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Spatial attention: normal processes and their breakdown

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High-level vision involves processes such as object recognition, selective attention, and visuomotor action, at the interface of perception and cognition. This article focuses on selective attention, a set of processes that allows selection of some stimuli over others and performance of multiple tasks in a coordinated manner [1,2]. This discussion is restricted to visuospatial attention—those attentional processes that select visual stimuli based on their spatial location. Spatial attention is perhaps the most widely studied variety of attention in normal populations and neurologic populations.

Before discussing spatial attention, this article addresses what attention *is*, and what it is useful *for*. A common view is that attentional processes are required because the environment contains more information than can be processed and comprehended at any given time. Attentional processes can be viewed as protecting an organism from information overload and are selective in that they allow processing of some stimuli while disregarding others. The stimuli that are selected may become attended for several reasons. For example, when faced with much sensory input, an optimal strategy is to attend to those that are relevant to current behavior. For example, a driver's distance from a lead vehicle is relevant for the task of safe driving, but cell phone conversation generally is not. The processes that permit an organism to choose some environmental inputs over others are referred to collectively as attention.

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The term ''attention'' appears in everyday language, but this intuitive, folk psychology use does not provide a solid definition of attention. The use of ''attention'' in the psychologic literature also is problematic, because it is often used to refer to tasks that require attention, as opposed to the processes of attention [2]. Task-defined attention does not explain the mechanisms or processes that permit the selection to occur. For example, consider a task in which an observer views two spatially adjacent letters, one red and one green, and is asked to report the red letter. Although this task requires the observer to ''pay attention'' to the red letter, it does not elucidate the mechanisms of attention, such as whether or not the attended letter is enhanced relative to the unattended letter, whether or not the unattended letter is inhibited relative to the attended letter, or both.

A more precise mechanistic, or ''process-oriented,'' definition of attention is useful for understanding when attention is necessary and how attention might operate. In the simple task described previously, a process-oriented definition of attention proposes how attention allows the red letter to be attended and reported and how the green letter is unattended. Perhaps the most well known process-oriented definition of attention comes from William James [3], who defined attention as involving ''withdrawal from some things in order to deal effectively with others.'' For James, attention restricts processing to some items over others and allows the attended item to become more salient, or enhanced, relative to unattended items. The authors rely on a process-oriented definition of attention and consider mechanisms that allow observers to select one spatial location over other locations.

Processes of normal spatial attention: review and framework

An understanding of the operation of spatial attention in neurologically normal observers can help guide assessments in brain-damaged patients. Knowing which process or subprocesses of spatial attention are disrupted may be useful for developing assessment techniques or care-giving strategies and rehabilitation.

Spatial attention involves selecting a stimulus on the basis of its spatial location. The region occupied by the item is selected and then receives further cognitive processing (eg, the item might enter visual working memory or become the target of a movement). Visuospatial attention also intersects with many other attentional processes and, for example, can select groups of items, based on how they cohere or group together. This latter form of selection has been referred to as object-based attention. Thus, spatial selection is central to many forms of object-based attention [4–6].

Spatial attention is closely associated with early processing, before stimulus identity is known. Attention is directed to a location in visual space and an item there is identified, possibly by enhancing the perception or binding the features of that item. This "early selection" account was one of the first theoretic views of attention [7], but does not imply that attention only operates at an early level, before stimulus identification. There are many varieties of attention and attentional selection [2,8,9]. Some attentional mechanisms operate earlier and others operate later in this framework [1].

Two experimental paradigms have contributed to the understanding of spatial attention: the spatial cuing paradigm and the visual search paradigm. In a typical spatial cuing paradigm, a stimulus or instruction precedes a target stimulus. This stimulus or instruction is referred to as the "precue" (or "cue"), and the cue either predicts the target's location or does not predict the target's location. In Posner's [10] widely used task, depicted in Fig. 1, each trial begins with a cue intended to orient an observer's attention to one of several locations. The cue can be a peripheral flicker (Fig. 1A) at the location where a target may appear or a centrally presented symbol, such as an arrow (Fig. 1B), that points to the location where a target may appear. After a delay, a target is presented and the observer indicates that he or she detects the target (eg, by pressing a button as soon as the target appears) or discriminates among several targets (eg, reporting if the target was a "T" or

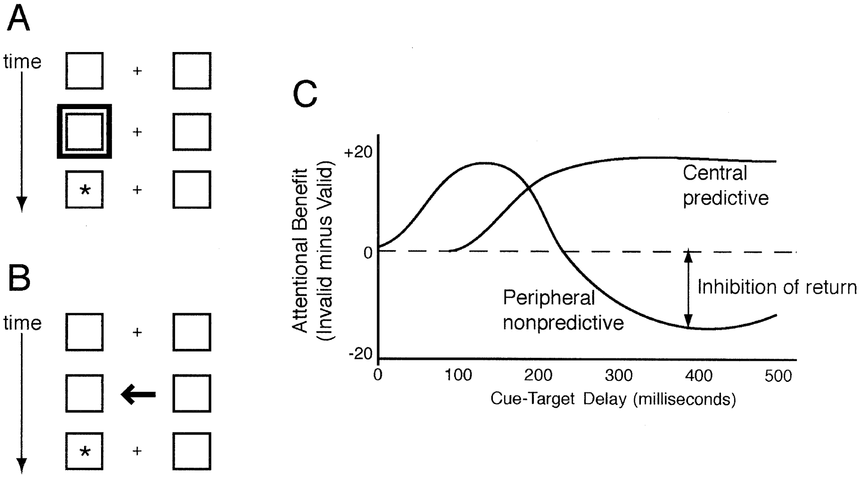

Fig. 1. The order of events in Posner's spatial cuing task. Observers are asked to detect the appearance of a target that has been validly or invalidly precued. (*A*) Peripheral precue that automatically summons spatial attention to the cued region. (*B*) Central, symbolic precue that can be used to voluntarily shift spatial attention to the cued region. (*C*) Typical results from spatial cuing studies. The graph plots the difference between response times to invalid and valid trials. Nonpredictive peripheral precues, in which valid and invalid trials are equally likely, result in attentional benefits initially, followed by a period of inhibition termed "inhibition of return" (IoR). Predictive central precues require more time to produce an attentional benefit, and these cues may not produce IoR in some circumstances.

an "L"). On "valid" trials, the cue correctly predicts the target's location; on "invalid" trials, the cue is misleading. Some experiments also include neutral trials that provide no information about the target's location. Observers typically respond fastest to valid trials and slowest to invalid trials, and this difference can be referred to as an "attentional effect" or a "validity effect" (Fig. 1C).

Many researchers use combined cue and target durations of less than 200 ms to ensure they are studying effects of covert spatial attention shifts and not overt eye fixation position changes. This minimizes the chance of making eye movements to a cued location because it typically takes approximately 200 ms to program and execute a saccadic eye movement to a location. Other studies explicitly monitored eye position to ensure that fixation does not deviate from the central fixation point. In either case, observers typically detect validly cued targets faster than invalidly cued targets, indicating that attention can affect the time to detect a target, even in the absence of an eye movement.

Investigators of spatial attention have researched the effects of two types of spatial precues: peripheral precues that appear abruptly at a potential target location and central, symbolic precues, such as arrows, that point toward a potential target location. Peripheral and central cues control attention differently [11]:

1. Observers cannot ignore peripheral cues, which appear to "attract" attention to the cued location automatically; observers can ignore central cues if instructed to do so.
2. Peripheral cues also operate faster than central cues; the difference between valid and invalid trials emerges sooner with peripheral cues than with central cues.
3. Peripheral cues are not affected by a concurrent working memory task in which observers remember a string of digits; central precues, in contrast, are less able to direct attention when working memory is occupied with a digit string.
4. Peripheral cues can interrupt the attentional orienting produced by a central cue, but central cues affect orienting from peripheral cues little, if at all [12].
5. Finally, studies that use central, symbolic cues tend to present more valid trials than invalid trials to encourage observers to attend to the cued location. For example, 75% of the trials may be valid and 25% invalid. In contrast, peripheral cues summon attention to the cued location even if valid and invalid trials occur equally (50% valid trials and 50% invalid trials) and even if valid trials are less frequent than invalid trials (eg, 25% valid and 75% invalid).

