

# Mechanisms of Attention

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## INTRODUCTION

This chapter provides an overview of findings from neuropsychological and neurophysiological research that have contributed to elucidating several aspects of attention. To define the issues and introduce the key experimental paradigms each section begins with a brief review of the literature on normal participants. The organization of the chapter follows a plan that is typical in present-day psychology (and neuropsychology) of attention. The first issue to be discussed is where, in the sequence of processing stages, attention begins to exert its influence. The second issue is whether attention selects regions of space or objects for enhanced processing. The third issue is how attention moves in space. The last issue is whether attentional selection is achieved by enhancing relevant information or inhibiting irrelevant information.

Most of the studies concern patients with neglect or extinction. This is because it is assumed that in the side of space affected by the deficit there is no attention, or attention is severely impaired. Therefore, results from these patients can reveal the type of processing that occurs without attention or with very little attention. A brief discussion of neglect and extinction is provided here. Reviews can be found in Bisiach and Vallar (in press), Rafal (1998), and chapters in I. H. Robertson and J. C. Marshall (1993).

Neglect can occur after a unilateral lesion to a wide range of neural structures (Desimone & Duncan, 1995), although its cognitive consequences have most often been investigated in individuals who have suffered a unilateral lesion of the parietal lobe (more often the right parietal lobe). Neglect patients fail to report or respond to events in the contralesional side of space (more often the left side of space). In extinction, such a deficit manifests itself only if competing events are present on the intact side. Both neglect and extinction are considered to be deficits of spatial attention.

The presence of a disorder of spatial attention in neglect is apparent in the overt everyday behavior of patients, as well as in their performance on a range of tests. Neglect patients may have their eyes, head, and body turned to the right. They may ignore people who approach or address them from the left side of space. They may fail to eat food from the left side of their plate, tend to bump into objects located on their left side when walking, and their walking trajectory can deviate to the right. A typical test of neglect in the visual modality is a task in which the patient is given a page that contains various items and is asked to mark them all with a pen. A failure to mark items located on the left side of the page indicates neglect. Other common tests for spatial neglect include the bisection task and the drawing task. In the former, the patient is given a horizontal line and is asked to mark its center. The patient

typically places the mark well to the right side. In the drawing task, the patient tends to omit elements on the left side when asked to draw an object either from memory or from a model. In neglect dyslexia, the patient omits letters on the left side when reading a word and/or omits the words on the left side of the page when reading a text.

It must be pointed out that Bisiach (1993; also see Bisiach & Vallar, *in press*; Rizzolatti, Berti, & Gallese, *in press*) has for many years advocated a representational account of neglect, mainly on the basis of studies that demonstrated that neglect affects also internally generated mental representations. In Bisiach's view, neglect is a deficit of space representation and the deficits of spatial attention would be caused by the representational deficit or co-occur with it.

## WHEN DOES ATTENTION HAPPEN?

Two issues concerning the processing stage at which attention begins to exert its influence have been debated. The first is whether elementary features are combined to form objects preattentively or attentively. The second is whether attentional selection operates early or late in the sequence of processing stages.

### Attentive versus Preattentive Processing

Some authors (e.g., Kahneman, 1973; Neisser, 1967) postulate the existence of an initial preattentive stage in which, based on Gestalt principles of organization, the visual field is parsed into objects against a background. The alternative view (e.g., Treisman, 1988; Treisman & Gelade, 1980) is that, at the preattentive stage, simple features present in the visual display are registered in parallel. Then, at a subsequent (focal) attentional stage, objects are formed by combining these simple features.

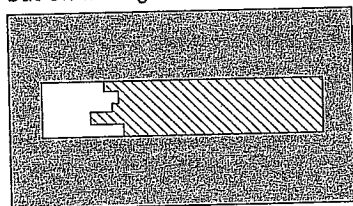
A prediction of Treisman's (1988) theory is that attention deficits, such as those of neglect and extinction, should affect search for conjunctions of features leaving search for simple features unaffected. A weaker prediction is that attention deficits should affect both feature and conjunction tasks, disrupting, however, the latter more than the former.

In a typical feature search task, normal participants detect a target defined by a salient unique feature (e.g., a red target among green distracters, or a vertical target among horizontal distracters) as rapidly when many distracters are present as when few distracters are present. In contrast, when the target is defined by a conjunction of features (e.g., a red vertical target among green vertical and red horizontal distracters) reaction time (RT) for detecting the target increases as a function of number of distracters.

Several studies tested extinction and neglect patients with versions of the search task (e.g., Arguin, Joannette, & Cavanagh, 1993; Cohen & Rafal, 1991; Eglin, Robertson, & Knight, 1989; Humphreys & Riddoch, 1993; Riddoch & Humphreys, 1987; see review in L. C. Robertson, 1998). Some found evidence in favor of the stronger prediction, showing that in the affected field search rate was slower than in the intact field for the conjunction task but not for the feature task. It would seem thus that feature integration (and, by implication, object segmentation) requires attention and cannot take place normally at a preattentive stage. Other studies, instead, showed that patients were impaired in both conjunction and feature tasks, but the deficit was greater for the conjunction task. This finding is no doubt problematic for the notion of a qualitative difference between the two types of search. In fact, it would seem that also coding simple feature requires attention and cannot take place at a preattentive stage (e.g., Joseph, Chun, & Nakayama, 1997).

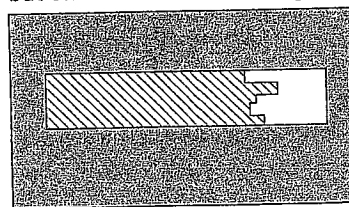
However, a different picture emerges from still other studies. The process of partitioning a visual display into coherent components that can be perceived as independent objects is referred to as segmentation, segregation, grouping, or parsing. The available neuropsychological evidence suggests that this process occurs also in the field affected by neglect or extinction.

(a) Contour lines in the left hemifield but on the right side of the figure



95% accuracy at judging whether line matches

(b) Contour lines in the right hemifield but on the left side of the figure



50% accuracy at judging whether line matches

Figure 6.1: The displays used by Driver et al. (1992), adapted from Rafal's (1998) Figure 22.10. The large area with diagonal shading was red, whereas the small area was green. The task was to compare the jagged dividing line to the isolated jagged line on the bottom of the display. From: Rafal, RD: Neglect. In Parasuraman, R. (Ed.), *The Attentive Brain*. MIT Press. Adapted with permission.

That is, it occurs in the absence of attention (i.e., preattentively; Driver, Baylis, & Rafal, 1992; Driver, Baylis, Goodrich, & Rafal, 1994; see review in Driver & Baylis, 1998).

Normally, regions delimited by symmetrical contours are perceived as objects lying in front of the background. Driver et al. (1992) showed that a patient with neglect could use, in his impaired field, symmetry for parsing the visual display into objects. The patient was presented with red symmetrical figures against a green background. When he was asked to report which color was in front of the background, he, like normal individuals do, perceived the symmetrical red shapes as objects in front of the green background. However, when he was asked to judge whether the red shapes were symmetrical or not, performance was at chance. That is, even though neglect prevented the patient from perceiving symmetry, symmetry nonetheless acted in the impaired field producing visual objects that were segregated from the background.

The same patient showed that segmentation in the impaired field could be produced on the basis of other factors (also see Marshall & Halligan, 1994). Normally, a small, bright region is perceived as a figure against a large, dim background. The dividing line is perceived as the contour, belonging only to the figure. Driver et al. (1992) presented the patient with displays of this type (see Figure 6.1) and asked him to remember the shape of the dividing line between the figure and the background, and to match it with a probe line that appeared half a second later in the center of the screen. Thus, the task was only to attend to the shape of the line bordering the two areas. The patient was able to segregate the figure from the background in either the intact or the impaired visual field, demonstrating that segmentation can operate in the absence of attention.

