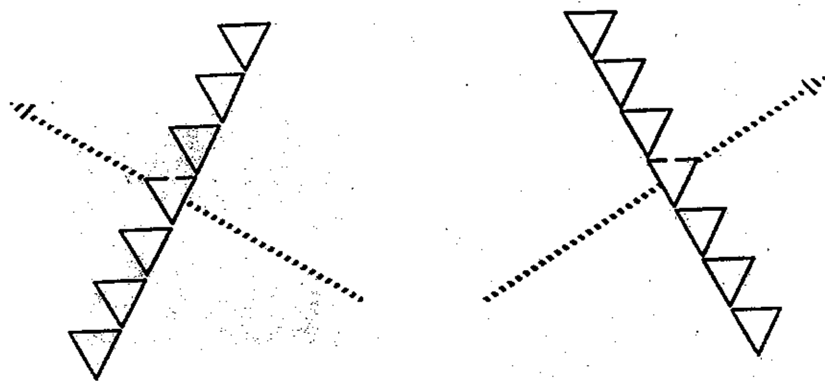


Figure 25-7
The figures used by Driver and coworkers[55] to study axis-based visual neglect. Three patients with left hemispatial neglect were asked to report whether or not the triangle in the center had a gap in it. Because of grouping of the triangles, triangles on the left were seen as pointing toward the northwest, so that the gap in the top of the central triangle is on the right side of its principal axis, whereas the triangles on the right are seen as pointing toward the northeast, so that the gap in the top of the central triangle is on the left side of its principal axis. All three patients had more neglect (missed seeing the gap) in the condition shown on the right than in the condition shown on the left. (From Driver et al.,[55] with permission.)

ceived symmetrical shapes as the objects in the visual scene.

Once candidate objects are preattentively segregated from background, they may then be grouped with other objects based on gestalt principals. Figure 25-7 shows a task used to test whether grouping is preserved in visual neglect.[55] The patient's task was simply to determine whether or not there was a gap in the top of the central triangle. The principal axis of the triangle (i.e., which way it appeared to point) was manipulated by the way in which the central triangle was grouped with the others. In the figure on the right, the alignment of the triangles (from southwest to northeast) causes them to appear to be pointing toward the northwest; the gap in the top of the central triangle is perceived to appear on the right side of its perceived principal axis. In the figure on the left, the alignment of the triangles (from southeast to northwest) causes them to appear to be pointing toward the northeast. The gap in the top of the central triangle is perceived to appear on the left side of its perceived principal axis. Results in three patients with left hemineglect showed that all missed more of the gaps in the condition on the right, in which the gap was on the perceived left of the triangle. These results demonstrate that grouping is preserved in visual neglect and that attention operates in the reference frame of the group such that visual neglect is determined based on the principal axis of the group.

Object-Centered Neglect

The results of the experiment shown in Fig. 25-7[55] provide a more formal proof of the phenomenon shown in Fig. 25-4. After figure-ground segmentation occurs preattentively, candidate objects become represented to which attention may then be directed. Attention is allocated to the attended object aligned with its principal axis. Neglect is then manifest for parts of the object or other objects contralateral to the primary axis of the attended object. If, as shown in Fig. 25-4, the principal axis of the attended object moves or rotates, neglect moves or rotates with it.[56] Behrman and Tipper showed object-based neglect which actually moved to the ipsilesional side of the object after it rotated. Reaction time was measured to targets appearing in either the left (contralesional) or right (ipsilesional) side of a dumbbell. Patients were slower to respond to targets on the left. If the dumbbell rotated, however, such that the two sides of the dumbbell reversed field, RTs were prolonged for targets on the right.

Object-based neglect has also been inferred from the reading errors of neglect patients. In a striking demonstration of neglect dyslexia,[57] a patient with right hemineglect made more errors at the end of the word regardless of the orientation of the word on the page—that is, even when the word was upside down, such that the right end of the word was in the left visual field. Patients with neglect have also been shown to make more reading errors when they read pronounceable nonwords than when they read words.[58–60] This shows that word forms are preattentively processed and integrate the constituent letters into a single object. The study by Brunn and Farah[59] incorporated cancellation or line bisection tasks along with the reading task. Less neglect was found on these secondary tasks when the primary task required reading a word as opposed to a nonword. This finding suggests that word processing causes an automatic deployment of attention to encompass the word and, in patients with left neglect, this draws their attention to the left.

