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Spatial Orientation following Commissural Section[1]

Jeffrey D. Holtzman, Bruce T. Volpe, and
Michael S. Gazzaniga

Introduction

The human visual system transmits an abundance of sensory information that, ultimately, is used for the coordination of behavior within the environment. Despite the overwhelming richness of the optic array, human information-processing capacity is profoundly limited—only a small fraction of the sensory world is available to conscious awareness at a given moment. If the conscious appreciation of a stimulus were a prerequisite for directed behavior, orientation to singificant sensory events would be severely impaired. Thus, although conscious activity coincides with certain visual functions, much of our behavior must depend on visual processing that does not have access to conscious awareness.

This "two-visual-systems" hypothesis, (i.e., that a functional distinction can be made between two kinds of visual information) is not a new one. Supportive evidence has been accumulated from electrophysiological, neuroanatomical, and clinical sources. This chapter is concerned primarily with the third source of evidence: patients with focal neurological damage whose behavior suggests that visual information that is used to orient to a stimulus is distinguishable from visual information underlying explicit stimulus identification. A general review of the clinical evidence in support of this distinction is provided in this chapter. Following this review, we summarize some observations from our laboratory on attentional control after disconnection of the cerebral hemispheres.

The data we present were collected from two patients who have undergone complete midline transection of the corpus callosum for the control of intractable epilepsy, so-called "split-brain" surgery (see Wilson, Reeves, & Gazzaniga, 1980 for a review). In both instances, callosal section did not include the anterior commissure. Our data describe several characteristics of the control of visual attention in humans that may reflect the functional role of the secondary visual

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system. First, we demonstrate that, whereas callosal section results in independent processing in the separated hemispheres with respect to stimulus identification, callosal surgery does not produce two independent orienting systems. Second, we show that, despite the interhemispheric disconnection of visual cortex, a spatial representation of both visual half-fields is available for visual orienting. Finally, we argue that the control of orienting can be unlinked from associated motor function.

Clinical Evidence for Two Visual Systems

In the late 1960s, several researchers proposed that there are two anatomically and functionally distinguishable subsystems that use visual information for different purposes (Diamond & Hall, 1969; Ingle, 1967; Schneider, 1969; Trevarthen, 1968). Although their empirical findings were limited to infrahuman species, and their positions differed in detail, their observations have been interpreted to support the existence of "two visual systems" in humans. In general, the primary geniculostriate visual pathway is thought to subserve the analysis of visual pattern underlying stimulus identification, whereas the secondary colliculus pulvinar parietal visual pathway is concerned with visual information as it exists for the control of spatial orientation. It was further proposed by Trevarthen (1968) that secondary visual processes, which he characterized as "ambient vision," in large part are not mediated by conscious awareness. He notes, "Vision in the lateral fields remains efficient in low light, is highly sensitive to motion, and produces little impression in consciousness" (p. 302).

Clinical evidence from which the functional role of secondary visual pathways can be inferred dates from patients with isolated missle wounds incurred during World War I. Holmes (1918) described impairments in visual orientation, visual localization of objects, and oculomotor and praxic control arising from focal lesion of the posterior parietal region. In contrast, Riddoch (1917) described patients with focal occipital damage who could consistently report movement within the affected area of the visual field. Riddoch stressed the elusiveness of these perceptions, indicating that patients had great difficulty in describing the nature of the movement they saw, characterizing it as "vague and shadowy." He emphasized that such perceptions of motion arose from stimulation within a field that was entirely blind to stationary objects.

More recent reports of residual visual function following focal occipital damage have emphasized both its role in orienting to visual stimulation and the unconscious nature of this visual process (termed *blind-sight* by Weiskrantz, Warrington, Sanders, & Marshall, 1974). Thus, whereas damage to primary visual cortex results in visual field deficits (e.g., an inability to identify stimuli in the area of the scotoma), the magnitude of voluntary saccadic eye movements to visual stimuli briefly flashed in the affected area increases monotonically with

target eccentricity (Poppel, Held, & Frost, 1973). This result has been confirmed by Weiskrantz *et al.* (1974) and Perenin and Jeannerod (1975). Analogous results have been obtained for pointing movements of the hand by these authors as well as by Williams and Gassel (1962). It should be pointed out, however, that some residual perceptual capacities also have been reported in "blind" visual areas. These include large-scale pattern discriminations, discriminations of stimulus orientation, color discriminations, and figural identification (Richards, 1973; Torjussen, 1978; Weiskrantz *et al.*, 1974). Except under unusual stimulus situations, however, perception is limited to the detection of gross changes in a large portion of the visual field. Therefore, such information may not be of sufficient resolution to account for the accuracy of elicited motor responses into the same areas, especially for pointing movements of the hand.