Further evidence of preattentive object segmentation comes from extinction patients. Driver, Mattingley, Rorden, and Davis (1997) found that extinction caused by two circles that were simultaneously presented in the opposite visual fields was eliminated when the circles were linked by a horizontal line to form a single barbell. Other grouping factors, like good continuation (Ward, Goodrich, & Driver, 1994) and three-dimensionality (Mattingley, Davis, & Driver, 1997) can reduce or eliminate extinction by linking the stimulus presented in the impaired field with the stimulus presented in the intact field to form a global object. Similarly, extinction between two letter strings is reduced when they form a compound word (Behrmann, Moscovitch, Black, & Mozer, 1990).

## Early Versus Late Selection

The *early-selection* view maintains that unattended information is discarded just after simple features are coded and prior to stimulus identification. The *late-selection* view maintains that unattended information undergoes semantic analysis and selective attention operates after stimulus identification.

The first studies of selective attention typically used the dichotic listening paradigm and favored the early-selection view, showing that only the physical properties of unattended stimuli are processed, and then these stimuli are filtered out before they can be processed further (e.g., Broadbent, 1958). However, very soon, results began to accumulate that showed semantic effects of non-attended stimuli (e.g., Corteen & Wood, 1972; Lewis, 1970), thus challenging Broadbent's early-selection theory and supporting Deutsch and Deutsch's (1963) late-selection theory.

The findings with visual stimuli closely replicated those with auditory stimuli. It was found that, as with dichotic listening, attending to one object resulted in negligible memory for unattended objects (e.g. Rock & Guttman, 1981; Neisser & Becklen, 1975). As in dichotic listening, however, indirect measures revealed that unattended stimuli were semantically processed and identified (see review in Kahneman & Treisman, 1984).

The Stroop effect (Stroop, 1935) and "flanker" effects (Eriksen & Eriksen, 1974), for example, implicated response competition at the (late) stage at which interference between attended and unattended information occurs. In fact, the effect of unattended information on RT could not be explained, unless unattended information had been analyzed to the point where it activated a response. In contrast, other results showed that early selection is, at least to a certain extent, possible (e.g., Kahneman & Treisman, 1984): When the experimental conditions were such as to allow the participant to focus attention narrowly on relevant information, Stroop and flanker effects virtually disappeared (e.g., Francolini & Egeth, 1980; Yantis & Johnston, 1990).

## Neuropsychological Evidence

Studies of neglect and extinction patients made an important contribution toward elucidating the extent of processing that unattended stimuli undergo (see review in Driver, 1996).

Berti and Rizzolatti (1992) provided evidence of semantic processing for stimuli presented in the contralesional visual field of neglect patients. Their patients were required to make a speeded animal/vegetable decision for a line drawing presented in the intact right field. Simultaneously, a line drawing was presented in the impaired left field. The drawing in the left field could be identical to the one in the right field, could be different but from the same category, or could be different and from the opposite category. Average RTs were 777, 795, and 890 ms, respectively. Clearly, categorization of the drawing in the right field was affected by the drawing in the left field.

Ladavas, Paldini, and Cubelli (1993; also see McGlinchey-Berroth, Milberg, Verfaellie, Alexander, & Kilduff, 1993) reported a patient who could not read aloud words presented in the left field, nor judge their lexical status or semantic content. He could not even detect the presence of a string of letters. However, a lexical decision to a word in the right field was faster when it was preceded by a related than an unrelated word in the left field (883 vs. 967 ms). That is, the patient showed semantic priming caused by unattended words in the affected field.

Berti, Allport, et al. (1992) studied a patient with extinction and investigated to what stage information is processed in the impaired field. They presented two pictures of objects simultaneously, one to each field, and asked the patient to name the two objects and to judge whether they had the same name. When the objects had the same name, the pictures were identical, or depicted different views of the same object, or depicted different exemplars of the same cat-

egory seen from different view points. The patient was severely impaired in naming objects presented to the left field (her average performance was 17.8 correct names out of 36) but was very accurate on the matching task (63.2 correct out of 72 pairs). In particular, she was above chance even when the objects were different exemplars of the same category (e.g., two different cameras; 8.9 correct out of 12 pairs). That is evidence that the matching task was not performed on low-level, visual information, but rather categorical information became available through the impaired field.

The picture that emerges from the studies of neglect and extinction patients is broadly consistent with the late selection view: Processing of stimuli presented in the impaired visual field, which are unattended by definition, reaches the semantic stage and leads to identification. However, neurophysiological studies are in accord with the early selection view.

### Neurophysiological Evidence

Event related potential (ERP) studies are unequivocal in showing that attention can modulate early sensory processing (see reviews in Luck, 1998; Luck & Girelli, 1998). In the auditory modality, the prototypical experiment is the one conducted by Hillyard, Hink, Schwent, and Picton (1973). In it, a rapid sequence of tones was presented to the two ears and participants were instructed to attend to one ear in some trial blocks and to the other ear in other blocks. Also, participants were instructed to attend to the stimuli delivered to one ear only (i.e., the attended ear) and press a button whenever the target (a slightly higher-pitched tone) was detected. Targets, which occurred infrequently and unpredictably, were presented occasionally in the unattended ear, but participants were instructed not to respond to them. Results showed that tones delivered to the attended ear elicited a larger negative wave (N1) than tones delivered to the unattended ear. This effect began about 60–70 ms after stimulus onset and peaked at approximately 100 ms poststimulus. In addition, there was some indication that even an earlier positive wave (P1), which manifests itself 20–50 ms poststimulus, was larger for the attended ear. Considering these time courses, and the generator sources of P1 and N1, it can be concluded that attention operates at an early stage of processing, probably as early as in the primary auditory cortex. This is no doubt in accord with the early selection hypothesis.

The locus-of-selection issue was addressed in the visual modality by using variants of the ERP paradigm (e.g., Heinze et al., 1994; Mangun & Hillyard, 1988; Mangun, Hillyard, & Luck, 1993; Rugg, Milner, Lines, & Phalp, 1987). Results were clear in showing that attention exerts its influence during early stages of processing. However, results were also clear in showing that attention influenced processing in the extrastriate visual cortex, but not in the primary visual cortex (V1). Therefore, it would seem that attention begins to operate later in the visual than in the auditory modality, in which attentional modulation affects the primary auditory cortex.

A single-unit study of visual attention adopted a similar paradigm (Luck, Chelazzi, Hillyard, & Desimone, 1997). In it, recordings were obtained from areas responsible for the early (V1) and intermediate (V2 and V4) stages of processing. Consistent with the ERP studies, no attentional effects were found in area V1, whereas many V2 and V4 neurons showed attentional effects.

The issue of whether attentional modulation occurs in the primary visual cortex was investigated in a functional magnetic resonance imaging (fMRI) study, in which ERPs were also recorded, by Martinez et al. (1999; also see Brefczynski & DeYoe, 1999). Displays of crosses were randomly flashed to either the left or the right visual field, and participants were instructed to maintain fixation on a central arrow and to direct attention, without moving their eyes, to the visual field indicated by the arrow. On most trials, the central element in the lateralized displays of crosses was an upright T, but in a few trials it was an upside-down T. The latter was the target, whose presence had to be signaled by a key-press. Attention-related activation was observed in all visual areas, from V1 to V4. However, ERP data cast doubt on

the possible attentional modulation of V1. In fact, the attended displays elicited an enlarged P1 component 70–75 ms poststimulus and an enlarged N1 component 130–140 poststimulus, whereas no enlarged component was observed 50–55 ms after the stimulus, which would have implicated area V1. The authors proposed that the attentional modulation of V1 activation observed with fMRI could be attributable to a delayed, re-entrant feedback from higher visual areas.