Although observers usually respond faster in valid trials than invalid trials, this pattern, referred to as a "validity effect," can be reversed under some situations. That is, invalidly cued targets can be detected faster than validly cued targets. In studies using unpredictive peripheral cues (50% valid and 50% invalid), observers respond faster to valid trials than invalid trials when the interval between the cue and target is less than 200 ms. As the interval exceeds 200 ms, observers respond faster to targets at the uncued location (invalid trials). This effect is called inhibition of return (IoR) [13]; IoR has been hypothesized to facilitate visual search, or visual foraging, by reducing the probability that a previously attended location be re-attended shortly after attention is withdrawn from that region [14,15]. Further research is needed, however, to test this hypothesis because the findings of inhibitory tagging in visual search have not always been replicated [16].

A second paradigm used to investigate spatial selection is the visual search paradigm (see Fig. 2). Visual search is the act of looking for a visual target among distracters (eg, finding a friend's face in a crowded room). In a typical visual search task, the number of distracters—the set size—is varied across trials, and reaction time (RT) is measured as a function of the set size.

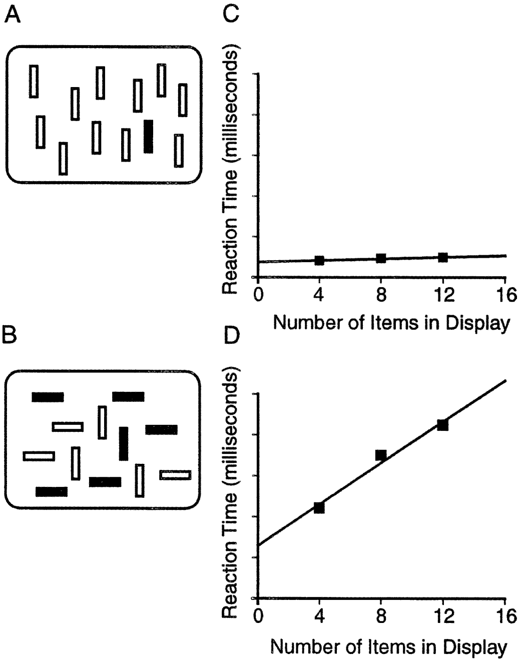

Fig. 2. (*A*) A visual search display in which the target differs from the distracters by a single feature (color). (*B*) A visual search display in which the target differs from the distracters by a conjunction of features (color and orientation). (*C*) Typical results from a feature-search display, such as that in (*A*). This search is efficient; adding additional distracters does not increase the time to search through the display. (*D*) Typical results from a conjunction-search display, such as that in (*B*). This search is inefficient; adding distracters increases the time to search through the display.

An "efficient" visual search is characterized by search functions with shallow slopes (Fig. 2B) and an "inefficient" visual search is characterized by search functions with steep slopes (Fig. 2D). Although early studies on visual search equated shallow search functions with parallel processing and steep search functions with serial, attentive processing [17], this parallel–serial distinction has fallen out of favor because some serial-looking processes can arise from parallel processing mechanisms [18,19]. For example, serial-looking search, in which responses become slower as more items are added to a display, can be produced from a limited-capacity parallel search mechanism. In a limited capacity parallel search, multiple items can be processed in parallel, but because this search has a limited capacity, searching through multiple items takes longer than searching through fewer items. As a consequence, most theorists discuss efficiency of visual search, with efficient searches characterized by shallow search functions (slopes <10 ms per item) and inefficient searches characterized by steep search functions (slopes >20 ms per item [20]).

Several studies suggest that visual search involves attending to the locations occupied by the items in a search array. Prinzmetal et al [21] demonstrated that adding cues to a visual search task could improve target identification on valid trials compared with invalid trials. Thus, knowing the spatial region of a target helps observers correctly identify a target. Kim and Cave [22] showed that a visual search display can influence how quickly an observer responds to a spatial probe. In this task, observers performed a visual search task and determined if a target was present or absent from a display. After some of the visual search displays, a small dot appeared, and observers had to press a button as soon as they detected this dot (similar to the task in Posner's spatial cuing task discussed previously). Observers were fastest to detect the dot when it appeared in the same location as the target in the visual search task, suggesting that spatial attention had been directed to the target location, which then allowed the subsequent dot to be detected rapidly.

Control and effects of attention: theoretic issues

Having discussed the major tasks used to study spatial attention, this article now turns to two theoretically important issues for spatial attention: "How is spatial attention controlled?" and "What are the effects of directing spatial attention to an item?" Attentional control involves those parameters and processes that determine which items become attended and which do not. Attentional control parameters determine which items attention selects. For example, abruptly appearing stimuli, such as a peripheral cue, control the allocation of attention by capturing attention automatically.

There are different parameters that influence attentional control. Two general classes of control are top-down sources that arise from the current behavioral goals and bottom-up sources that arise from sensory stimuli present in a scene [20,23]. These two sources can be illustrated by reconsidering the visual search task. In a typical visual search task, observers are instructed to search for a particular target, such as a black vertical line, that appears in a field of distracters (Fig. 2). The target description—that is, the target an observer is actively looking for—can be conceptualized as a "template" that is temporarily stored in visual memory. This memory template influences visual search in a top-down manner; observers actively attempt to look at black and vertical items. The actual scene presented in a visual search task provides the bottom-up information that is searched through; this information indicates where objects are located and which features (eg, color, orientation, shape, and so forth) are present at each location. Visual search requires the observer to find a balance between the top-down information and the bottom-up information.

An example of an effective search is searching for a single feature, such as a black vertical line among white vertical lines (Fig. 2). When the target differs from the distracters by one feature (eg, color; see Fig. 2A), the bottom-up information is consistent with the top-down information in constraining where an observer should search. Such a search is efficient; the target "pops out" at the viewer and can be identified rapidly, irrespective of the number of items in the scene (Fig. 2B). A less efficient search involves searching for a conjunction of features, such as a black vertical line among black horizontal lines and white vertical lines (Fig. 2C). In this search, any single piece of bottom-up information is not unique to the target item, so the bottom-up constraints are weaker than in the feature search. Top-down constraints are required to resolve the competition among the input items. Conjunction searches are inefficient and operate more slowly than feature searches. When the bottom-up constraints are no longer unique, the search becomes progressively slower as items are added to a display (Fig. 2D).

Bottom-up and top-down control of spatial attention also has been examined using spatial cuing tasks, which direct attention to a location before a target event occurs. The type of spatial cue used can bias attentional control to favor bottom-up factors or top-down factors. For example, peripheral cues that involve an abrupt luminance change (eg, a flicker in the visual periphery) automatically attract attention via bottom-up control parameters, and this attentional capture occurs irrespective of the observer's intentions. In contrast, central, symbolic cues orient attention only if the observer voluntarily interprets the cue and shifts attention accordingly. Because central cues are dependent on task-related goals and observers' expectancies, they involve top-down control processes. As in visual search, the control of attention in spatial cuing tasks involves a balance between bottom-up and top-down factors. Although bottom-up peripheral cues capture attention, they may be influenced by top-down attentional control settings (eg, expectations of where the target will appear).

How can bottom-up and top-down attentional control parameters be integrated into a single framework for control? A popular framework for understanding attentional control is Desimone and Duncan's [23] biased competition account of visual search. In the biased competition account, the visual stimuli that provide bottom-up (stimulus–based) input compete with each other for attention. An observer's goals—such as the target template—provide the top-down (goal driven) control of attention. The top-down inputs can bias processing to favor one of the bottom-up inputs over the others. The competition among items is biased by a top-down signal, hence the name "biased competition."

