
Parsing cognitive processes: Psychopathological and neurophysiological constraints

Anne Sereno

The concept of attention is most intriguing since, at first glance, it appears impossible to study. Somehow it seems more feasible to examine and determine the basic structure of perceptual or mnemonic processes – establishing parameters such as perceptual thresholds and memory capacities. It is unsettling to learn that a slight attentional change, for example in the instructions of a task, can radically change these so-called parameters of the system. That is, telling a subject *where* a target is likely to appear, or *what* target is likely to appear, might determine whether or not the subject will be able to detect, discriminate, or even remember the target.*

The relation between attention and eye movements

The relation between eye movements and attention has been discussed for over a century, but usually in the context of *dissociating* attention from eye movements. In 1890, William James in *The Principles of Psychology* noted that “we may attend to an object on the periphery of the visual field and yet not accommodate the eye for it” (p. 413). He further elaborated by referring to Helmholtz, who, according to James, “states the fact so strikingly that I will quote his observations in full” (p. 414). The quote from Helmholtz begins with the description of an experiment, and concludes,

then, our attention is quite independent of the position and accommodation of the eyes, and of any known alteration in these organs, and free to direct itself by a conscious and voluntary effort upon any selected portion of a dark and undifferentiated field of view. This is one of the most important observa-

* See glossary at end of this chapter for definitions of technical terms – Eds.

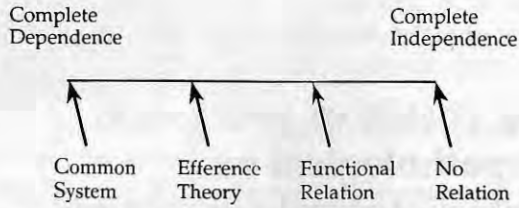


Figure 18.1. Logical relationships between overt and covert orienting of attention (adapted from Posner, 1980).

tions for a future theory of attention. (Helmholtz, *Physiologische Optik*, quoted in *The Principles of Psychology*, p. 414)

James, however, also commented that

no object, lying in the marginal portions of the field of vision can catch our attention without at the same time 'catching our eye' – that is, fatally provoking such movements of rotation and accommodation as will focus its image on the fovea, or point of greatest sensibility. Practice, however, enables us, *with effort*, to attend to a marginal object whilst keeping the eye immovable. (p. 413)

This striking ability to allocate attention to different parts of the visual field while maintaining fixation has dominated the theories of researchers interested in the relation between attentional movements and eye movements. Posner (1980) outlined four possible relations between eye movements and attention ranging from complete dependence to complete independence (see Figure 18.1). He argued that the attention and eye movement systems cannot be one and the same because attention can be shifted with the eyes fixed. A less restrictive view of the relation between eye movements and attention has been labeled *efference theory* (Posner, 1980) or *oculomotor readiness theory* (Klein, 1980). This view proposes that attentional shifts are eye movement programmings. Posner (1980) and Klein (1980) argued against this view, contending that there seemed to be no relation between shifts of attention and a readiness to move the eyes. Neither Posner nor Klein proposed, however, that eye movements are unrelated to attention. Posner (1980) concluded that the relation is a functional one. That is, attention and eye movements are both summoned by important peripheral events and thus have a close functional relationship but no intrinsic physiological relationship.

Much of the research examining the relation between attention and eye movements in the past few decades has emphasized the *differences*

between these two forms of orienting; nevertheless, this same research also documents a close relation between the two systems. Many studies have reported a facilitation in processing for items in a location to which a saccade is about to be made (Bryden, 1961; Crovitz & Daves, 1962; Jonides, 1976; Rayner et al., 1978). Rayner et al. (1978) presented subjects with two stimuli (one on each side of the fixation point). One of the stimuli was a word and the other a random letter string. Subjects were instructed to look to the left or right stimulus on a given block of trials. During the eye movement, the extrafoveal random letter string was replaced on the screen so that the target word was the same in both locations. Subjects were unaware of any change in the display and were instructed to name the word that was the target of their eye movement as quickly as possible. Rayner et al. found that an extrafoveal preview of a word in the location to which the eyes were about to move facilitated naming latency over having an incorrect preview, whereas a preview in a location opposite to that in which the eyes were about to move provided no facilitation in naming latency. The Rayner et al. (1978) results suggest that, prior to the eye movement, useful information is acquired from the position to which the eyes are about to move. In addition, the results indicate that little information is acquired from an extrafoveal location which is in the opposite direction from that in which the eyes are about to move. The most common explanation for these findings is that there is a covert shift of attention (to the target location) that precedes this next eye movement.

Although many findings seem to suggest a consistent relation between an attentional shift and an eye movement, there are several studies that show either mixed or negative results. Using a threshold detection task, Remington (1980) performed a series of experiments examining the relation between eye movements and attention. Subjects were instructed to make an eye movement to a target presented 10° randomly to the left or to the right of fixation. Following the presentation of the target (but in some cases before the eye movement), a 3 msec probe stimulus was presented in one of four possible positions (on 50% of the trials) and subjects were required to report whether the probe stimulus was present or absent. Before, during, and after the saccade, probes were more often detected if they occurred in the same position as the eye movement target. In another experiment, he used a central cue (i.e., an arrow) to initiate the saccade. In this experiment he found that the cued position showed no

advantage in probe detection until after the eye movement was completed. Remington concluded that a peripheral stimulus summons both attention and an eye movement, whereas when saccades are directed by a central cue, there is no advance allocation of attention to the destination of the eye movement. Thus, he claimed, in the absence of a peripheral stimulus, a saccade does not involve the allocation of attention to the target position.