## WHAT IS THE OBJECT OF ATTENTION?

Whether visuospatial attention operates on the basis of locations or of objects is a matter of debate (see reviews in Egeth & Yantis, 1997; Shapiro, Hillstrom, & Husain, *in press*; Umiltà, *in press*). The object-based view holds that attention is not assigned to a specific region of visual space, but, rather, to the objects that occupy those regions (e.g., Duncan, 1984; Kahneman & Henik, 1981). The space-based view (e.g., Eriksen & Eriksen, 1974; Posner, 1980) holds, instead, that attention is directed to regions of visual space, which may be empty or occupied by objects.

A related issue concerns whether attention can be allocated in viewer-centered coordinates as opposed to object-centered coordinates. In viewer-centered coordinates, the spatial codes of the object's component parts are computed in relation to one of the observer's reference axes (e.g., his body or head midline; see, e.g., Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Làdavas, 1993). In object-centered coordinates, the spatial codes of the object's component parts are computed in relation to the structural description of the object (e.g., Gibson & Egeth, 1994; Umiltà, Castiello, Fontana, & Vestri, 1995).

## Space

The space-based view of attention derives support from experiments that show that focal attention shifts from one location to another, selecting particular regions in visual space. Stimuli within these selected regions are processed more efficiently than stimuli that fall into non-selected regions (see section on orienting of attention, and review in Umiltà, *in press*). In further support of space-based allocation of attention, several studies reported that the spatial separation among the elements in the display modulated attentional benefits and costs (e.g., Downing, 1988; Eriksen & Eriksen, 1974; Hoffman & Nelson, 1981).

The abnormalities in neglect patients' performance (see introduction) clearly suggest a deficit in directing spatial attention to the contralesional side of space. The notion of a deficit of spatial attention is corroborated by the fact that neglect improves (only temporarily, though) if the patient is trained to attend toward the left side of space (e.g., Làdavas, Menghini, & Umiltà, 1994). Also, manipulations, like vestibular caloric stimulation (e.g., Rode & Perenin, 1994), neck vibration (e.g., Karnath, 1994), and optokinetic stimulation (e.g., Pizzamiglio, Frasca, Guariglia, Incoccia, & Antonucci, 1990), which can indirectly produce a shift of attention to the left, temporarily improve neglect.

As discussed above, neglect patients ignore stimuli located on the left side of space. However, space can be defined in either egocentric or allocentric coordinates (see section on object-centered neglect). Even if one considers only egocentric coordinates, there is more than one definition of "left" (e.g., Bhermann & Moscovitch, 1994; Walker, 1995). Left can be defined in retinal coordinates (i.e., the patient's left visual field), with respect to the body trunk (i.e., left of the patient's body midline), or with respect to the head (i.e., left to the patient's head midline). It has been demonstrated that neglect can manifest itself in one or more of these frames of reference, which are dissociated when the patient's viewing position changes or the stimulus rotates (e.g., Làdavas, 1993; Bhermann & Moscovitch, 1994). That happens, for example, when the head is tilted about 90° to the left or right, so that the right visual field is

above and the left visual is below, or vice versa. It appears, therefore, that spatial attention can independently operate in several frames of reference.

Another important distinction concerns the sectors of space. Rizzolatti, Matelli, and Pavesi (1983; see review in Rizzolatti et al., in press) suggested that areas of the primate brain are specialized for orienting attention in the near, peripersonal space (i.e., within grasping distance), whereas others are specialized for orienting attention in the far, extrapersonal space (i.e., within pointing or throwing distance). Another sector of space is personal space, which is occupied by the animal's own body.

Although in humans neglect in personal space, peripersonal space, and extrapersonal space very often co-occur, there is evidence for double dissociations between the three sectors of space (see Rizzolatti et al., in press). That is, a patient can show severe neglect in one sector of space, but not in the other two. Halligan and Marshall (1991) documented one of these dissociations. Their patient showed severe neglect in peripersonal space on conventional tests, including the horizontal line bisection task. However, when line bisection was performed in extrapersonal space, by pointing a light or by throwing a dart, neglect was abolished or attenuated. The patient did not show neglect in personal space either. In fact, he did not show any deficits concerning left-side parts of his own body, as often happens with neglect patients. Berti and Frassinetti (in press) have confirmed this dissociation, whereas others have documented opposite dissociations, that is neglect for extrapersonal space only (Cowey, Small, & Ellis, 1994; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998), and neglect for personal space only (Guariglia & Antonucci, 1992).

It appears that spatial attention is impaired in one sector of space, but continues to function more or less normally in the other sectors. That suggests that there may be independent mechanisms for orienting attention within specific representations of space (Rizzolatti et al., in press; Umiltà, 1995).

## Objects

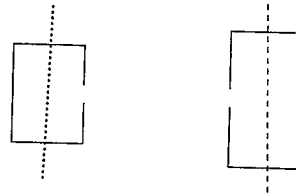
As already mentioned, the object-based view holds that attention is assigned to objects rather than to regions of space. There is also the possibility that attention is assigned to an object's component parts, whose locations are coded with reference to the object's structure (see also McCloskey, this volume, for further discussion of issues of spatial frame of reference raised in this section).

### Object-Based Attention

Because objects occupy spatial locations, to support the object-based view one has to decouple objects from locations. Duncan (1984) achieved that by briefly presenting normal participants with two superimposed visual objects, an outline box and a diagonal line, which occupied (roughly) the same spatial position (see Figure 6.2). Participants had to make judgments about one or two attributes: the size of the box, the location of a gap in the box, the orientation of the line, and the texture of the line. They were able to make judgments concerning the same object (i.e., the orientation and texture for the line or the size and gap side for the box) simultaneously without loss of accuracy, compared to when only a single feature was relevant. In contrast, they showed a cost (i.e., loss of accuracy) in making two judgments rather than one for features from different objects (e.g., the orientation of the line and the size of the box). Duncan's interpretation was that attention selects one object at a time, even when objects occupy the same location in space.

Many subsequent studies replicated Duncan's (1984) findings (see reviews in Driver & Baylis, 1998; Shapiro et al., in press; Umiltà, in press). An ERP study by Czigler and Balázs (1998) used a version of Duncan's paradigm and found a shorter P3 latency in the single-object

Figure 6.2: Examples of the displays used by Duncan (1984), adapted from his Figure 1. Left: small box with gap on right, dotted line with tilt clockwise. Right: large box with gap on left, dashed line with tilt counterclockwise.



condition than in the two-object condition. This single-object advantage was present from 200 ms up to 800 ms after stimulus presentation and was most evident in lateral occipital sites. Also, Roelfsema, Lamme, and Spekreijse (1997) found evidence of a single-object advantage in primary visual cortex with a single-cell recording study. However, the most convincing evidence of object-based attention originates from the demonstration of so-called object-based neglect (see reviews in Driver, 1998; Rafal, 1998; Walker, 1995).

Gainotti, Messerli, and Tissot (1972) provided what is perhaps the first example of object-based neglect. Their patients were asked to copy several objects drawn horizontally on a sheet of paper. The patients copied only the right side of objects, regardless of whether the objects were located on the affected or the intact side of space.

Two very elegant demonstrations of object-based neglect were provided by Driver et al. (1992) and Halligan and Marshall (1993). As already mentioned (see section on attentive vs. preattentive processing and Figure 6.1), Driver et al. presented their patient with a display containing small figures against a large background, in which a jagged dividing line was perceived as the contour of the figure. The task was to remember the shape of the dividing line and to match it with a probe line that appeared in the center of the screen. What is significant about the displays was that when the dividing line fell into the impaired field it was on the right side of the figure, whereas when it fell into the intact visual field it was on the left side of the figure. If neglect were space based, more errors would have been expected when the line was in the left than the right field. The results showed the opposite pattern: The patient was much more accurate when the line was in the left field but on the right side of the figure than when it was in the right field but on the left side of the figure.