Another important issue in the study of attention is how an attended stimulus is processed differently from an unattended stimulus. For example, the neural representation of an attended item could be enhanced relative to the representations of unattended items. Or, an attended item could integrate together the visual attributes of the attended stimulus, allowing the features of attended objects to be bound together [17,24]. There are several effects of attention highlighted in recent theories and supported by empiric data:

1. Attention reduces an observer's uncertainty in making judgments about a stimulus. Under this "decision-noise account" or "noise reduction account" [25], optimal performance (ie, accuracy) decreases as the number of stimuli increases, because each stimulus contains some uncertainty (or random noise). Attention reduces the random noise associated with the attended stimulus.
2. Attention also may reduce noise at a perceptual level of representation by enhancing the signal-to-noise ratio of attended items. This "sensory-gain account" hypothesizes that attention enhances the perception of attended items compared with unattended items. This effect of attention is to allow attended items to be of higher fidelity than unattended items [26].
3. Attention may be needed to bind together the features of an object [27]. Consider a display that contains a red circle and a blue square. How does the visual system bind the features "red" and "circle" together and avoid the incorrect combination of "red" and "square"? One solution to this binding problem is to focus attention on a single stimulus, thereby "gluing" or binding the features together. Directing spatial attention to a location reduces the number of incorrect feature combinations at that attended location [21].
4. Spatial attention also seems to have the effect of increasing the spatial resolution of perception. Multiple stimuli that appear in the lower visual field are more easily distinguished from one another than multiple stimuli that appear in the upper visual field, possibly as a result of parietal-lobe attentional processes. A single stimulus in the upper field, however, is perceived as accurately as a single stimulus that appears in the lower field. Thus, the differences in spatial attention between the upper and lower fields are produced when multiple stimuli are close to

one another and require attention to be "narrowed" around a single target stimulus.

5. Finally, spatial attention seems to influence the entry of items into visual short-term memory [28,29]. When the appearance of many visual objects must be retained across a delay, visual short-term memory processes are required to retain three to four of the objects. If one of the objects is preceded with a small spatial precue, this item is more easily remembered than other, uncued items.

The use of spatial attention in several situations to produce different effects suggests that it is unlikely to be a single process. Instead, spatial attention likely is controlled by several sources of information and likely arises from several different anatomic areas that work in concert (see discussions of influential theories [30–32]). This review of the behavioral literature on spatial attention provides the background for interpreting various attentional impairments that follow focal brain damage or that arise in degenerative disorders such as Alzheimer's disease.

Disorders of spatial attention: focal effects of cortical and subcortical areas

As in neurologically normal participants, most studies of attention with focal brain-damaged patients emphasized spatial attention. Because behavioral neurology and neuropsychology benefited from theoretic analyses of attention and vice versa, the authors emphasize what neuropsychology can contribute to cognitive theory and how cognitive theory can assist clinical practice in diagnosis and rehabilitation. The authors reviewed the cortical and subcortical contributions to spatial attention in patient populations elsewhere [33].

The parietal lobes, neglect, and extinction

Of all the multiple cortical and subcortical areas that contribute to the process of spatial attention, the posterior parietal region has been studied the most extensively. Unilateral damage to the human parietal lobe results in a profound syndrome referred to as neglect or hemineglect [34–38]. Because neglect and extinction most often follow right parietal damage, clinical symptoms are most evident for the left side of extrapersonal space or the left side of the patient (left hemineglect). Of course, neglect can occur after focal lesions to other areas (eg, frontal lobe areas), but most neuropsychologic studies of spatial attention focused on parietal-damaged patients.

Patients with parietal-lobe damage typically fail to attend to stimuli falling on the hemispace opposite the lesion (the contralesional side); these patients also may fail to acknowledge a person sitting on the left, eat food on the left side of the plate, read words on the left side of a page, and make head or eye movements to the left. These failures to respond to stimuli in the fields opposite the lesion are not the result of sensory deficits (eg, a visual scotoma or hemianopia). Patients with these sensory disturbances typically are aware of and orient to a contralesional hemifield stimulus to compensate for their impairment. Patients with hemineglect, however, generally are unaware of their deficit, and, if confronted with a defect on the impaired side (such as a hemiparesis), even deny the problem, a condition termed anosognosia. It is difficult, however, to accurately map visual sensory deficits that occur in a neglected hemifield. The authors suspect that this detection problem confounded the results of several studies of visual attention in parietal-damaged patients; some of the neglect cases reported in the literature may show subtle sensory deficits that have gone unnoticed.

There are some procedures that can help distinguish sensory difficulties from attentional difficulties. For example, a patient with auditory neglect may not notice sounds from the contralesional side of space, even though localized sounds reach both ears and afferent projections in the auditory system are bilateral (ie, each ear projects to both hemispheres). Failure to notice a contralesional sound by a neglect patient can be distinguished from a peripheral sensory impairment: A patient with a peripheral auditory sensory deficit should remain able to detect sounds localized to either side of space because the sound could be carried to both hemispheres by the intact ear's projections (see Heilman et al for a summary [35]).

Attentional neglect and extinction also can affect motor performance. In motor neglect, the patient might not move a contralesional limb, despite normal strength in this limb. The lesions that produce motor neglect may also extend into primary motor representations (Brodmann's area 4) in the frontal lobe. It is difficult to detect motor neglect in a paretic limb. A limb affected by motor neglect may seem paretic unless it is observed moving "automatically," including moving away from a noxious stimulus or moving to prevent the affected limb from falling in the patient's face after being dropped by the examiner. Motor extinction is distinguished more easily from paresis and neglect. In motor extinction, the patient can move a contralesional limb when the ipsilesional limb is stationary, but not when the ipsilesional limb is moving [35]. The co-occurrence of attentional neglect and extinction with motor neglect and extinction suggests that attentional and motoric processes may share neural mechanisms.

Neglect typically occurs immediately after damage to the parietal region and, as a patient recovers and the neglect becomes less severe, patients can process a single stimulus presented in the contralesional visual field. The patients may begin to show another disorder, however, extinction, in which they extinguish or fail to notice the stimulus in the contralesional field when two stimuli are presented simultaneously in both visual fields. That is, extinction patients exhibit neglect of contralesional stimuli only in the presence of ipsilateral stimuli. Of course, damage to the parietal cortices may produce a variety of other disturbances, but the focus here is only on the attentional impairments after damage to the parietal region.

Neglect and extinction can be diagnosed easily at the bedside or clinic. In one standard bedside evaluation, the patient is asked to fixate the examiner's nose and to indicate (verbally or by pointing) which field contains the examiner's wiggling fingers. Patients with neglect fail to report on single stimuli in the aberrant field, whereas those with extinction fail to detect targets in the aberrant field with double simultaneous stimulation (finger wiggling) in both hemifields. Even a patient with extinction, however, may have difficulty detecting multiple stimuli presented in the impaired shield, resembling the perceptual defect in simultanagnosia, a full-field defect of simultaneous perception often associated with bilateral parietal lobe lesions.

Neglect and extinction also are diagnosed using a variety of widely used paper-and-pencil tasks [35,37,38]. These patients neglect features on the contralesional side of space (and on the contralesional side of objects) during tasks that involve direct copy (eg, complex figure test [CFT]) or recall (eg, Benton visual retention test; CFT recall at 30 minutes) and from mental imaging of familiar places and objects [39,40]. In many cases, the patients fail to include features that appear on the left side of the object when asked to reproduce an analog clock from memory. For example, all the numbers might be placed on the right side of the clock (Fig. 3).

Another widely used paper-and-pencil task is the line bisection task. In this task, patients are asked to divide a horizontal line in half. Patients with hemispatial neglect often bisect the line to the right of center, presumably because they do not attend to the left-most portion of the line. In another task, object cancellation, patients view a cluttered display containing several objects (eg., lines, letters, geometric shapes, and so forth) and are asked to cross out (ie, cancel) all the objects in the display. Again, patients with damage to the right parietal area fail to detect objects in the left visual field, and these objects are not cancelled by the patient. Severely affected patients may fail to detect their errors on visual inspection. Patients with visual loss alone (eg, homonymous hemianopia) do not make these types of errors on line bisection and cancellation tasks, provided that gaze and head movement are not restricted and viewing time is longer than a few seconds.