In a dual task paradigm, Klein (1980) tested (1) whether preparing to make an eye movement to a particular location would facilitate the detection of events presented there (similar question as Remington, 1980), and (2) whether attending to a location would facilitate making an eye movement to that position. He reported no evidence for either of these effects. However, he noted that the dual-task blocks in both experiments were very difficult for the subjects. Although he did not see this as a problem, some have argued that the results may not be replicable under more normal conditions. Furthermore, in both experiments subjects had to distinguish an asterisk from the brightening of a dot in peripheral vision, before they would know whether to make an eye movement or press a key, respectively. This detail of the design would seem to undermine an assumption of the first experiment: it was assumed that given that subjects knew where to make the eye movement (e.g., always to the left), they would prepare it ahead of time. However, since the subjects needed to discriminate a peripheral event that could occur on either side of the fixation before knowing whether to make an eye movement, it is not clear that they could program the eye movement ahead of time.

A series of experiments by Shepherd et al. (1986) suggests a close relation between attention and eye movements and directly challenges Remington's (1980) and Klein's (1980) findings. Shepherd et al. (1986) used a central arrow cue as a signal to make a saccade and as a cue to indicate the likely location of a probe stimulus requiring a manual response. The probe stimulus onset could occur before, during, or after the saccade. They found that the detection of the probe at the eye movement target location was facilitated long before the eye movement began, even though saccades were directed by a central cue rather than elicited by a peripheral stimulus. This finding, they suggest, indicates that making a voluntary saccade necessarily involves an allocation of attention to the target position. In addition, they found that a probe stimulus shortened saccadic latency if it appeared in the eye movement target location and lengthened saccadic latency

if it appeared at a location different from the eye movement target location. They conclude that the results suggest a reciprocal relationship between eye movements and spatial attention: attention to a peripheral position is facilitated by preparing to make a saccade to that position, and saccade latency is reduced by attention to the eye movement target location. They do also note an asymmetry in the relation between attentional shifts and eye movements: that is, it is possible to shift the focus of attention without moving the eyes, but it is not possible to make eye movements without also moving the focus of attention. They do not assign this asymmetry, however, any special role in defining the relation between, or rather distinguishing between, attentional movements and eye movements.

Klein et al. (1992) carefully point out that the original experiments (Klein, 1980) do not apply to exogenous orienting (peripheral cue/target), where there may be a tight linkage between attention and saccade execution. In addition, they concede that there may also be a linkage between attention and endogenous saccade execution (cf. Bryden, 1961; Crovitz and Daves, 1962; Rayner et al., 1978; Shepherd et al., 1986). However, they maintain that attention is not linked to endogenously generated saccade programming. In his 1980 paper, Klein argues that the onset of a stimulus may attract both the eye movement system and attentional mechanisms without any causal relationship between the two systems being implied. Thus, one may have "tight linkage" with no relationship between the two systems. He later adds, however, that the linkage between the eye movement and attention systems may be a reflexive one that is not under cognitive control. Thus, an eye movement necessitates an attentional shift, whereas cognitive preparation to look does not. This situation was addressed by Rafal et al. (1989), who showed that cognitive preparation to make a saccade can cause an attentional shift because under some conditions it results in inhibition of return (a phenomenon tightly coupled to an exogenous attentional shift).

Rafal et al. (1989) discuss saccade preparation and its role in the phenomenon of inhibition of return. Their goal is to determine how neural systems responsible for attention are integrated with eye movement systems. They begin with the fact that a visual signal or cue that is eccentric to fixation has a biphasic effect both on the covert orienting of attention and on eye movements. Initially, the cue summons attention automatically and facilitates detection of stimuli at the location of the signal (Posner et al., 1982). The cue also biases midbrain

oculomotor centers to prepare a saccade toward it (Posner & Cohen, 1980). These facilitating effects are followed by an inhibition (inhibition of return), which slows detection at the cued location and induces a bias against making a saccade toward it (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1985; Posner et al., 1985; Tassinari et al., 1987).

Whereas inhibition of return appears after covert shifts of attention summoned by an eccentric (or exogenous) visual signal, it does not usually occur with endogenously activated shifts in attention (e.g., using symbolic cues, such as an arrow at the fixation point). The explanation for the different effects of exogenous and endogenous orienting of attention on inhibition of return was clarified in an elegant paradigm by Rafal et al. (1989). They showed that it was possible to activate inhibition of return to an endogenous signal merely by priming the oculomotor system to prepare a saccade. The results suggest that inhibition of return does not arise either from sensory exogenous processes alone (since it occurs after endogenous cueing that involves saccade preparation) or from covert orienting of attention alone (since it does not occur after endogenous cueing without saccade preparation), but rather from activation of the oculomotor system. Thus, exogenous signals (i.e., peripheral signals) automatically begin saccade preparation and hence produce inhibition of return, whereas endogenous signals will produce inhibition of return only under circumstances that induce saccade preparation.