Halligan and Marshall (1993) required their neglect patient to copy a drawing of a plant in a pot. The plant had two branches with a flower each, which departed from a stem. Thus, the drawing was unified into a single object by the presence of the common stem and pot. The patient copied the right branch only, omitting the left branch. This is in accord with either space-based or object-based neglect. Then, the drawing was changed by eliminating the common stem and pot, leaving just the two unconnected branches with the two flowers. Now the patient copied both branches and flowers, but both objects (i.e., branches with flowers) had features missing on their left side. This outcome can be explained only by assuming that neglect was object based.

Egley, Driver, and Rafal (1994; also see Egley, Rafal, Driver, & Starrveveld, 1994; Humphreys & Riddoch, 1994, 1995; Kramer, Weber, & Watson, 1997) demonstrated that both space-based and object-based mechanisms coexist. They tested normal participants and brain-damaged patients and investigated speed of target detection when attention was directed by a cue to a particular location and the target appeared in the same or a different location. On invalid trials, the target could appear either in the same object as the cue or in a different object (see Figure 6.3). Not surprisingly, both types of invalid trials were slower than valid trials (364 vs. 324 ms). More interestingly, there was an additional cost (13 ms) for between-objects invalid trials as compared to within-objects invalid trials, even though the distance between locations of cue and target was smaller on between-objects invalid trials than on within-objects invalid trials.

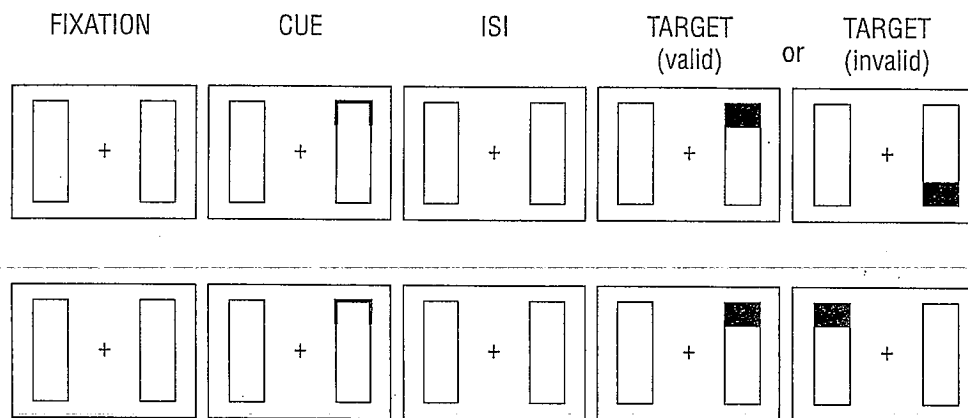


Figure 6.3: Examples of the displays used by Egly et al. (1994), adapted from their Figure 1. The heavy black lines in the panels of the second column represent the cue. The filled squares in the panels of the fourth and fifth columns represent the target. The panels in the fourth column represent a valid trial. The fifth panel of the upper row represents a within-object invalid trial, whereas the fifth panel of the bottom row represent a between-object invalid trial.

Egry, Driver, and Rafal (1994) provided evidence that the neural substrate mediating the two mechanisms differed, with the left hemisphere subserving the object-based mechanism and the right hemisphere subserving the space-based mechanism (also see Buck, Black, Behrmann, Caldwell, & Bronskill, 1997). Both right- and left-parietal patients were impaired for a contralesional target stimulus after presentation of an ipsilesional cue, but the right-parietal patients were particularly impaired (an additional cost of 22 ms). This was the space-based component of the attentional deficit. However, only the left-parietal patients showed a further abnormality concerning the object-based component: Their difficulty with contralesional targets after an ipsilesional cue was exacerbated when between-object shifts of attention were required (an additional cost of 76 ms). Also, Egry, Rafal, et al. (1994) found that the between-object cost was present only in the right visual field (left hemisphere) of a split-brain patient.

### Object-Centered Attention

Objects have an intrinsic structure that depends on the spatial relations of their component parts relative to one another. Therefore, in an object-centered frame of reference, the spatial codes of the object's parts are computed in relation to the structural description of the object, and, if the object moves, the relative spatial codes of its component parts are stable with respect to the object's structure. Umiltà et al. (1995) showed that attention is allocated also in an object-centered frame of reference. In their study, a cue was presented on a vertex of a two-dimensional drawing that was perceived as a three-dimensional cube. In the critical condition, following the cue, the cube rotated and a target then appeared either in the originally cued location or in the cued vertex, which now occupied a different spatial location. Facilitation in target detection was not only observed when spatial location was the same for cue and target (i.e., *space-based* attention), but also when the target appeared in the cued vertex defined in purely object-centered coordinates (i.e., *object-centered* attention).

It is important to stress that in an object-based frame of reference "left" and "right" sides of an object are defined with respect to the viewer, that is in egocentric coordinates. That is what happens in *object-based* neglect. In contrast, *object-centered* neglect should be viewer-indepen-

dent, that is it should affect one side of the object, regardless of the object's location or orientation with respect to the viewer (see Walker, 1995).

The best known case of object-centered neglect is a patient (NG) studied by Caramazza and Hillis (1990a, 1990b; also see Rapp & Caramazza, 1991), who was left-handed and showed right neglect following a left-hemisphere lesion. She made reading errors only on the right, end part of words, irrespective of whether the words were presented horizontally, vertically, or mirror-reversed (see Table 6.1). That is, she continued to make errors for the word endings, which, when the words were mirror-reversed, were actually located on the left, intact side. By following Marr (1982), Caramazza and his colleagues proposed a three-level model of word representation. The level that would be impaired in their patient is a word-centered (i.e., object-cen-

Table 6.1  
Examples of NG's Errors Across Orientations of the Stimulus.

Examples of NG's Errors in Normal (Horizontal) Reading (Stimulus → Response)		
Word Stimuli		
humid → human	hound → house	stripe → strip
sprinter → sprinkle	dumb → dump	study → stud
though → thoughts	emotionally → emotional	hazardous → hazard
Nonword Stimuli		
petch → petcher	dring → drill	stould → stoutly
Examples of Reading Topographically Nonstandard Text		
Errors in Vertical Reading		
blending → blemish	vivid → vivian	rang → ran
motionless → motel	discovery → discover	habitual → habit
strist → strip	neither → neither	sipter → sip
Errors in Mirror-reversed Reading		
common → comet	joint → joint	regulated → regular
greenish → greenery	discovery → disco	dashes → dash
cring → crime	vigid → vigor	dring → drink
Errors in Recognition of Aural Spelling		
earns → earring	sparrow → space	village → villa
basis → bass	requirement → require	planet → plane
dring → drink	fin → fine	womar → woman
Examples of Errors in Various Spelling Tasks		
Errors in Written Spelling		
floor → floore	sneeze → sneed	cloud → clou
unit → untie	jury → jurd	faith → fait
skart → skarr	remmun → remmey	chench → chen
Errors in Oral Spelling		
career → carred	sneeze → sneed	ground → grou
poodle → poodler	afraid → afrain	period → perio
achieme → achiemd	emplain → emplained	spond → spone
Errors in Backward Spelling		
absorb → absown	sky → skik	church → chur
garbage → garbsi	oyster → oyste	sample → sampl
Errors in Delayed Copying		
square → squard	afraid → afrain	method → meth
turkey → turket	fabric → fabriact	starve → starv

Adapted with permission from Tables 1, 3, and 8 of "Levels of Representation, Co-ordinate Frames, and Unilateral Neglect," by A. Caramazza and A. E. Hillis, 1990b, *Cognitive Neuropsychology*, 7, pp. 404, 408, and 415.

tered) grapheme description. Other patients with a similar deficit were reported by Hillis and Caramazza (1995) and Barbut and Gazzaniga (1987).