Insights into the attentional impairments that follow parietal-lobe damage have come from theoretically motivated studies using the attentional paradigms discussed previously. Posner and colleagues [41] were among the first to study patients with parietal-lobe damage under the guidance of an explicit cognitive theory of attention. Using Posner's spatial cuing task, Posner et al [41] found an asymmetry in attentional orienting in parietal-damaged patients, who were slower to detect invalidly cued targets presented in the contralesional field. That is, a patient with right parietal damage was slower to detect a target in the left field after a cue in the right field than to detect a target in the right field after a cue in the left field. (These patients could detect validly cued targets appearing in each visual

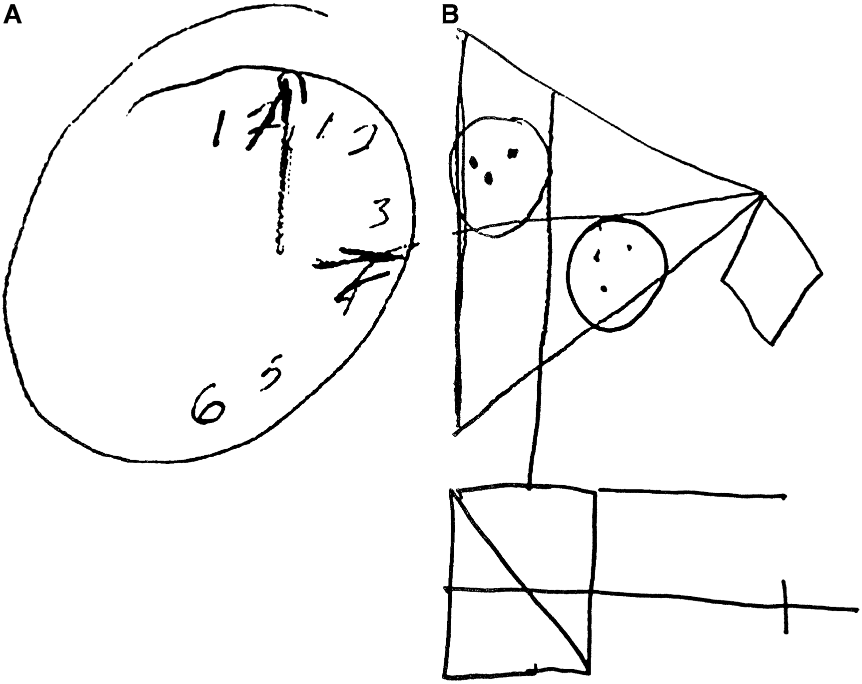

Fig. 3. Sample results from parietal-damaged patients that demonstrate the contralesional impairment in copying geometric stimuli or drawing objects from memory. In (*A*), a parietal-damaged patient was asked to draw an analog clock from memory, and the left side of the object is neglected. In (*B*), drawing an object from memory also exhibits left-sided neglect.

hemifields, although RTs are typically longer to targets in the contralesional field.) Similar results were obtained with central symbolic cues (arrows) and peripheral cues.

Based on this response (asymmetry for detecting invalidly cued targets in the two hemifields) Posner and colleagues suggested that the parietal lobes allow disengagement of attention. Further, Posner and colleagues hypothesized that damage to one of the parietal lobes causes a "disengage deficit," which hinders disengagement of attention from the ipsilesional visual field. Thus, in a right parietal damaged patient in whom a cue appears in the ipsilesional (right) field and a target follows in the contralesional (left) field, the patient has difficulty detecting the targetThis interpretation, however, requires that each parietal lobe must mediate disengagement of attention from the ipsilesional field, which is a counterintuitive mechanism given the crossed visual pathways and the predominant left-sided deficit after right parietal damage.

Recent views of the neglect and extinction syndromes attempted to explain these patients' impairments in spatial attention without appealing to a "disengage deficit." Cohen et al [42] presented a neural network model as an alternative explanation of the disengage deficit. In their model (Fig. 4), neural representations of the visual hemifields compete with each other for attentional selection (as in Desimone and Duncan's model). This attentional competition is the result of inhibitory connections between two pools of units in the network that represent the left and right sides of space. If the representation of the left field is damaged, it competes less effectively with the representation of the right field. As a consequence, when attention is directed to the right (intact) field, a target appearing in the left (damaged) field is at a competitive disadvantage. Thus, detecting the invalidly cued target that appeared in the left field is more difficult. In contrast, when attention is directed to the disordered left field, a target appearing in the intact right field can compete effectively for attention, allowing this target to be detected relatively quickly. According to this model, no mention of "attentional disengaging" is required. Patients' seem to have a disengagement of attention, but the mechanism underlying the patients' behavior is based on competition between damaged and intact representations of space, not on "attentional disengagement."

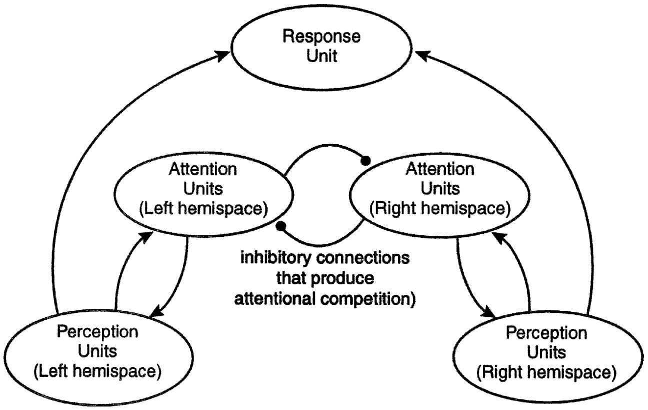

Fig. 4. The architecture of the neural network model used by Cohen et al [42] to simulate the "disengage deficit" observed in some patients with parietal-lobe damage. This network performs a simulated version of Posner's spatial cuing task. The perception units provide parallel input to pools of attentional units and to a response unit. Spatial cues and the target are presented as input to the model by "turning on" one of the perception units. This activation propagates through the network and activates the attentional units and the response unit. When a spatial cue is presented to the left perception unit, the left pool of attentional units is partially activated and inhibits the right pool of attentional units. Thus, if a target is then presented to the right perception unit—an invalidly cued target—the model takes long to respond because the right pool of attention units has been inhibited. This model exhibits a disengage-like pattern of results because damage to one of the attentional pools impairs these units' ability to compete with the intact pool of attentional units. If the right pool of attentional units is damaged, a spatial cue on the left, which activates the left pool of attentional units, is able to inhibit the damaged right pool of attentional units more than if the model was undamaged.

The effects of right parietal damage on visual search are consistent with results from spatial cuing paradigms. Eglin et al [43] asked patients with parietal damage to search for conjunctions between features (eg, color and shape) amid varying numbers of distractors (see Fig. 2). The patients' responses were slowed dramatically when the distractors appeared in the ipsilesional field compared with the contralesional field. The presence of ipsilesional distractors prevented the contralesional representation of the target from competing effectively for attention, consistent with Cohen et al's [42] account of the disengage deficit associated with parietal lobe damage.

Frames of reference for neglect

The phenomena of spatial neglect and extinction can be interpreted with respect to several coordinate frames. In visual cognition, a coordinate frame determines the reference point (origin) from which space is measured. Visual locations can be represented with respect to the environment (eg, the left or right side of a room—an environmental reference frame), the observer (eg, on the observer's left or right side—a viewer-centered reference frame), or an object (eg, the left or right side of the letter "B"—an object-centered reference frame).

Attempts to define effects of hemineglect in different coordinate systems must consider issues of overlap and alignment of the reference frames. For example, a ceiling is typically "up" or "above" in environmental coordinates and in viewer-centered coordinates (ie, the ceiling appears above the viewer's head or fixation point and above the rest of the room). To study the effects of reference frames, these reference frames must be disentangled from one another, which is typically done by tilting the patient or tilting an object that the patient is viewing.

Using these types of manipulations to disentangle coordinate systems, Calvanio et al [44] found that neglect can occur in multiple reference frames. Neglect patients with right parietal damage not only failed to report items to their left side (viewer-centered coordinates), but also reported few objects from body-centered left and reported few objects from environmental left, suggesting that hemineglect disrupted viewer-centered (or body-centered) and environmental-centered reference frames. Ladavas [45] also reported results indicating that neglect can occur in several reference frames (eg, viewer-centered and environment-centered frames).

Other observations indicate that several coordinate or reference systems may be damaged in neglect. For example, patients with hemineglect resulting from acute or chronic lesions in parietal [46] and parietoinsular regions may experience a tilt of visual percepts of the earth-fixed vertical axis away from the side of the brain lesion. Such patients might also experience rotation [47,48] or displacement [49,50] of an egocentric visual coordinate system toward ipsilesional hemispace. Ipsilesional coordinate shifts have been found on a kinesthetic "point straight ahead" task [51–53] and on visual tasks in which subjects stop a moving spot of light directly in front of the body midline [53–55]. Shifts in subjective body midline position might cause a shift in the egocentric frame of reference for coding locations in extrapersonal space, but alone are not sufficient to account for hemineglect [56].