Not all attempts to identify object-based neglect have been successful; a contrast of the studies that demonstrated object-based neglect and those that did not is instructive. Farah and colleagues[61] asked patients to name colors surrounding pictures of common objects. When the pictures were rotated, the colors neglected did not rotate with the object; that is, neglect remained location-based rather than object-based. Behrman and Moscovitch[62] used the same paradigm and confirmed the lack of object-based neglect with object drawings. However, object-based neglect was manifest in the special case where the objects were asymmetrical letters. That is, object-based neglect was manifest when the object's identity was uniquely defined by its principal axis.

Spatial Representations and Neglect

Neglect can result not only in the failure to perceive or to respond to contralesional signals or objects but also to a lack of conscious access to the contralesional side of visual images stored in memory.[65] Bisiach and Luzzatti[64] asked patients with left hemineglect to imagine themselves in the Piazza del Duomo in Milan. In one condition, they asked the patients to imagine themselves at one end of the square, looking toward the cathedral dominating the other end of the square, and to describe what they would be able to see. In another condition, the patients were asked to imagine themselves standing on the cathedral steps facing the opposite way. In both circumstances, the patients reported fewer landmarks on the contralesional side of the mental image. (For non-Milanese clinicians, a baseball imagery task may be substituted. In one condition, the patient is asked to imagine herself as the catcher and to name the positions of all the players that she would be able to see. Then the patient is told to imagine being in center field and is asked the same question.)

These kinds of observations have engendered an account of neglect in which the parietal lobes are assumed to maintain a representation of space in viewer-centered coordinates, and that parietal lesions produce a degradation of the contralesional representation. In an elegant experimental test of this account, Bisiach and coworkers[65] had patients view cloudlike shapes that were passed slowly behind a slit (so that only part of the shape could be seen at any moment). The task required that a mental image be generated and maintained as the slit moved over the shape they were attempting to remember. The patients were shown two shapes that could be either the same or different, and they were asked to respond whether the shapes were the same or not. On the trials in which the shapes were different, they could be different on the patients' left or right side. The patients made more errors on this task when shapes were different from each other on the contralesional end than on the ipsilesional end.

We need to know more about the neuroanatomic and pathophysiologic basis for the deficit of spatial representation in neglect.[66] Some authors have considered spatial representation in terms of oculomotor coding,[67,68] while others have emphasized spatial working memory.[69] Recent reports show that perceptual neglect and neglect of internal imagery may be dissociated. Two patients with perceptual neglect and mainly parietal lesions did not evidence neglect in visual imagery,[70] whereas a patient with a frontal lesion causing neglect of imagined scenes did not have perceptual neglect.[71]

CONCLUDING REMARKS

In neglect, a constellation of symptoms is seen affecting both perception and exploratory behavior. Which symptoms (and with what severity) occur in any given patient depends upon the extent and location of the lesion, its chronicity, and the premorbid cognitive architecture of the individual. Across the rather heterogeneous population of patients with elements of the neglect syndrome, the pathophysiologic mechanisms underlying each of the component symptoms are diverse. We are just beginning to understand some of these: hyperreflexive orienting toward the ipsilesional side or to local elements in the visual scene; impaired ability to disengage attention; a deranged internal representation of space, which is not only shifted but contracts contralesionally; impaired voluntary orienting toward the contralesional field; a motor bias toward the ipsilesional side that causes defective contralesional exploratory behavior; deficient ability to generate contralesional voluntary saccades; and failure of contralesional stimuli to produce arousal. The manifestations of neglect in an individual patient may not simply represent the additive contributions of each of these mechanisms, depending on which are affected by the lesion, but rather an interaction between them.[72]

The study of neglect has advanced our understanding of preattentive vision and the functions of attention in object recognition and the control of goal-directed behavior. We have learned that the visual scene is parsed preattentively into candidate objects and that attention then operates on these objects to afford awareness and recognition of them and to guide subsequent action. We are developing a better understanding of the plight of these patients and of their perplexing behavior. These insights can be applied to fashioning more rational approaches to their rehabilitation.[73–75]

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