Further evidence that an object-centered mechanism can be impaired in neglect comes from a study by Behrmann and Tipper (1994; also see Tipper & Behrmann, 1996). They had patients with neglect perform a target-detection task in two conditions. In the static condition, the target appeared on either the left or the right part of a centrally presented object (a barbell). In the rotating condition, the patient watched the barbell undergo a 180° rotation. After the rotation, the left and right parts of the object, which were depicted in different colors, fell into the right and left space, respectively. In the static condition, performance was worse for targets on the left part of the object for all patients. Relative to the static condition, in the rotating condition, all patients showed poorer performance on the right part of the object, and some even showed better performance on the left part. The clearest result was that of patient P5, for whom error rate was about 75% on the left and about 25% on the right in the static condition, whereas, in the rotating condition, error rate was about 10% on the left and about 65% on the right.

### HOW DOES ATTENTION MOVE?

When attention moves in visual space, one has to distinguish between overt and covert orienting. Overt orienting is accompanied by eye movements, whereas covert orienting occurs while the eye remain still. Evidence that attention can be oriented covertly was obtained through the work of Posner (e.g., 1980). Posner's spatial cueing paradigm makes use of differences in RT to a stimulus at expected and unexpected locations as a measure of the efficiency of detection attributable to the orienting of attention to the expected location. Before the imperative stimulus, a cue is presented. If the cue does not signal a specific location in space, the trial is neutral. If the cue signals a location, the trial can be either valid (the stimulus appears in the cued location) or invalid (the stimulus appears in an uncued location). The effects of spatial attention manifest themselves as attentional benefits (the difference in RT between neutral and valid trials; about 10-15 ms) and attentional costs (the difference in RT between invalid and neutral trials; about 20-30 ms).

### Orienting of Attention

In Posner's (1980) paradigm, on invalid trials the orienting process may be subdivided into three more elementary operations: disengage, move, and engage. Attention is first engaged at the cued location, then, when the stimulus appears elsewhere, attention must be disengaged from the cued location, moved to the stimulated location, and engaged at the new location.

On the basis of double dissociations observed in brain-damaged patients, Posner and his colleagues (e.g., Posner, Inhoff, Friedrich, & Cohen, 1987; Posner, Walker, Friedrich, & Rafal, 1984) suggested the existence of separate neural systems that subserve these operations. Patients with extinction after unilateral parietal lesions were able to shift attention in response to the cue, and thus had normal benefits on valid trials. However, they had exceptionally great costs on invalid trials after a cue that had directed attention to the intact side. Posner and his colleagues argued that this shows a selective deficit for disengaging attention from the intact side toward the impaired side. Patients with progressive supranuclear palsy, in which the primary lesion involves the superior colliculus, had benefits and costs only when the interval between the cue and the stimulus was very long. That shows that they were very slow at moving attention. Also, there was some evidence that patients with a lesion of the pulvinar, a nucleus of the thalamus, had very small benefits on valid trials, suggesting a selective impairment of the engage operation.

The role of the parietal lobe in the disengage operation is supported by those studies that showed that neglect improves if objects, which presumably engage attention, are removed from

the intact side. Mark, Kooistra, and Heilman (1988; also see Làdavas, Umiltà, Ziani, Brogi, & Minarini, 1993) used two versions of the task in which patients are required to mark with a pen lines on a sheet of paper. In the standard version, the patients failed to mark most of the lines on the left side. In the other version, they were given an eraser and were asked to actually erase the lines. Omissions on the left side were for fewer in the erasing condition than in the marking condition. The patients performed the task by first erasing the rightmost lines, which were removed from the display, gradually proceeding toward the left. That demonstrates that the disengage operation from the impaired side became easier after the objects were physically removed from the intact side. In support of the idea that attention is captured by the most ipsilesional objects, one can cite also the observation that neglect patients are faster and more accurate than controls in discriminating stimuli that occupy the right relative position in the intact visual field (Làdavas, Petronio, & Umiltà, 1990).

James (1890/1950) distinguished between active and passive attention. Modern terms for denoting the two modes of orienting are endogenous or voluntary and exogenous or automatic. In Posner's (1980) paradigm, one can use central or peripheral cues to direct attention to the peripheral position of impending targets. Central cues, like arrowheads, are cognitive in nature because they must be interpreted to extract the locational information they convey. Peripheral cues, which are shown near the location of the impending target, are not cognitive in nature because they automatically capture attention.

Central and peripheral cues are thought to give rise to different modes of orienting, endogenous and exogenous, respectively (see reviews in Umiltà, *in press*; Egeth & Yantis, 1997). However, the neuropsychological evidence does not provide unequivocal support for the notion that exogenous and endogenous orienting are mediated by different neural mechanisms.

The extinction-like pattern in patients with parietal lesions reported by Posner and colleagues (Posner, Walker, & Friedrich, 1984; Posner, Inhoff, & Friedrich, 1987) was observed with both peripheral and central cues, that is a flash in the intact field or an arrow pointing to the intact field. That suggests that the parietal lobe is involved in the disengage operation for both types of orienting. In contrast, a rehabilitation study of neglect (Làdavas et al., 1994; also see Riddoch & Humphreys, 1983) showed that central cues that induce the patient to endogenously orient attention to the impaired side can bring about an improvement, whereas peripheral cues do not. That suggests that in neglect the endogenous mechanism is, at least in part, still operational, whereas the exogenous mechanism is severely damaged.

The notion that endogenous and exogenous orienting are subserved by different mechanisms is only apparently contradicted by a positron emission tomography (PET) study of Nobre et al. (1997). The study used two versions of Posner's (1980) paradigm. In both conditions there were two boxes, at 7° from fixation, within which the target to be discriminated (x vs. +; a go/no-go task) appeared. In one condition, the location where attention had to be directed was signaled by the brightening of one of the peripheral boxes. The cue was valid on 80% of the trials. In the other condition, the brightening of one of the peripheral boxes signaled that the target would appear with 80% probability in the opposite box, and thus participants had to shift attention, without moving the eyes, contralateral to the cue. The idea was that the condition in which attention was directed to the cued side would produce exogenous orienting, whereas the condition in which attention was directed to the uncued side would cause endogenous orienting. In either condition, the same cortical areas were activated: the right anterior cingulate gyrus, the right posterior parietal cortex, and, bilaterally, the mesial and lateral premotor cortices. It must be pointed out, however, that the cue was always informative and had a high validity. Therefore, endogenous orienting no doubt occurred in both conditions, regardless of whether attention was directed to the cued or the uncued side.

It is interesting to note that the results of Nobre et al. (1997; also see Corbetta, Miezin, Shulman, & Petersen, 1993) were congruent with a proposal put forward by Mesulam (1981) to explain why lesions to the right hemisphere result in neglect for the left side of space, whereas

lesions to the left hemisphere very seldom result in neglect for the right side of space. Mesulam proposed that the right hemisphere controls orienting to both sides of space, whereas the left hemisphere controls orienting to the right side of space only. Nobre et al. (1997) found that the right parietal cortex only was activated during attention shifts to the left field. In contrast, bilateral activation of the parietal cortex was observed during attention shifts to the right field.