Neglect also may occur with respect to object-centered coordinates, and objects can reduce the effects of neglect. For example, the eye movement patterns of parietal-damaged patients demonstrate that object information that crosses from the intact field to the neglected field can encourage patients to search in the neglected field. Patients with hemineglect are more likely to make eye movements into the neglected field when they view scenes in which a single object or perceptual group crosses from the intact visual field into the neglected visual field [57]. If hemineglect patients view a face that falls in both visual fields, they make fixation transition across the midline between the eye features of face displays even when the features are located in the neglected hemifield. In contrast, when viewing a scene in which objects do not cross from the intact field to the neglected field, fewer fixations occur across midline.

In addition to objects reducing the effects of neglect, objects encourage neglect to occur in the patient's intact field, as defined by viewer-centered coordinates. Neglect can occur in object-centered coordinates, in which the patient fails to report information from the left side of an object, even when that object falls on the patient's right side. Some patients with right parietal damage are less likely to report items from the left side of an object than from the right side of an object, even when the left side of the object appears in the right (ipsilesional) visual field [37,58 (review)]. Although there have been failures in finding object-centered neglect [59], such failures may occur when the objects are secondary to the task that patients are asked to perform.

Neglect also occurs across different sensory modalities. Neglect patients have difficulty attending to visual and auditory stimuli in contralesional space, suggesting that parietal lobe attentional processes operate on a representation of space that codes visual and auditory stimuli. Farah et al [60] found evidence for cross-modal neglect in parietal-damaged patients who were asked to detect a lateralized visual stimulus on a multimodal version of Posner's spatial cuing task. This visual target was preceded by a cue presented in either the visual or auditory modality. Patients with parietal damage oriented similarly to both types of cues; they had difficulty "disengaging" attention from cues presented on the ipsilesional side of peripheral space regardless of cue modality. These results suggest that parietal lobe attention mechanisms are supramodal (see Spence and Driver [61,62] for methodologic concerns with studying cross-modal spatial attention).

Control parameters and spatial attention

As discussed previously, attention can be deployed—or controlled—by several factors. Some are environmental (bottom-up, exogenous) factors, such as the appearance of a new object or event. Others are endogenous (top-down) factors that arise from within the observer based on goals or expectations. Which of these control parameters is impaired after parietal-lobe damage? The disorder of attention in parietal-damaged patients seems to involve bottom-up control parameters. This does not suggest that neglect is a sensory-level impairment. Perceptual processing may be largely intact in neglect patients, but attention is not effectively captured by stimuli on the contralesional side of space. Although these stimuli have intact perceptual representations, they do not fully capture or drive the damaged attentional processes.

Evidence for poor bottom-up control comes from simulating aspects of neglect in neurologically normal observers by degrading one side of a visual scene. These observers show the "disengage" deficit if half of a computer monitor is degraded with translucent tracing paper (S. Vecera, unpublished data, 2002). Targets on the degraded side of the display are more difficult to detect after a cue on the nondegraded side than targets appearing on the nondegraded side after a cue to the degraded side [63].

Studies using the Posner cuing paradigm suggest that some forms of top-down attentional control are intact after parietal damage. Use of a central arrow cue (considered an endogenous cue) pointing to the left (contralesional) side can reduce the number of targets missed by right parietal patients; the same reduction in misses does not occur for exogenous peripheral cues [64]. As central arrows and peripheral cues are not alike physically, these differences could be the result of perceptual, not attentional, processes. Bartolomeo et al [65] addressed this issue using peripheral cues only; to manipulate exogenous and endogenous attention, the cue's informativeness was manipulated by making the cue informative. Informative peripheral cues, which indicate the likely location of the target, tap endogenous attentional processes, whereas uninformative cues tap exogenous processes. Bartolomeo et al [65] reported that parietal damaged patients could reduce their response times to contralesional stimuli if most of the invalidly cued targets appeared in the contralesional field. The patients correctly anticipated the target's expected location in the contralesional field and directed attention accordingly. Parietal patients can make use of top-down expectancies or task-relevant goals. A contralesional stimulus may not be extinguished if the ipsilesional stimulus is task irrelevant and the patient is asked to ignore it [66]. For example, a right parietal patient who is asked to name the color of each of two stimuli, one in each visual field, is more likely to extinguish the contralesional stimulus if the two stimuli are the same color. If the two stimuli are the same shape (eg, both circles) or different shapes (eg, one circle and one square), however, only the task-relevant attribute of color influences extinction. The task-irrelevant shape dimension does not influence extinction.

The parietal lobes, neglect, and extinction: attentional effects

Having addressed the attentional control processes that seem disrupted after parietal damage, this article now discusses the effects produced by parietal damage. Recall that spatial attention has many hypothesized effects, including (1) providing attended stimuli with greater resources than unattended stimuli; (2) enhancing sensory-level or decision-level representations for attended items compared with unattended items; (3) binding together the features of an object; and (4) increasing the spatial resolution of perception. The attentional impairments after parietal damage seem to disrupt some of these attentional effects.

Little is known about attentional resources after parietal damage. Some results from patients, however, support the sensory enhancement effect of spatial attention in which attention may ‘‘amplify’’ sensory information transmission [26]. The results suggest that bottom-up control is impaired [64,65] and that sensory amplification effects are diminished so that attention is not captured effectively by events in the contralesional field. More direct evidence of the effect of sensory amplification after parietal damage could be obtained by using early visual evoked potentials after parietal damage or by applying psychophysical techniques to study amplification effects [67].

Additional evidence also is needed of the role of parietal cortex in reducing decision noise, one of the hypothesized effects of spatial attention. Spatial cues seem to reduce the uncertainty of observer’s decisions [25], and the disrupted spatial orienting observed suggests that parietal patients may have difficulties making decisions about targets in the contralesional field. The authors have preliminary data from a study that investigates decision noise effects after right parietal lobe damage (S.P. Vecera and M. Rizzo, unpublished data, 2002). Consistent with a decision-noise deficit, the authors’ patient showed a larger difference between validly and invalidly cued targets in her contralesional field than in her ipsilesional field. These observations need to be replicated in this patient and others, but the results suggest that parietal damage may influence a host of attentional effects, including the reduction of decision noise.

Spatial attention seems to increase the spatial resolution of perception [68,69]. When observers are asked to report the orientation of a textured pattern, performance differs between the upper and lower visual fields (ie, above and below fixation) when multiple stimuli are present (Fig. 5B) but not when a single stimulus is present (Fig. 5A). Because there are no upper/lower field differences in primary visual cortex, the visual field difference may be produced by the resolution of spatial attention, which is greater in the lower field than in the upper field [69]. The authors have unpublished results that support this hypothesis. Patients with parietal-lobe damage were asked to determine the orientation of a texture grating that appeared alone or flanked by irrelevant gratings. The stimuli were presented in either the contralesional or ipsilesional field. In two patients, the authors found no visual field difference for the single texture gratings, but did find a statistically significant field difference when multiple gratings appeared (Fig. 5C). Specifically, the patients’ performance was poorer when multiple items appeared in the contralesional field than in the ipsilesional field. No visual