Although Klein concluded that endogenous orienting is not involved in saccade programming, the Rafal et al. findings only provide evidence that endogenous orienting is not automatically or directly involved in reflexive saccade programming, but can affect it under certain conditions (as evidenced by inhibition of return after preparing but not executing a voluntary eye movement). Endogenous attention may not be involved as closely (or in a facilitatory manner) in the exogenous or reflexive eye movement programming system (examined in Rafal et al., 1989) as in the endogenous or voluntary eye movement programming system.

A model of the relation between attention and eye movements

One finds apparent contradictions in the literature as to whether attention facilitates or inhibits an eye movement. For example, Fischer and colleagues claim that in order to make an eye movement, atten-

tion needs to be disengaged from its current focus (Fischer & Breitmeyer, 1987). They observed that attention directed to the target position provides no advantage when an eye movement to a peripheral target is required. On the other hand, Shepherd and colleagues, as noted above, obtained evidence that saccade latencies are shortened if a probe stimulus appears at the target position. That is, attention to the target position reduces saccade latency. There are important differences among experiments in how attention is cued and how the eye movement is made. These differences may have led to the different findings.

Some of the differences have been addressed and most clearly described by Klein and colleagues (1992). They highlight two important distinctions: (1) whether or not an eye movement accompanies or follows the attentional shift, and (2) whether or not there is an abrupt peripheral onset in the position of the object to be attended. The first distinction is usually labelled overt versus covert orienting (that is, for eye movements versus attentional movements). The second distinction is often labelled exogenous versus endogenous or, equivalently, reflexive versus voluntary orienting (that is, for a peripheral onset cue versus a central or cognitive cue). In this chapter, the terms "reflexive" and "voluntary" are used preferentially. Despite differences in paradigms that may be the cause for the different findings, the question remains: Is visuospatial selective attention related to saccadic eye movements? And, if so, how?

It can be argued that spatial selective attention *is* related to saccadic eye movements. The following schematic model (adapted from Sero, 1992) suggests how they may be related (see Figure 18.2). The model serves two functions: First, it makes explicit the proposed relation between visuospatial attention and saccadic eye movements. Second, specific hypotheses can be generated from the model about the interactions and influences between visuospatial selective attention and saccadic eye movements not only for normal subjects, but also for subject populations with dysfunctions involving regions of the brain important for orienting.

A few principal features of the model deserve brief discussion. A variety of evidence suggests a model where there are two basic orienting systems (i.e., subcortical for reflexive and cortical for voluntary). The cortical system tonically inhibits the subcortical system (via the caudate and substantia nigra; Illing & Graybiel, 1985; Hikosaka & Wurtz, 1989), and although there is also a direct phasic excitatory projection from the cortical to the subcortical system (Lynch & Gray-

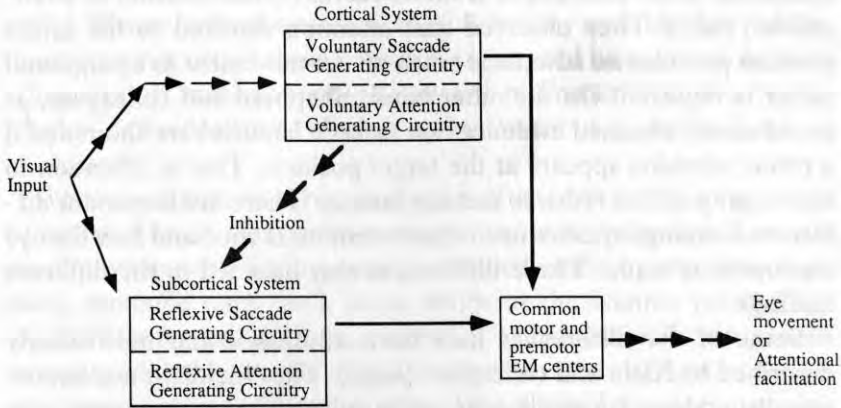


Figure 18.2. Model of orienting systems.

biel, 1983; Illing & Graybiel, 1985; Segraves & Goldberg, 1987), inhibition represents the primary relation between the cortical and subcortical systems at both a cellular and a behavioral level of organization (Guitton et al., 1985; Hikosaka & Wurtz, 1985; Schiller et al., 1987). By decreasing the inhibition and/or increasing the excitation, the cortical system can act through the subcortical system.

The model also proposes that within each system (cortical and subcortical), attention is conceived as a subthreshold activity of an eye movement center. In order for a saccade to be executed, a superthreshold attentional activation in the target position is required. Such a scenario would explain the asymmetry so often observed with attention and eye movements: i.e., you need attention to get an eye movement, but you can have attentional changes (subthreshold activations) without ever having an eye movement. The model suggests a fairly explicit structure for spatial selective attention. Some of the evidence that forms the basis for this model is reviewed below.