A PET study by Corbetta et al. (1993) contained four conditions—that is, shifting attention (i.e., endogenous orienting), passive viewing (i.e., exogenous orienting), central detection, and central fixation. In the endogenous orienting condition, participants responded to a series of target stimuli (asterisks) that flashed in a predictable horizontal sequence in the periphery, thereby allowing voluntary orienting to the location of the impending target. In the exogenous orienting condition, participants fixated centrally while stimuli flashed randomly at the periphery. Results showed that both orienting conditions produced activation in the superior parietal region, whereas the superior prefrontal region was activated in the endogenous but not in the exogenous orienting condition. However, although the exogenous orienting condition was better controlled than in the Nobre et al. (1997) study, Corbetta et al. (1993) did not provide an optimal comparison between endogenous and exogenous orienting either. In fact, exogenous orienting was evaluated using a passive viewing condition rather than peripheral cues.

An fMRI study by Rosen et al. (1999) had carefully controlled conditions. In the endogenous orienting condition, the location of the peripheral target was predicted with 80% validity by a central arrow pointing to the left or right. In the exogenous orienting condition, two cues were used: First, a peripheral cue (a circular light) oriented attention to the periphery, then a second, identical cue re-oriented attention back to the center. Neither cue predicted the location of the forthcoming target. In the control condition, the peripheral target was preceded by a neutral central cue. Results indicated faster RTs for valid than for invalid trials for the endogenous conditions, but slower RTs for valid than for invalid trials for the exogenous condition (i.e., inhibition of return; see section on inhibition of return). Note that inhibition of return is considered to be the hallmark of exogenous orienting. Both exogenous and endogenous orienting activated the superior parietal regions bilaterally (also see Wojciulik & Kanwisher, 1999, for fMRI evidence that links the parietal lobe to various aspects of visual attention; see Rizzolatti et al., in press, for a discussion of the functional organization of parietal areas) and the dorsal premotor regions bilaterally, including the frontal eye fields (remember that premotor activation was demonstrated also by Corbetta et al., 1993; Nobre et al., 1997; for a discussion of the functional organization of the frontal eye fields and other premotor areas, see Rizzolatti et al., in press). However, the right dorsolateral prefrontal region was activated by the endogenous orienting condition only.

Neuroimaging evidence points to a common network of interconnected neural structures that mediate both endogenous and exogenous orienting. However, Rosen et al. (1999) found that endogenous orienting activated a larger brain area and evoked an overall greater activation than exogenous orienting did. This is consistent with the notion that endogenous orienting is controlled and effortful, whereas exogenous orienting is automatic and reflexive. In addition, in their study the regional patterns of activation induced by the two conditions were not identical, because endogenous orienting selectively engaged the right dorsolateral prefrontal region. Finally, it is worth noting that Yamaguchi and Kobayashi (1998), in an RT and ERP study on patients with Parkinson's disease, demonstrated that the dopaminergic system contributes to endogenous orienting, but does not contribute to exogenous orienting.

### Saccadic Eye Movements

A widely-held view (e.g., Posner & Dehaene, 1994; Posner & Petersen, 1990) is that there are two attentional systems—a posterior system that mediates spatial attention, and an anterior system that mediates selective attention and cognitive control. These attentional systems are

thought to be separate from the systems that are in charge of processing information. That is, they would modulate the activity of perceptual and motor systems but would be independent, even anatomically, from them.

A different view (the premotor theory of spatial attention; e.g., Rizzolatti et al., in press; Rizzolatti, Riggio, & Sheliga, 1994) is that attention depends on those same systems that underlie perception and action. That is, spatial attention would originate from the activation of those cortical and subcortical neural circuits that transform spatial information into action. This activation causes an increase of motor readiness to act in the direction of the region of space that is the goal of the motor program. Also, the processing of information that originates from that same region is enhanced. Therefore, the mechanisms of spatial attention coincide with the mechanisms that generate action, and one need not invoke separate attentional mechanisms to explain spatial attention (see Craighero, Fadiga, Rizzolatti, & Umiltà, 1999, for an extension of the theory to grasping movements).

Several studies have provided evidence that, when visuospatial attention is directed to a location, an oculomotor program is prepared to perform a saccade to the target location (see review in Umiltà, in press).

Rizzolatti, Riggio, Dascola, and Umiltà (1987; also see Umiltà, Riggio, Dascola, & Rizzolatti, 1991) investigated how attention shifts in visual space by using a variant of Posner's (1980) paradigm. The main finding was that, when the stimulus was presented at non-cued locations, RT was slower on the non-cued than on the cued side, even though non-cued locations were equidistant from the cued location on either side (the so-called meridian effect). The authors proposed that, once a directional cue was presented, a motor program for a saccade was prepared, which specified the direction of the eye movement. The motor program was prepared even though the saccade was then vetoed and not executed. When the imperative stimulus appeared in the expected location, the response was immediately executed. In contrast, when the stimulus was shown on the side opposite to the cued location, the direction feature of the motor program had to be modified before execution of the response. This time-consuming change produced the meridian effect.

Sheliga, Riggio, and Rizzolatti (1994; also see Sheliga, Craighero, Riggio, & Rizzolatti, 1997) instructed participants to direct attention to a spatial location to the left or right side of fixation and to perform a vertical saccade in response to the presentation of a visual or an acoustic imperative stimulus. Results showed that, regardless of the modality in which the imperative stimulus was presented, the trajectory of the saccade deviated away (i.e., to the right or left) from the location where attention had been directed. That can be explained by assuming that, even though the eyes remained at fixation, the oculomotor program that was needed to direct attention caused the representation of space used by oculomotor centers to shift to the attended side (a "remapping" process; Sheliga et al., 1994). Therefore, when a saccade was performed, the eye trajectory veered from the side where attention had previously been directed. A different, but not necessarily alternative, explanation for why the eye trajectory veered from the side of attention is based on the circuit that modulates excitability of the superior colliculus (a "suppression" process; Rizzolatti et al., 1994; Sheliga et al., 1994).

A neurophysiological study by Kustov and Robinson (1996) provided clear evidence of the existence of links between visuospatial attention and eye movements. It showed that, in monkeys, the trajectory of a saccade evoked by electrical stimulation of the superior colliculus depended on where attention was directed. Even more interestingly, it was found that collicular excitability changed not only when the monkey was instructed to perform a saccade in response to the imperative stimulus, but also when the response was manual and the eyes did not move. That demonstrated that a shift of attention affected excitability of the oculomotor system in the absence of eye movements.

Other single unit studies reported that cortical areas, like the frontal eye fields (e.g., Kodaka, Mikami, & Kubota, 1997), the supplementary eye fields (Bon & Lucchetti, 1997), and the

parietal cortex (Andersen, 1995; Snyder, Batista, & Anderson, 1997), may mediate both attention and oculomotor processes. Colby, Duhamel, and Goldberg (1996) even reported that the very same neurons in the lateral intraparietal area responded to shifts of attention and saccadic eye movements.

The studies mentioned above, as well as several others (see Hoffman, 1998, for a review of behavioral studies, and Corbetta, 1998, for a meta-analysis of brain imaging studies) demonstrated the existence of links between eye movement mechanisms and the mechanisms involved in shifts of visuospatial attention. Direct evidence of a functional anatomical overlap between attention and eye movements systems was provided by an fMRI study of Corbetta et al. (1998), which showed that the same anatomical regions are involved in both attention orienting and saccadic eye movements.