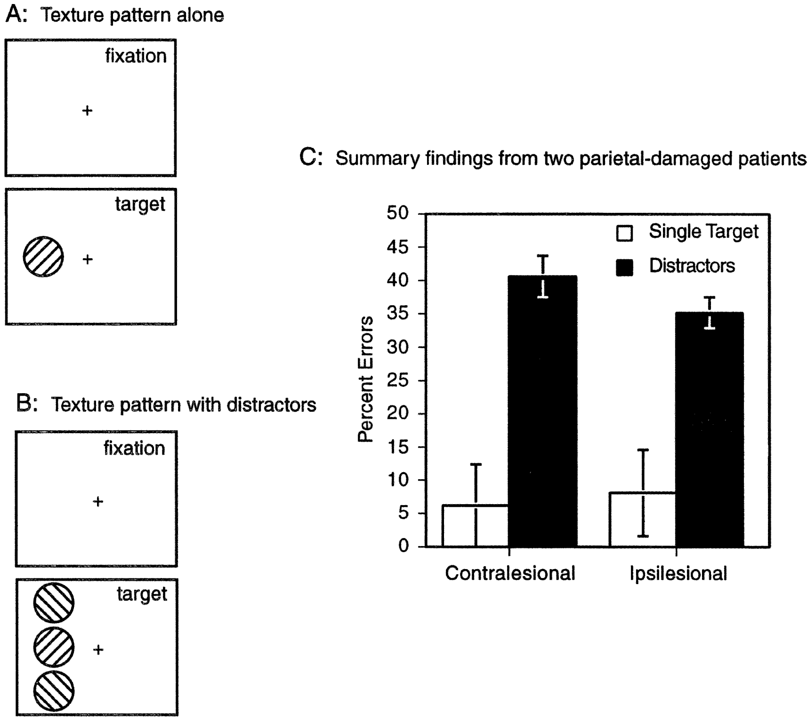

Fig. 5. (*A* and *B*) Procedure used to investigate the spatial resolution of attention. A texture pattern is presented, and an observer must determine if the pattern is tilted to the left or right. The target pattern appears alone or surrounded by irrelevant texture patterns. (When the pattern is target surrounded by irrelevant distracters, the central pattern is always the target.) (*C*) When texture patterns are presented briefly (150 ms or shorter) to parietal-damaged patients, the patients easily can report the texture orientation if the texture pattern appears alone. When the texture pattern is presented with distracters, however, the patients are poorer at determining the texture orientation in the contralesional field than in the ipsilesional field. The spatial resolution of attention is coarser in the contralesional field than in the ipsilesional field.

field effects were observed for neurological control participants. Parietal-lobe damage seems to impair spatial resolution in the contralesional field.

Finally, perhaps the most studied effect with parietal patients is the role of spatial attention in solving the binding problem. When neurologically intact observers are distracted by asking them to perform a secondary task, features of different objects can become miscombined, resulting in illusory conjunctions of features [70]. Results from parietal patients also suggest that spatial attention is involved in binding or conjoining the features of objects, because these patients misconjoin features and show high rates of illusory conjunctions. Cohen and Rafal [71] asked a patient with parietal damage to perform two tasks concurrently. The first task was a digit identification task: two digits, one large and one small, were presented at fixation, and the patient was instructed to identify the large digit. The second task was a letter identification task: one of the letters was a target (“F” or “X”) and the other was a distracter (“O”). The letters were colored, and the patient was instructed to name the color and the identity of the target letter (“Was it ‘F’ or ‘X,’ and what color was it?”). In the second task, there are two types of errors. The first is a feature error, in which either letter name or color is reported incorrectly. For example, if the patient is presented with a blue “F” and a red “O,” reporting a yellow “F” is a feature error. The second type of error is a conjunction error, in which a feature of the distracter letter “O” “migrates” to the target letter, forming an illusory conjunction. For example, if the patient is presented with a blue “F” and a red “O” but reported a red “F,” the color of the red “O” was misconjoined with the target letter “F.” Cohen and Rafal’s patient showed a larger number of conjunction errors in the contralesional field than in the ipsilesional field. Similar numbers of feature errors were made in the contralesional and ipsilesional fields, indicating that feature perception was similar in both fields. Presumably, the damaged parietal-based spatial attention system impaired feature integration, although the individual features are represented, allowing for accurate perception of individual features.

Even more direct evidence for the role of parietal attention areas in solving the binding problem comes from Robertson and colleagues [72], who investigated illusory conjunctions in a patient with bilateral parietal and cerebellar damage. The patient showed features of a syndrome originally described by Bálint and later called Bálint’s syndrome (also see Rizzo and Vecera for a recent review [73]). Patients with Bálint’s syndrome typically have deficits in visually guided reaching (optic ataxia) and eye movements (ocular apraxia). The hallmark of the syndrome, however, is a set of visuospatial impairments including visual disorientation manifested by a difficulty judging the depth between objects and an extreme inability to perceive more than one object or shape at a time, known as simultanagnosia. Robertson et al’s patient could search effectively for a target defined by a single feature (eg, searching for a red target or searching for an “X”).The patient was impaired dramatically at searching for conjunctions (eg, finding a red “X”) and for integrating the features of objects, however. Robertson et al’s patient showed illusory conjunction errors even when the visual display was present for 10 seconds, an exposure duration at which neurologically intact observers should make no illusory conjunctions. Presumably, this patient’s spatial confusion and simultanagnosia prevented him from having an accurate representation of spatial location, which is necessary for conjoining the features of an object.

In summary, patients with damage to a network of structures that mediate attention, especially parietal lobe areas, have a variety of different attentional impairments. These impairments extend across different visual reference frames and across different modalities, and many of the typical effects of attention, such as the ability to bind features of an object, seem to be defective. The bottom-up capture of attention seems to be disrupted in association with a failure of sensory amplification. The lack of capture also may prevent the damaged hemisphere from competing with the intact hemisphere for attention, resulting in an attentional imbalance that seems to favor the ipsilesional field (any may appear as a "disengage deficit").

Understanding the control and effects of spatial attention after parietal damage may offer insights for rehabilitation. If parietal damage disrupts bottom-up capture of spatial attention and involves an attentional imbalance between the cerebral hemispheres, then rehabilitation that increases the input to the disrupted hemisphere may reduce the attentional imbalance and the associated neglect or extinction. Some reports suggest that neglect symptoms may be reduced by patching the ipsilesional eye, which (1) reduces some of the ipsilesional visual input and (2) reduces the activation of the ipsilateral colliculus (see Heilman et al for a brief discussion of treatments for neglect [35]). Unfortunately, most treatments that have been investigated only provide temporary relief from neglect [35].

The frontal lobes and spatial attention

Although deficits in spatial attention have been studied extensively in patients with parietal lobe damage, it has long been known that spatial neglect and other spatial deficits can follow lesions to frontal cortices (see Bisiach and Vallar for a recent review [74]). Because the frontal lobes participate in the operation of multiple cognitive processes, however, including language, motor control, working memory, and attention, less is known about the particular attentional processes associated with frontal areas. For example, little is known about the neuropsychology of visual search in patients with frontal lobe damage. This lack of knowledge may occur because studies of neglect sometimes include patients with frontal damage and patients with parietal damage, thereby obscuring possible differences between these groups; the attentional processes of the medial frontal lobe seem to differ from those associated with the parietal lobe (see Swick and Knight for an overview [75]).

One area of spatial attention studied in patients with frontal lobe damage is the control of overt attention—the production of eye movements. Typically, directing the eyes to a region of space is preceded by directing covert spatial attention to the target region [76]. Lesions of superior frontal lobe areas that include the frontal eye fields (FEF) seem to disrupt some types of overt eye movements. Guitton et al [77] demonstrated that eye movements to an abruptly appearing visual target (a "prosaccade" in which the eyes move to the target) do not differ between frontal patients with FEF damage and control patients with temporal lobe damage. Eye movements in a direction opposite an abruptly appearing target ("antisaccades"), however, are dramatically impaired in frontal patients. In the antisaccade task, the FEF patients often made reflexive eye movements to the target location instead of moving in the opposite direction. When the FEF patients did make antisaccades, the latency of their eye movements was longer than those of control patients. FEF seems to play an inhibitory role in overt attention by preventing unwanted reflexive eye movements.

Guitton et al's study is important for demonstrating the role of frontal lobe areas in overt attention, but does not address the different types of spatial cues that can control covert and overt attention. To address the role of different spatial cues (peripheral cues versus central symbolic cues), Henik and colleagues [78] studied patients with frontal lobe lesions that included superior dorsolateral prefrontal cortex, which included the FEF and patients with frontal damage that excluded FEF. The patients performed two tasks. One task was a saccade task, in which eye movements were made to a peripheral location that was cued with either a central arrow cue or a peripheral cue. The other task was a detection task in which the patients pressed a key that corresponded to a target signal; this target signal was preceded by either a central arrow cue or a peripheral cue. In both tasks, half of the cues (central and peripheral) were valid and half were neutral; there were no invalid cues.