Physiological localization

Reflexive attention and the superior colliculus

In 1980, Posner argued that the relation between attention and saccadic eye movements was a functional one; that is, attention and eye movements are both summoned by important peripheral events and

thus have a close functional but no intrinsic physiological relationship. Perhaps the best supported finding to emerge from neural considerations, however, is the idea that the superior colliculus and related eye movement brainstem structures play a role in reflexive or exogenous attention.

This picture began emerging when Posner et al. (1982) examined attention and eye movements in progressive supranuclear palsy patients with midbrain degeneration (involving the superior colliculus, pretectum, periaqueductal gray, and mesencephalic raphe). Although these patients were able to orient attention in directions to which they could not move their eyes voluntarily (findings supportive of a merely functional relation between the two systems), covert orienting was delayed in directions in which eye movements were most affected. In fact, whereas covert orienting was quite rapid in the direction of unimpaired eye movements (as reflected by an advantage for the cued position beginning around 50 ms after cue onset), there was no evidence for covert orienting in the impaired direction until 1,000 ms after the cue. Although they concluded that only the latency of covert orienting seemed to be affected, we now know, as more detailed evidence concerning the time course of facilitation following a peripheral cue (as well as a central or symbolic cue) has accumulated (e.g., Nakayama & Mackeben, 1989), that it is unlikely that the advantage that occurred at 1,000 ms after cue onset was due to a delayed *reflexive* shift of attention. This suggests that reflexive attention and reflexive saccadic eye movements were similarly impaired across direction.

Some evidence also suggests that inhibition of return, a phenomenon intimately associated with reflexive orienting, is mediated by a midbrain mechanism involving the superior colliculus. Posner et al. (1985) demonstrated that neurologic patients with progressive supranuclear palsy involving peritectal degeneration had a deficit of inhibition of return in the same directions in which eye movements were most severely impaired. In addition, Rafal et al. (1989) showed a temporal hemifield dominance under monocular viewing conditions for inhibition of return; they suggested that it may be mediated by the retino-tectal pathway or midbrain pathways.

Early neurophysiological work suggested that the superior colliculus and related brainstem structures play a role only in overt orienting (i.e., that accompanied by an eye movement), whereas the posterior parietal cortex plays a unique role in covert shifts of attention (Wurtz & Mohler, 1976; Wurtz et al., 1980; Bushnell et al., 1981;

Wurtz et al., 1984). A fixating monkey was trained to release a bar when a peripheral receptive field stimulus dimmed (spatial attention condition), but not when the fixation point dimmed (baseline cell response condition). Cells in posterior parietal cortex showed an enhanced response even when no eye movement to the receptive field stimulus occurred, indicating independence of attention and eye movements. For cells in the superior colliculus, a most dramatic enhanced response occurred when the monkey responded with a saccade to the receptive field stimulus. Although these studies are often cited as evidence against the superior colliculus's playing a role in covert orienting, caution is warranted for two reasons. First, the task could be considered a *voluntary* or *endogenous* attention paradigm; thus, these studies suggest that the superior colliculus does not play an important role in *voluntary* covert orienting. Second, recent findings suggest that there *is* modulation of cell response in the superior colliculus that is specific to voluntary covert orienting, beginning about 300 ms after the cue (Glimcher & Sparks, 1992). It is likely that this cell modulation in the superior colliculus is not the site for the *generation* of such a signal (in a related task, modulation of cell response in prefrontal cortex begins about 250 ms after the cue; Goldman-Rakic et al., 1990). Rather, the effects of voluntary covert orienting detected in the cell response of the superior colliculus may instead be viewed as a spillover of the voluntary covert orienting signal generated in other brain areas such as prefrontal or parietal cortex. In sum, much evidence suggests that the superior colliculus and other closely related brainstem oculomotor structures play an integral role in the generation of reflexive or exogenous attention.

Voluntary attention and prefrontal cortex

In the cognitive literature, many quite different paradigms have been employed to elicit voluntary or endogenous attention. It is therefore difficult to suggest a neural substrate of voluntary attention since it is difficult to define strictly what one is seeking. A general description may be to look for a signal in the brain that is not directly dependent in either space or time on a sensory signal, or, perhaps, a signal that can be maintained for a relatively long period following a sensory cue. Most reports showing attentional modulation of cell response have demonstrated stimulus selective attentional effects rather than spatial selective effects. Detailed studies have documented changes in cell

response in area V4 and in inferotemporal cortex (IT) that are dependent on what stimulus properties the monkey is searching for (see, e.g., Fuster & Jervey, 1982, for cell modulation dependent on color; and Haenny et al., 1988 and Maunsell et al., 1991, for cell modulation dependent on orientation). The task most often used in these studies has been a match-to-sample (MTS) task. In a MTS task, the monkey is briefly presented a sample stimulus and, after a brief delay, a test stimulus. If the test stimulus matches the sample, the monkey responds (e.g., by releasing a response bar).

Moran and Desimone's 1985 *Science* paper, purportedly showing that attenuation of irrelevant information in neurons in monkey visual cortex can be based purely on spatial location, is often cited as providing evidence for a *spatially* selective attentional mechanism in temporal cortex. Their task, however, was a modified match-to-sample task where successful performance required the monkey to attend to the *color* or *orientation* of the sample. Thus, it remains to be demonstrated whether the effects in question can be obtained independently of *stimulus* selective effects (see Sereno, 1990). Such stimulus selective effects (e.g., color or orientation selective effects), as mentioned above, have already been demonstrated to occur in MTS tasks in temporal cortex.