In the Corbetta et al. (1998) study there were three tasks. In the shifting attention task, participants had to maintain central fixation and perform sequential shifts of attention to a series of boxes, located at 1°, 3°, 5°, 7°, and 10°, to detect a visual target (an asterisk in one of the boxes). An arrow indicated the box to which attention had to be shifted. In the eye movement task, the display was identical but participants were instructed to sequentially shift their eyes, and, presumably, attention. Note that shifts of attention in the attention shifting task and saccades in the eye movement task were endogenously generated because they preceded target presentation. In the fixation control task, the display was as in the other two tasks, but neither attention nor the eyes had to be shifted, and the target was not presented.

Results showed a nearly perfect overlap in the pattern of activation for the shifting attention task and the eye movement task. The areas active in both tasks were the frontal cortex near the precentral sulcus, the posterior end of the superior frontal sulcus, the medial frontal gyrus, and the parietal cortex along the intraparietal sulcus. Importantly, no region was uniquely active in one or the other task. The only difference between shifts of covert attention and saccadic eye movements was that the former produced a lower level of activation. The functional anatomy shown by Corbetta et al. (1998) closely replicated the findings of PET studies on covert visual orienting (Corbetta et al., 1993; Nobre et al., 1997; Vandenberghe et al., 1997). Note that also the Rosen et al. (1999) fMRI study demonstrated that covert shifts of endogenous and exogenous attention activated the frontal eye fields.

## HOW DOES ATTENTION OPERATE?

We live in cluttered environments and our senses are inundated by stimuli, only a small number of which are relevant to our goal-directed behavior. Attention allows us to pick up and process relevant stimuli while ignoring the myriad of irrelevant and potentially distracting ones.

Introspectively, it appears that selection of relevant information at the expense of irrelevant information is achieved by an enhancement of processing of the former. In effect, in most of the foregoing discussion it has been taken for granted that attention enhances (i.e., facilitates) processing of relevant information. However, the *mechanisms* of the selection process need not necessarily be *facilitatory* in nature. Selection of relevant stimuli may also be *inhibitory* in nature. That is, attentive processing of relevant information may be achieved by mechanisms that inhibit processing of irrelevant information. LaBerge (1995), among others, for example, aptly distinguished between the subjective *expression* of attention, which appears to be facilitatory, and the *mechanisms* by which that expression is achieved, which can be either facilitatory or inhibitory.

### Facilitation

It is widely accepted that information to which attention is selectively allocated is processed more efficiently than non-attended information. Therefore, for sake of brevity, I will confine

myself to pointing out that there are many methods that allow one to measure increases in processing efficiency caused by attention. The most frequently used are speed of response (e.g., Eriksen & Hoffman, 1972; Posner, 1980), recognition accuracy (e.g., Egly & Homa, 1984; van der Heijden & Eerland, 1973), stimulus detection (i.e., sensitivity vs. criterion shifts; see e.g., Bashinski & Bacharach, 1980; Downing, 1988), amplitude and/or latency of event related potentials (e.g., Mangun & Hillyard, 1988; Rugg et al., 1987), and brain activation (e.g., Brefczynski & DeYoe, 1999; Martinez et al., 1999). Information to which attention is allocated is operatively defined as that for which improved efficiency of processing is observed in terms of one or more of these indexes.

## Inhibition

There are mechanisms that achieve attentional selection by impeding the processing of irrelevant information. Some of these inhibitory mechanisms manifest themselves through effects for which there is neuropsychological evidence: inhibition of return, negative priming, and attentional blink. For other effects, like repetition blindness and change blindness, which too are presumably attributable to inhibitory mechanisms, neuropsychological evidence is not yet available (see Shapiro et al., in press).

### Inhibition of Return

This phenomenon was first described by Posner and Cohen (1984) and was termed inhibition of return (IOR) by Posner, Rafal, Choate, and Vaughan (1985). This term indicates a decreased likelihood that attention returns to a previously attended location (Klein, 1988): IOR would improve spatial selectivity by favoring the exploration of new positions at the expense of those already explored.

The characteristics of IOR and its relations with oculomotor mechanisms have been elucidated by a number of subsequent studies (see reviews in Milliken & Tipper, 1998; Umiltà, in press). Also, it was suggested that IOR can be related to either attended locations or attended objects.

*Space-Based Inhibition of Return.* In variants of Posner's (1980) paradigm, appearance of the target stimulus in the cued location may cause a delay and/or a loss of accuracy in the response: When the cue is peripheral, and thus causes exogenous orienting, and is not predictive of the target position, RT is slower and accuracy is lower if cue and target locations coincide than if they do not coincide.

IOR is caused by covert shifts of attention elicited by peripheral, non-predictive cues, but it does not occur with all shifts of attention. In particular, it does not occur with endogenously activated covert shifts of attention in response to central cues that indicate where to expect the forthcoming target. However, as was shown by Posner et al. (1985), if a central arrow induces the observer to make a saccade to an eccentric location, and the eyes are then returned back to fixation, IOR does occur at the location to which the saccade had been directed. Thus, the inhibitory effect seems to be produced by a cue presented in the periphery of the visual field while the eyes do not move or by endogenous activation of a saccade. Likely, a common mechanism, related to oculomotor preparation, is involved in both circumstances (see Rafal, Calabresi, Brennan, & Sciolto, 1989).

*Object-Based Inhibition of Return.* Evidence has been accumulating that IOR, besides being related to cued locations, can also be related to cued objects (Tipper, Driver, & Weaver, 1991; Tipper, Jordan, & Weaver, 1999; Tipper, Weaver, Jerreat, & Burak, 1994). In the standard experimental paradigm for IOR, attention is first oriented to, and then withdrawn from, not only a location but also an object (often an outline box). Therefore, it is unclear whether

attention is inhibited from returning to recently attended locations or to recently attended objects. These two possibilities can be tested in experimental conditions in which objects move in space. The cueing of moving objects permits one to evaluate inhibition related to the object when it is in a location different from the cued one. Also, one can independently evaluate inhibition related to the location in which the cueing took place when that location is no longer occupied by the cued object.

This experimental procedure was used by Tipper et al. (1994; also see Abrams & Dobkin, 1994; Tipper et al., 1991) who showed that IOR manifests itself in both space-based and object-based frames of reference, and that both types of inhibition can coexist.

Gibson and Egeth (1994) found another type of IOR associated with objects, which too coexists with space-based IOR. In their experiments, inhibition accrued at locations that remained invariant with respect to the object's internal structure. Therefore, that would be object-centered rather than object-based IOR (see section on object-centered attention). Tipper et al. (1999) found three types of IOR: one space-based, one that follows moving objects (object-based), and one related to parts of rotating objects (object-centered).

*Neural Substrate of Inhibition of Return.* That the superior colliculus mediates space-based IOR is attested by several, though indirect, lines of evidence (see review in Rafal & Henik, 1994). Patients with progressive supranuclear palsy, which, as already mentioned (see section on orienting of attention), results in damage to the superior colliculus, are the only patients who do not show IOR with a spatial cueing paradigm (Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). Space-based IOR is present in patients with hemianopia, a condition in which the geniculostriate pathway is destroyed, whereas the retinotectal pathway is preserved. When healthy participants view display monocularly, space-based IOR is greater in the temporal than in the nasal visual field, which indexes mediation by the retinotectal pathway (Rafal et al., 1989; Rafal, Henik, & Smith, 1991). Spatial cueing in newborn infants, whose visual behavior is predominantly mediated by the superior colliculus, produces IOR that is greater in the temporal than in the nasal visual field (Simion, Valenza, Umiltà, & Dalla Barba, 1995; Valenza, Simion, & Umiltà, 1994).

Direct evidence of the involvement of the superior colliculus in space-based IOR was provided by Sapir, Soroker, Berger, and Henik (1999), who tested a patient with a lesion restricted to the right superior colliculus. They used a monocular variant of Posner's (1980) paradigm. Results showed that IOR was present only in the visual field projecting to the intact left superior colliculus, and was greater in the temporal than in the nasal field. No IOR was found in the visual field projecting to the damaged right superior colliculus.