Henik et al [78] found that FEF lesions disrupted eye movements to peripheral locations, but not all eye movements were disrupted equally. The FEF patients were slower to make eye movements into the contralesional field than into the ipsilesional field after central cues. Also, after peripheral cues, the FEF patients made faster eye movements into the contralesional field than into the ipsilesional field. Patients with intact FEF made eye movements into the contralesional and ipsilesional field approximately equally after central and peripheral cues. The results from the FEF patients indicate that voluntary overt orienting is impaired in this group—these patients are slowed only in directing eye movements to the contralesional field after the symbolic arrow cue. The authors hypothesize that the FEF patients may be speeded in directing overt attention into contralesional space after a peripheral cue because the FEF lesion may disinhibit ipsilesional midbrain areas; this disinhibition has the effect of inhibiting the opposite colliculus and delaying reflexive eye movements into the ipsilesional field. Finally, the FEF group did not show any impairments in the detection task, suggesting that the attentional impairments were confined to overt attention (eye movements); covert attention could be directed to cued locations and facilitate responses that did not involve an eye movement.

Finally, patients with frontal lobe lesions also exhibit an attentional impairment related to covert attention (ie, attentional orienting that does not require eye movements). Voluntary attentional orienting in frontal patients seems to be impaired. Using Posner's spatial cuing task with symbolic precues, Alivisatos and Milner [79] presented patients with word cues that either signaled the upcoming target's location (valid trials) or provided no information about the target's location (neutral trials). Frontal lobe patients showed a smaller attentional benefit (the difference in performance between valid and neutral trials) than control participants or temporal lobe patients. Koski et al [80] reported similar results using centrally presented arrow cues that either validly predicted or did not predict the upcoming target's location. Again, frontal patients showed smaller attentional benefits than either control participants or temporal lobe patients. The frontal patients in these studies had varied lesion locations that included dorsolateral frontal areas and ventromedial frontal areas. The authors' results suggest that at least one frontal patient, EVR [81], cannot use symbolic precues (words or eye gaze direction) to direct spatial attention, although he can use peripheral precues to orient spatial attention.

Superior colliculus and pulvinar: subcortical influences on spatial attention

In addition to the cortical control of spatial attention, there are at least two subcortical regions that seem critical for spatial selection: the superior colliculus and the pulvinar nucleus of the thalamus. Most studies investigating the role of these subcortical regions used Posner's spatial cuing task to investigate covert spatial attention.

Progressive supranuclear palsy (PSP) is a neurodegenerative disorder that resembles Parkinson's disease and affects the basal ganglia. One difference between these two degenerative disorders is that PSP produces a marked impairment of voluntary gaze control, likely the result of damage to degeneration of dorsal midbrain structures, especially the superior colliculus [82]. PSP patients have an inability to make voluntary saccadic eye movements, especially vertical eye movements. For example, PSP patients often do not look up at a person who is speaking to them and cannot make saccades to move their eyes upward if given a command to do so. If the PSP patient, however, is asked to continue to fixate a target while the head is tilted downward, the eyes are able to maintain fixation by moving upward slowly using vestibulo-ocular mechanisms more closely related to smooth pursuit movements.

In a series of studies, Posner and colleagues and Rafal et al investigated spatial orienting in PSP patients [83,84]. PSP patients were cued to locations that appeared in one of four locations: above, below, left, or right of fixation. After the cue, a target appeared at the validly cued location or at an invalidly cued location, and patients were instructed to press a button as soon as they detected the target. There were two cue conditions in these studies. In the exogenous condition, the cue was a peripheral flicker valid on 50% of trials and invalid on 50% of invalid trials; in the endogenous condition, the cue was a central arrow that was predictive (valid on 80% of the trials and invalid on 20% of the trials). The patients were faster at detecting validly cued targets than invalidly cued targets in the horizontal direction but not in the vertical direction; control patients with Parkinson's disease showed no differences between orienting horizontally or vertically [84]. Also, the movement of attention in PSP patients was slower in the vertical direction than in the horizontal direction. Finally, there was a slight, but nonsignificant, trend for a greater impairment in the exogenous cue condition than in the endogenous cue condition, possibly because endogenous cues involve more cortical processing than exogenous cues.

Based on their results, Posner and colleagues and Rafal et al suggested that the superior colliculus might be involved with one specific component of spatial attention. In general, spatial attention may involve several component operations for normal performance, including disengaging from an attended location, moving attention to a new location, and engaging attention at the new location. PSP patients seem to have difficulty with the ''move operator'' that permits attention to be moved from one location to another: PSP patients orient spatial attention more slowly in the vertical direction than in the horizontal direction. This finding suggests that the superior colliculus may be involved with the movement of spatial attention. Of course, the same difficulties with the disengagement hypothesis of parietal damage also apply here. Specifically, a disorder that seems to be produced by a damaged attentional ''mover'' or ''move process'' might be the result of damage to a system that does not contain an explicit move process.

PSP also seems to affect IoR, the decreased tendency to re-orient attention to a previously attended location described above in studies of neurologically normal subjects performing Posner's task. PSP patients also show reduced IoR effects in the vertical direction than in the horizontal direction. Control patients with Parkinson's disease exhibited IoR in the horizontal and vertical directions, suggesting that IoR may be linked to the eye movement system controlled by the superior colliculus [85].

The pulvinar nucleus of the thalamus seems involved in the subcortical control of spatial attention. Pulvinar lesions can cause neglect and attentional impairments. Rafal and Posner [86] had acute pulvinar patients perform a spatial cuing task with highly predictive (80% valid and 20% invalid) peripheral cue. The patients were slower to detect targets in the contralesional field than in the ipsilesional field across long cue-target intervals (almost a second). Rafal and Posner inferred that the pulvinar might be responsible for engaging spatial attention at a cued location. Across both hemifields, RT to validly cued targets decreased as the time between the cue and target increased, which suggests that patients with pulvinar lesions can deploy, or move, spatial attention similarly in both visual fields. The pulvinar patients showed a ''disengage deficit'' similar to that of parietal patients, but only for short cue-target intervals, unlike parietal patients, suggesting that pulvinar lesions produce a different disengage deficit from parietal lesions. The results from pulvinar patients suggest that attention can be disengaged (eventually) from an attended location and moved to a new location, but that attention a ineffectively engaged at the new location. CT scans revealed posterior thalamic damage in these patients, however, which could have involved areas other than the pulvinar. Converging evidence from neuroimaging studies and single-unit recordings suggests that the pulvinar plays a role in visuospatial attention [87,88], although these studies use different attentional paradigms making it difficult to completely understand the attentional functions of the pulvinar.

Disorders of spatial attention in Alzheimer's disease

The diagnosis Alzheimer's disease (AD) involves progressive memory impairment [89,90]; recent reviews underscore the progressive impairment of several attentional processes [91–93]. Spatial attention impairments in AD are important because most higher-level cognitive processes require some form of attention and because patients with AD might present with attentional impairments before presenting with other cognitive impairments, such as memory impairments [92].

As with studies of control participants and focal brain-damaged individuals, research on spatial attention in patients with AD has relied on the spatial cuing and the visual search paradigms discussed previously. The findings from these information-processing paradigms and the theories developed from these paradigms generally are consistent with results from standardized tests used in clinical practice. For example, tasks such as the useful field of view (UFOV) and the "Starry Night" target detection task demonstrate attentional impairments in patients with AD [94].

Spatial selective attention, spatial cuing, and AD

Patients with AD show difficulties using spatial attention to orient to a location to detect an upcoming event on Posner's spatial cuing paradigm (see Fig. 1). In one of the earliest studies, Parasuraman et al [95] presented patients with AD with a symbolic central precue—a small arrow that pointed to the left or right (an endogenous precue). After this precue, a target letter appeared, which the patients categorized as a consonant or vowel. Patients with AD categorized validly cued targets faster than neutrally cued targets, and this benefit was similar in magnitude to the control participants. Patients with AD, however, showed a larger attentional cost than the control participants and were disproportionately slower in categorizing an invalidly cued target than categorizing a neutrally cued target. Similar results were obtained when peripheral precues (exogenous precues) preceded the letter to be categorized.