At first glance, the modulation of cells in posterior parietal cortex, as discussed above, appears to be the clearest neurophysiological correlate for voluntary or endogenous spatial selective attention (e.g., Wurtz et al., 1984). A related task, perhaps, is a spatial delayed-response task. In this task the monkey must maintain fixation on a central point, during which time a visual target flashes briefly in the periphery. After a delay, the fixation point is extinguished, which signals the monkey to make a saccade to the location where the target previously appeared. Delay-period modulation of cell response in this task has been reported in several different areas, including the principal sulcus (Funahashi et al., 1989), the frontal eye fields (Bruce & Goldberg, 1985), the posterior parietal cortex (Gnadt & Andersen, 1988), the basal ganglia (Hikosaka & Wurtz, 1983; Hikosaka et al., 1989), the premotor and motor cortex (Tanji et al., 1980; Tanji & Kurata, 1985), and the hippocampus (Watanabe & Niki, 1985). The usual interpretation of this activity proposes that these cells are involved in maintaining an image of the location of the target in spatial working memory (Goldman-Rakic, 1987). It is perhaps the striking demonstrations, beginning with Jacobsen (1936), of prefrontal cortex

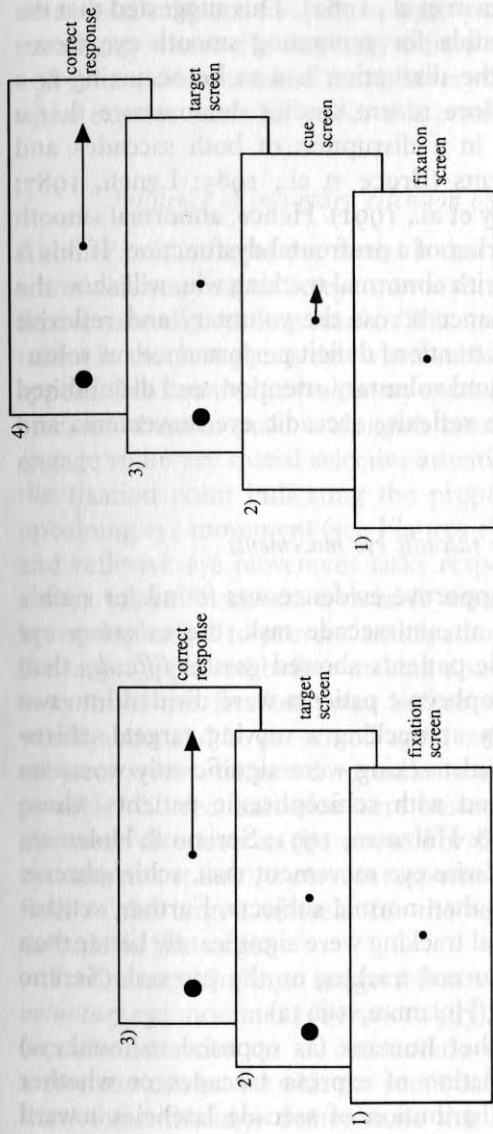
damage producing a profound and selective deficit in spatial delayed response tasks that most strongly suggest that the prefrontal cortex, compared to other areas, plays a particularly crucial role in spatial working memory. The fact that one may describe the activity of some neurons as a "transient spatial memory" process or as a "sustained spatial attention" process suggests that this distinction in terminology may no longer serve a useful purpose (see Conclusion, this chapter).

Schizophrenia and orienting

In view of the present model, schizophrenic patients are an interesting population to investigate for several reasons. First of all, one of the most commonly cited deficits in schizophrenia has been an attentional deficit (McGhie & Chapman, 1961). In addition, there is a long history of reports of eye movement problems in schizophrenia, starting with Diefendorf and Dodge (1908) and rediscovered and advanced by Holzman and colleagues (for a review, see Holzman, 1985). And, finally, over the years, many studies have suggested that there is a prefrontal cortex dysfunction in schizophrenia (for reviews, see Levin, 1984a; Levin, 1984b; Goldman-Rakic, 1987).

If schizophrenia involves a dysfunction of prefrontal cortex, according to the model, this dysfunction would lead to two behavioral changes. First, schizophrenic patients would show deficits in the voluntary system: that is, on an antisaccade task (see Figure 18.3, panel A), schizophrenic patients would have longer reaction times (RTs) and make more errors, and on a voluntary attention task schizophrenic patients would not show as much attentional facilitation as would normal subjects. Second, there would also be a disinhibition or enhancement of the reflexive or exogenous system: that is, in a gap paradigm schizophrenic patients would show a greater benefit than normal subjects and, on a reflexive attention task, schizophrenic patients would show greater attentional facilitation than normal subjects. In a gap paradigm, the fixation point is extinguished before the target appears; hence, there is a brief temporal gap before the target onset which allows the subject to make express saccades (i.e., saccades with very short latency, typically 100–150 msec).