Tipper et al. (1994) speculated that different neural structures may subservise space-based and object-based IOR: The former would be mediated by the superior colliculus, whereas the latter would be mediated by the cortex. Tipper et al. (1997) found that, in two split-brain patients, object-based IOR did not transfer between hemispheres. That might be taken as supportive of the notion that object-based IOR is cortically mediated, and thus needs an intact corpus callosum to transfer from one hemisphere to the other.

## Negative Priming

The phenomenon of negative priming (NP) refers to the slowing of responses to recently ignored stimuli (i.e., distracters). Even though a distracter was successfully ignored on a trial, there is a slowing of the response when that same distracter is re-presented as a target on the subsequent trial.

A study by Tipper and Cranston (1985) illustrates the NP effect. In it, participants were presented with lists of partially overlapped red and green letter pairs and were asked to read aloud the red letters and to ignore the green letters. The lists were presented under two

conditions: In the ignored prime condition, the distracter (green) letter in each pair was identical to the subsequent target (red) letter. In the unrelated distracter condition, the distracter letter and the following target letter were different. NP was evidenced by slower responses in the ignored prime condition than in the unrelated distracter condition.

Negative priming has been demonstrated with many different experimental paradigms (see reviews in Milliken & Tipper, 1998; Neill, Valdes, & Terry, 1995), which suggests that the mechanism(s) that cause(s) it may play an important role in selective attention. Even though the attribution of NP to inhibitory attentional mechanisms(s) is not straightforward (e.g., Milliken & Tipper, 1998) the two more convincing explanations invoke some form of inhibition. One is that the activation of the distracter internal representation is reduced and this inhibition is still effective when the next trial is presented. The other is that the distracter representation is denied access to the response system and its isolation from the control of action must be overcome when, on the next trial, the distracter requires a response.

Diminished NP has been observed in individuals for whom it can be argued that inhibition of irrelevant information is impaired: schizophrenics (e.g., Beech, Powell, McWilliams, & Claridge, 1989), depressed patients (e.g., Benoit et al., 1992), and Alzheimer's patients (e.g., Sullivan, Faust, & Balota, 1995).

An interesting study was conducted by Fuentes and Humphreys (1996), who tested a patient with a right parietal lesion showing left visual extinction to double simultaneous stimulation. They used a version of the "flanker" task (Eriksen & Eriksen, 1974), in which the patient was required to classify two target letters at fixation, one in the prime display and one in the subsequent probe display, on the basis of whether they were same or different. The central target letters could be flanked either by two plus signs or by one plus sign and a letter (the distracter), presented to the left or right visual field. In the critical condition, the distracter in the prime display became the target in the probe display. RT was measured. Like normal participants, the patient showed NP when the distracter appeared in the intact field (1683 ms in the ignored prime condition vs. 1420 ms in the unrelated distracter condition). In contrast, he showed positive priming when the distracter appeared in the affected field (1322 ms in the ignored prime condition vs. 1607 ms in the unrelated distracter condition). Two important conclusions can be drawn from this study. First, stimuli in the neglected field activate internal representations that produce positive priming, that is faster and more accurate processing of the target (see section on early vs. late selection). Second, in the absence of attention, the inhibitory mechanism(s) that produce(s) NP cannot operate.

Stuss et al. (1999) examined three measures of inhibition, interference, NP, and IOR, in patients with frontal lesions (bilateral, left, or right) or non-frontal, predominantly parietal lesions (left or right). With regard to NP, results showed that right hemisphere lesions, either frontal or parietal, virtually eliminated it. That supports Fuentes and Humphreys's (1996) finding that areas of the right hemisphere are implicated in NP.

### Attentional Blink

When a human observer has to identify two objects presented in succession, the processing of the first object interferes with the processing of the second object. This phenomenon, which lasts for several hundred milliseconds, was termed the attentional blink (AB) or dwell time, and is a measure of the observer's ability to shift attention over time (see reviews in Milliken & Tipper, 1998; Shapiro et al., in press).

The standard procedure for studying AB is based on the rapid serial visual presentation (RSVP) of stimuli. In a study by Raymond, Shapiro, and Arnell (1992), participants were presented with an RSVP stream of letters. One of the letters was white, whereas the other letters were black on a gray background. The single white letter was the target, and one of the black letters (an X) was the probe. On experimental trials, the task was to identify the white

letter and to indicate whether the probe had appeared following the target. On control trials, the task was to indicate only whether the probe had appeared, without identifying the target. The RSVP streams contained between 7 and 15 pre-target items and 8 post-target items. Results showed that, on experimental trials, the participant's ability to detect the probe varied according to its temporal position in the RSVP stream: If the probe occurred within about 400 ms of the target, detection was impaired.

The term AB was used to indicate that participants experience an attentional impairment after engaging the target. The exact mechanism of this loss of attention is still a matter of debate (see Milliken & Tipper, 1998; Shapiro et al., *in press*). Raymond et al. (1992) originally proposed an explicit inhibitory process. Later Shapiro and Raymond (1994) proposed a competitive retrieval process. A third account is based on the notion of a bottleneck created by a capacity-limited stage of processing (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998).

Husain, Shapiro, Martin, and Kennard (1997) examined AB in patients with left neglect following right hemisphere stroke involving the inferior parietal lobe, the inferior frontal lobe, or the basal ganglia. These patients had an abnormally severe and protracted AB in comparison to elderly control participants (1,440 vs. 360 ms). In contrast, age-matched patients with right hemisphere stroke but without neglect showed a normal AB that lasted 360 ms. Husain et al. (1997) concluded that neglect is a disorder of directing attention in time, not only in space. In particular, it would seem that the deficit of the disengagement of attention that characterizes neglect and extinction (see section on orienting of attention) is not purely spatial in nature (also see Shapiro et al., *in press*). It is interesting to note, that other studies demonstrated non-spatial attentional deficits in patients with extinction by using different experimental procedures, (di Pellegrino, Basso, & Frassinetti, 1998; Humphreys, Romani, Olson, Riddoch, & Duncan, 1994; also see review in Shapiro et al., *in press*).

## CONCLUDING REMARKS

The results reviewed here clearly show that neuropsychological and neurophysiological research has provided important contributions toward elucidating key issues concerning the mechanisms of attention. Attention selects both regions of space and objects for enhanced processing, and, likely, selection for space and selection for objects depends on different neural mechanisms. Even though attention can be shifted in space in the absence of eye movements, there can be little doubt that there is a functional neuroanatomical overlap between attention and eye movement systems. Also, it is clear that attentional selection implies both facilitation of relevant information and inhibition of irrelevant information.

A key issue in the study of attention that has yet to be fully clarified concerns the fate of unattended information. Neurophysiological evidence shows that attention modulates neural activity at very early stages along the processing pathway, perhaps even at the level of the primary sensory areas. That is clearly in favor of the early selection hypothesis. In contrast, neuropsychological evidence supports the late selection hypothesis by showing semantic interference effects produced by unattended stimuli. Perhaps, facilitation of attended information occurs at early stages, which are tapped by neurophysiological methods, whereas inhibition of unattended information occurs at later stages, which are tapped by neuropsychological tasks. However, Valdes-Sosa, Bobes, Rodriguez, and Pinilla (1998) reported suppression of P1 and N1 associated with non-attended objects, which seems to suggest that inhibition acts at early stages. Likely, as argued by Yantis and Johnston (1990), the question is not either/or: Selection is early or late depending on task demands.

## Acknowledgements

The writing of this chapter was supported by grants from MURST. I thank Brenda Rapp for many helpful suggestions on an earlier version of this chapter.

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