What is the implication of increased attentional costs in AD? Recall that the parietal-damaged patients studied by Posner et al [41] showed a larger attentional cost in the ipsilesional visual field compared with the contralesional visual field and proposed that this pattern reflected impairment in disengaging spatial attention from its current focus. Using this analysis, Parasuraman and colleagues [95,96] argued that patients with AD have an impairment in disengaging spatial attention. As discussed previously, however, there are plausible alternatives to the "disengage deficit" hypothesized in parietal-damaged patients (eg, attentional competition across different hemifields). Whether or not these alternatives explain the increased attentional costs observed in patients with AD could be a direction for fruitful research.

In addition to investigating the benefits and costs of spatial precuing, studies in AD investigated the IoR of spatial attention. As discussed previously, when the time delay between a spatial precue and target is sufficiently long (200 ms or slightly more), neurologically normal participants are faster to detect invalidly cued targets than validly cued targets [13], and this pattern of response times is thought to reflect the difficulty in returning spatial attention to a previously attended location. Under some conditions, patients with AD do not exhibit IoR [97]. When a spatial precue appears in a peripheral location, spatial attention can be directed away from this precued region spontaneously by the observer or by another spatial precue presented at a new location [13,98]. Patients with AD show IoR when a second spatial precue directs attention away from a currently attended location but not when attention is directed away from the currently attended region spontaneously by the individual with AD [97]. This failure to find IoR without a second spatial precue suggests that attentional re-orienting may be sluggish in AD. Patients with AD may re-orient spatial attention or sample visual space using spatial attention more slowly than neurologically healthy individuals.

Visual search and AD

Patients with AD differ from healthy control participants in using spatial attention to search through a cluttered visual scene. Foster et al [99] asked patients with AD and controls to search for a target (a filled circle) among different numbers of distracters so that the search task was either a feature search or a conjunction search (see Fig. 2). In the feature search, a shaded circle appeared among filled circles; in the conjunction search, a shaded circle appeared among shaded squared and unfilled circles. Recall that neurologically healthy younger observers perform feature searches efficiently; adding additional distracters slows target identification little, if at all. In contrast, feature searches are performed inefficiently; as distracters are added to the display, the time to identify the target increases.

Foster and colleagues found that patients with AD seemed to respond slower in the feature search than did control patients, yet appeared to search the displays efficiently. Specifically, as the number of distracters increased, patients with AD and controls did not show dramatic increases in baseline response time. With the addition of a distracter, moderately demented patients were slowed by 4.25 ms, mildly demented patients were slowed by 0.71 ms, and controls were slowed by 0.53 ms. All these estimates of search efficiency fall within the "efficient" range described in the cognitive literature on search [20].

When individuals with AD performed a conjunction search task, they differed from controls in two respects. First, as with the feature search task, patients with AD responded more slowly than control participants. Second, and more theoretically interesting, the individuals with AD showed a more dramatic increase in response times than control participants as distracters were added to the display. That is, the slope of the search function was steeper for the patients with AD than for the controls. Moderately demented patients were slowed by an average of 50.25 ms for every distracter added to a scene; mildly demented patients were slowed by an average of 34.9 ms per distracter; and controls were slowed on average by 24.5 ms per distracter. Although all these slope estimates are in the "inefficient" range [20], the differences among the slopes indicates an impairment in spatial attention in the group with AD, especially for the moderately demented subset of patients. One straightforward explanation of the increase in slopes for the patients with AD performing the conjunction search is that they have an impairment in disengaging spatial attention from the currently attended item. As the number of items to search increases, this disengage difficulty disproportionately slows response times compared with control participants. This disengage account is consistent with the interpretation of other attentional impairments exhibited by individuals with AD [95,96]. As with the disengage deficit hypothesis for parietal-damaged patients, however, there are likely to be alternative explanations for a disengage deficit hypothesis in patients with AD. Again, it is possible that attentional competition across the two hemifields could produce a disengage-like pattern of response time results. Other attentional effects, including decision noise reduction, might be impaired in patients with AD, as discussed later.

Finally, visual search in patients with AD also has been used to investigate the spatial scale, or spatial window, of spatial attention. The visual search paradigm used to study spatial scale differs from the standard search paradigm developed by Treisman and used by Foster et al [99]. In this adapted visual search task, patients with AD view a rectangular array of letters that was preceded by a spatial precue [100,101]. The size of the precued region is manipulated so that it encompasses a single letter in the search display (high precision of localization), one column of two or three letters (medium precision), or the entire set of letters (low precision). Further, in this paradigm, the target of visual search can appear in the precued region (valid trial) or outside the precued region (invalid trial). Using this procedure, Greenwood et al [101] found that performing a conjunction search task was facilitated by valid precues, but that this facilitation effect was smaller for patients with AD [100]. Performance in a feature search task was affected little by the size of the precued region, supporting the hypothesis that feature searches are performed in parallel across the visual field and require little or no attention. These results indicate that patients with AD may be impaired in controlling the size of the window of spatial attention, which might be narrower in patients with AD than in normal individuals [100,102,103].

Unanswered questions regarding spatial attention and AD

There seem to be observable impairments in spatial attention in AD. These impairments are studied because spatial attention plays a central role in high-level cognitive processes, such as visual short-term memory [28] and spatial memory [104,105]. General attentional impairments may be the cause of other cognitive deficits observed in AD [106] and the cause of the decline of everyday behaviors. It has become increasingly clear to those who work with patients with AD that understanding how attention can produce the cognitive decline in AD depends on cognitive theories of attention [107]. For this reason, future studies of attention in AD must rely on mature theories of attention developed in cognitive psychology.

Earlier in this article, some of the major theoretic issues regarding spatial attention developed by cognitive theories were reviewed. Although many of these issues have been explored in patients with AD (eg, endogenous versus exogenous precuing), most of these issues remain unexplored. For example, many cognitive theorists point out the difficulties in studying simple detection tasks using Posner's precuing task [25,108]. Also, there are many effects of spatial attention, and spatial precuing results and visual search results can be explained by hypothesizing that spatial attention reduces an observer's uncertainty in making judgments about a target item [25,108–111]. One hypothesis regarding AD is that declines in these patients' cognitive and attentional abilities might be produced by less reliable (ie, noisy) information processing. Such a hypothesis could be addressed using either a spatial precuing task or a visual search task that does not rely exclusively on response time measures.

Summary

Although "attention" is a general term in everyday folk and psychologic use, using research from cognitive psychology allows a focus on the processes associated with attention. A process-oriented definition of attention [2] makes "attention" a concept that can be studied rigorously. Attention is necessary for eliminating unwanted sensory inputs or irrelevant behavioral tasks and is useful when some cognitive system or process receives too many inputs. Attention acts to restrict the number of inputs and allow processing to continue in an effective manner. Although there are many forms of attentional selection, spatial attention is the most studied and perhaps the best understood form of selection.

Spatial attention is the variety of attention most widely studied in neuropsychologic populations. As was evident from the authors' review, different neuropsychologic syndromes can be characterized as involving different difficulties with the component processes of spatial attention. Different neural structures work in concert to produce normal spatial selection, and damage to any of these neural structures, including the parietal and frontal lobes, pulvinar, and superior colliculus, produce an attentional impairment. Attentional impairments often have been studied in cases of focal brain damage resulting from stroke, traumatic brain injury, tumor, and surgical resection. Focal or multifocal lesions caused by neurodegenerative impairments, such as PSP and AD, however, also have marked effects on neural processes of attention. Patients with AD exhibit a range of impairments in spatial attention, and these impairments have been studied relatively little.

Despite the understanding of attention provided by various patient populations, gaps remain in knowledge of the mechanisms involved in attending to space. For example, most studies of neurologic patients have used a simple spatial cuing paradigm with highly predictive cues. Although this task yields robust results and can be adapted for use with many different patient groups, the spatial cuing effects produced by such tasks have multiple interpretations (eg, allocation of resources versus reduction of decision noise).

This review highlights the general point that different neural sites seem to be responsible for different forms of attentional control, such as object-based attention, attentional task switching, and the executive control of attention [8,33]. Understanding the integration of these neural sites and their relationship to cognitive processes and, ultimately, behavior, will increase understanding of normal and disordered attentional selection.

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