Early findings by Holzman and colleagues showed that although smooth pursuit was impaired in many schizophrenic patients, these same patients showed intact smooth eye movements during vestibulo-ocular reflex (VOR) or optokinetic nystagmus (OKN) (Levy et al.,



B

A

Figure 18.3. Schematic of an anti-saccade task (Panel A) and an anti-saccade task with a voluntary attentional cue that is always valid (Panel B). In an anti-saccade task, subjects are instructed to make an eye movement in the direction opposite to the target when the target appears. When there is a voluntary attentional cue, subjects know ahead of time where they need to make the upcoming eye movement, but must wait for the target to appear at some random interval after fixation. The attentional cue shortens saccade latency in an antisaccade task.

1978; Latham et al., 1981; Levin et al., 1982). This suggested that the subcortical pathways responsible for generating smooth eye movements were intact and that the disruption had to be occurring at a higher level in the brain. More recent studies demonstrate that a prefrontal lesion can result in a disruption of both saccades and smooth pursuit eye movements (Bruce et al., 1985; Lynch, 1987; Schiller et al., 1987; MacAvoy et al., 1991). Hence, abnormal smooth pursuit tracking may be a marker of a prefrontal dysfunction. If this is so, it is perhaps the patients with abnormal tracking who will show the following pattern of performance across the voluntary and reflexive tasks of eye movements and attention: deficit performance on voluntary saccadic eye movements and voluntary attention, and disinhibited or enhanced performance on reflexive saccadic eye movements and reflexive attention.

Voluntary and reflexive saccadic eye movements

In a study of these issues, supportive evidence was found for such a pattern (Sereno, 1991). On an antisaccade task, the *voluntary* eye movement task, schizophrenic patients showed *greater difficulty* than normal subjects. When schizophrenic patients were divided into two groups based on their ability at tracking a moving target, schizophrenic patients with abnormal tracking were significantly worse on the antisaccade task compared with schizophrenic patients whose tracking was normal (Sereno & Holzman, 1991; Sereno & Holzman, 1995). On the gap task, a *reflexive* eye movement task, schizophrenic patients showed *greater benefit* than normal subjects. Further, schizophrenic patients with abnormal tracking were significantly better than schizophrenic patients with normal tracking on the gap task (Sereno & Holzman, 1991; Sereno & Holzman, 1993a).

It remains debatable whether humans (as opposed to monkeys) really show a separate population of express saccades or whether there is just a shift in the distribution of saccade latencies toward smaller values (see Wenban-Smith & Findlay, 1991). The original experiments did not elicit many saccades with short latencies, making it difficult to make a comparison of the *number* of express saccades across subject groups. Preliminary results from some experiments in progress, however, do show greater numbers of short latency saccades and support the original findings (Sereno & Holzman, 1993b). Schizophrenic patients show significantly more express saccades than

do normal subjects, not only in a gap paradigm, but also in an overlap paradigm, where Fischer and others (e.g., Fischer & Breitmeyer, 1987) have demonstrated that it is very difficult for normal subjects to make express saccades under this condition.

Influence of voluntary attention on saccadic eye movements

Another prediction of the model is that voluntary attention will facilitate a voluntary saccadic eye movement, whereas it will inhibit a reflexive saccadic eye movement. This second prediction is counterintuitive in that it suggests that when subjects know where the target will appear, this knowledge (voluntary spatial attention) will *slow them down* or cause them to make a sluggish saccade to the target. In order to engage voluntary spatial selective attention, an arrow was presented at the fixation point indicating the proper direction required for the upcoming eye movement (see Figures 18.3 and 18.4 for the voluntary and reflexive eye movement tasks respectively). This arrow cue was always valid. There was a variable interval between this cue and the upcoming target to prevent anticipations. Subjects had to wait until the target appeared before making a saccade. If they made a saccade away from the fixation point before the target appeared, the trial would abort and be presented again later. When the target appeared, subjects were instructed to make a correct saccade as quickly as possible. Correct saccades were saccades of a specific amplitude in the same direction as the arrow. For the antisaccade task (voluntary eye movement task), a correct response was a saccade to the opposite field of the target, whereas for the reflexive saccade task, it was a saccade to the target.

Preliminary findings suggest that voluntary attention *facilitates* a *voluntary* eye movement (Sereno, 1993). That is, subjects have shorter saccadic latencies on an antisaccade task when they are given the arrow cue compared with the same task without the arrow cue. Further, these findings demonstrate that voluntary attention *inhibits* a *reflexive* eye movement. That is, subjects have longer saccadic latencies on a reflexive saccade task when they are given the arrow cue compared with the same task without the arrow cue. This is true both for normal subjects and for schizophrenic patients. There is, however, an additional prediction of the model: that schizophrenic patients should show less attentional facilitation in the voluntary eye movement task and less attentional inhibition in the reflexive eye movement task.

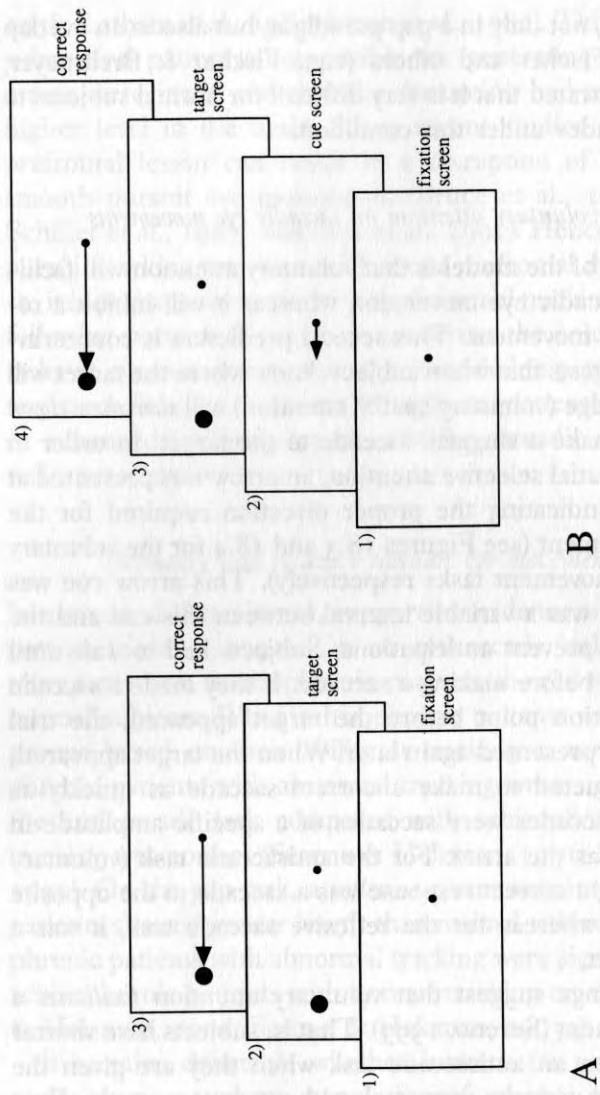


Figure 1.8.4. Schematic of a reflexive saccade (overlap) task (Panel A) and a reflexive saccade task with a voluntary attentional cue that is always valid (Panel B). In a reflexive saccade task, subjects are instructed to make an eye movement to the target when the target appears. When there is a voluntary attentional cue, subjects know ahead of time where they need to make the upcoming eye movement, but must wait for the target to appear at some random interval after fixation. The attentional cue lengthens saccade latency in a reflexive saccade task.

Although preliminary findings agree qualitatively with this hypothesis, this interaction was not statistically significant in a small sample.

Voluntary and reflexive attention

On a voluntary attention task, schizophrenic patients showed a *reduced* attentional benefit compared with normal subjects. On a reflexive attention task, schizophrenic patients showed a *greater* or *enhanced* attentional benefit compared to normal subjects (Sereno & Holzman, 1992; Sereno & Holzman, submitted).

In summary, schizophrenic patients show impaired performance on voluntary eye movement and voluntary attention tasks. On the other hand, schizophrenic patients show enhanced or disinhibited performance on reflexive eye movement and reflexive attention tasks. In addition, within the schizophrenic group itself, the abnormal trackers were significantly *worse* on the voluntary eye movement task and significantly *better* on the reflexive eye movement task compared with schizophrenic patients with normal tracking.

Conclusions

The present findings seem directly related not only to the neurophysiological findings of Funahashi et al. (1989), who used a spatial delayed working memory task, but also to the detailed studies with both infant monkeys and human infants in the developmental literature (for a review, see Diamond, 1990). Specifically, the similarity between a spatial working memory task and a selective visual attention task seems clear if, in a spatial delayed working memory task, one thinks of the first stimulus as a cue. During the interval in a spatial working memory task, while cells in prefrontal cortex are firing, the animal is holding on to a spatial position to which it will eventually make a saccade. But as Goldman-Rakic noted (see Chapter 2, this volume), a large percentage of these cells do not fire during the response (eye movement), but only during the delay, as if their function is to hold that position on line. This, it can be argued, is similar to what occurs on a task of spatial selective attention, where subjects must hold information on line about a particular location in the visual field where the target is most likely to appear. And, indeed, in recent positron emission tomography (PET) findings, Petersen and col-

leagues reported prefrontal activation during a voluntary spatial selective attention task (Petersen et al., 1991).

This brings us to a problem that one often sees between disciplines, or even research programs: the findings in one field become inaccessible to another field because the issues become bogged down in terminology. As we attempt to bridge the gap between fields such as experimental psychology and neuroscience, one can foresee two fundamental changes. First, we may be able to tie separate processes together: for example, to see how what some researchers label *spatial selective attention* may involve the same neurophysiological underpinnings as what others call *spatial working memory*; or, to realize that there may be *more* than superficial similarities between attentional shifts and saccadic eye movements. Second, we may be able to break down cognitive processes, such as attention, into more physiologically realistic processes. Over the years, it has become clear in the cognitive literature that "attention" is not a very precise or unambiguous term. When we use the term "attention," do we mean arousal, vigilance, orienting, search, selection, or shift? Quite different neurophysiological mechanisms are probably involved in these different aspects of attention.

Even within a given literature, such as the visual selective attention literature, there may be important distinctions that are not carefully observed – distinctions grounded in separate physiological mechanisms. One such distinction can be made between selective attention to an object's *properties* (such as color, form, or direction of movement) versus selective attention to an object's *location*. Careful manipulation of attention to object properties separately from attention to spatial location has rarely been performed in either physiological or psychological experiments (cf. the discussion of Moran & Desimone, 1985, above). For recent experiments attempting to distinguish between feature and spatial attention, see Sereno and Maunsell, 1995 (cf. also Chapter 2 by Goldman-Rakic, this volume).

In 1982, Ungerleider and Mishkin proposed that visual processing proceeds along two anatomically segregated streams of processing in cerebral cortex: a ventral pathway and a dorsal pathway. Each pathway comprises a different series of cortical visual areas and supports distinct types of functions. The ventral stream includes areas of temporal cortex and is involved in form analysis and object recognition (the "what" pathway), whereas the dorsal stream includes areas of parietal cortex and is important for vision related to spatial relations (the

"where" pathway; Maunsell & Newsome, 1987). This distinction between object and spatial properties may also be an important distinction in understanding the mechanisms of attentional effects. Attentional modulation of cell response, like sensory processing, may perhaps show anatomically segregated effects. That is, modulation of cell response arising from attention to object properties (e.g., color or orientation) may occur in the later stages of the ventral pathway (e.g., areas V4 and inferotemporal cortex), whereas modulation of cell response that is due to attention to spatial location may occur in the later stages of the dorsal pathway (e.g., area 7a and the lateral inferior parietal area).

One important step toward understanding the brain mechanisms of attention will be to determine whether attention to object properties and attention to spatial location are anatomically segregated. The parietal and temporal pathways in visual cortex interact (Felleman & Van Essen, 1991; Ferrera et al., 1992) and both project to prefrontal regions (e.g., area 46 and area 10, respectively). Higher stages of processing in prefrontal cortex are particularly likely sites of convergence for information from the two pathways. There is little existing neurophysiological data that addresses the question of interactions between different types of attention. For example, one interesting avenue for research, currently under investigation by the author, is to explore the degree of segregation of the effects of *stimulus selective* versus *spatially selective* attention in cortical neurons using single unit recording techniques in behaving rhesus monkeys performing these visual attention tasks. With careful experimental design, both tasks can be constructed so that they present the same visual stimuli and require the same response. Under these conditions, one can dissociate at the cellular level the effects of the two forms of attention on cell response. Several areas, including temporal, parietal, and prefrontal cortices, and superior colliculus, can be examined. Exploring the role of these separate areas in different aspects of attention may provide a clue to where these different processes may be occurring in the brain. Both prefrontal and temporal cortical areas have been implicated in the pathophysiology of schizophrenia. A closer examination of the physiological basis of different aspects of attention as described here may provide researchers in schizophrenia with clues about what aspects of voluntary attention are affected in schizophrenia and what areas of the brain may be involved in the disruption of such processes. Distinctions between behaviors that are grounded in physiologically

distinct mechanisms, such as might be the case for spatial and object property selective attention, are important to any understanding of behavior.

Cognitive neuroscience really represents just a *reawakening* of interest in the biological basis of cognitive functions. And just as neuroscience can guide and inform experiments in psychopathology, psychopathology can reveal potentially instructive dissociations of behavior that provide a clue about how the brain functions. Discoveries about how the brain functions at both the cellular and system levels will be as important as cognitive experiments in determining the structure of cognitive processes and how they occur. Understanding the biological mechanisms, in some cases, can do more than just guide experimental psychology – it can also alter the way cognitive psychology carves up human behavior into processes such as attention or memory. Changes in our conceptions of behavior that come about either by collapsing across what were once separate and distinct entities (such as visuospatial selective attention and visual working memory) or by creating distinctions (such as attention to spatial location and attention to object properties) will be crucial for a reparsing of cognitive processes.

Glossary

endogenous:	voluntary, internally generated, willful; frequently prompted by a symbolic cue
exogenous:	reflexive, externally prompted, automatic; prompted by the onset of a stimulus in the position where the attention/gaze is to be moved
saccade execution:	the process of actually performing an eye movement
saccade programming:	the processes involved in determining exactly where and how the eye will move, before the actual saccade
peripheral onset cue:	a sudden onset cue in the position where attention/gaze is to be moved; used in exogenous attention/eye movement tasks
central cue:	a cue located at the point of fixation, usually of a symbolic nature (e.g., an arrow)

- and indicating the likely position of an upcoming target; used in endogenous attention/eye movement tasks
- overt orienting: a shift in the location of gaze
- covert orienting: a shift in the location of attention
- antisaccade task: a voluntary eye movement task, requiring a subject to make an eye movement away from a target appearing in the periphery
- reflexive saccade task: a task requiring the subject to make an eye movement to a target in the periphery immediately after the target appears
- overlap task: a saccade task in which the fixation point remains present after the onset of the target
- gap task: a saccade task with a brief gap (usually 200 ms) between the offset of the fixation point and the onset of the target
- express saccade: a very short latency reflexive saccade; such saccades are more frequent in a gap task
- dual-task experiment: each trial requires the subject to perform two tasks at the same time; e.g., making an eye movement to a target and simultaneously detecting whether or not there is a small change in luminance in the visual field.

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