On the other hand, studies of residual function following focal damage to parietal cortex, and more recently the superior colliculus and pulvinar, reveal intact sensory capacities but a constellation of attentional deficits in response to contralateral stimulation. These include deficiencies in spatial orientation, directed saccadic eye movements, and smooth pursuit eye movements (Cogan, 1965; Hecaen & De Ajuriaguerra, 1954; Heywood and Ratcliff, 1975; Oxbury, Campbell, & Oxbury, 1972; Zihl & Von Cramon, 1979); inaccurate pointing movements of the hand (Teuber, 1963); and a general reluctance to acknowledge stimuli in the impaired field. This latter syndrome, termed *hemiinattention* or *hemineglect* (see Weinstein & Friedland, 1977, for a review) has been characterized by Mountcastle (1978) as a "reluctance or inability to direct visual attention to the contralateral half-field of behavior space, or to make stereotaxic exploration within it" (p. 18).

Relevant observations of neurologically intact subjects have produced somewhat conflicting results. On the one hand, several studies have demonstrated that observers can accurately localize visual targets with a motor response despite gross perceptual mislocalizations. This has been noted for pursuit eye movements by Dichgans, Kerner, and Voigt (1969), Festinger, Sedgwick, and Holtzman (1976), Herman (1972), Mack and Stoper, (1967), and Wyatt and Pola (1979); for saccadic eye movements by Hallit and Lightstone (1976) and Wong (1981); and for ballistic arm movements and manual pointing by Bridgeman, Lewis, Heit, and Nagle (1979) and Hanson and Skavinski (1976). Bridgeman *et al.* speculate as to a possible organization of such performance:

> Two levels of the visual system might process different kinds of information, so that spatially oriented motor activity might have access to accurate position information even when that information is not available at a cognitive level that mediates symbolic decisions such as button presses or vocal responses (p. 693).

In contrast, other findings reveal the importance of perceptual information for the control of pursuit eye movements (Holtzman & Sedgwick, Note 1; Holtzman, Sedgwick, & Festinger, 1978; Steinbach, 1976; Wyatt & Pola, 1979) and saccadic eye movements (Miller, 1980; White & Holtzman, Note 2), even when such information is erroneous. Overall these data seem to imply that, although perceptual information is used for the control of visual–motor behavior, visual and motor information that is not consciously perceived also plays an important role in motor function associated with the control of visual orientation.

Conclusions regarding the functional specialization of two visual systems in humans based on lesion studies are subject to criticisms on both theoretical and methodological grounds. First, although such observations have demonstrated that one visual function can be spared when the other is lost, they do not substantiate the coexistence of two visual systems simultaneously subserving different visual functions in the intact brain. Instead, residual visual function following the critical lesion may reflect compensatory processes rather than basic visual organization. Sprague (1966), for example, has noted in cats that if Areas 17, 18, and 19 are lesioned, there are transient periods of hemianopsia that recover after several days. When the ipsilateral superior colliculus is lesioned as well, hemianopsia is permanent, implying that ancillary visual structures may compensate for cortical blindness. Mohler and Wurtz (1977) have noted comparable findings in monkeys with regard to elicited saccadic eye movements. Analogously, Zihl (1980) has noted that in patients with occipital lesions, repeated saccadic eye movements to targets within a blind hemifield improve in accuracy; and that some patients come to report the ability "to 'feel' the correspondence between target and eye position." Zihl and von Cramon (1982) also report restitution of perceptual function in visual scotomas following practice at detecting lights in these regions.

Such functional reorganization need not take place, however. Meienberg, Zangemeister, Rossenberg, & Hoyt, and Stark (1981), for example, have demonstrated an alternative strategy used by patients with occipital lesions to foveate stimuli appearing within visual scotomas: a large initial saccade that respositions the stimulus in the intact field followed by a smaller saccade that brings the stimulus to fovea. Thus, unless required to do otherwise, these patients tend to rely on perceptual information for the programming of saccadic eye movements.

Second, and most importantly, the assessment of attentional capacities in patients with parietal or occipital damage has focused primarily on overt motor behaviors associated with changes in the locus of attention (e.g., the presence or absence of elicited saccadic eye movements, reaching or pointing movements of the hand) rather than on attentional control per se. Although visually elicited motor behavior depends on an observer's capacity to orient to visual stimulation, the absence of such behavior does not necessarily imply a deficit in the antecedent attentional processes (Robinson, Goldberg, & Stanton, 1978). Furthermore, with regard to oculomotor and praxic localizations of visual stimuli appearing within visual scotomas, it is surprising that pointing responses were more accurate than saccadic eye movements (see Perenin and Jeannerod, 1975; Weiskrantz *et al.*, 1974) because eye movements to briefly flashed targets are normally quite accurate (Miller, 1980). It is unfortunate that eye movements to stimuli appearing in the intact field were not reported because such data would be useful in calibrating the accuracy of their recording technique, particularly because electrooculography was used. This technique is of limited accuracy and is subject to a number of recording artifacts (see Robinson, 1968). It is also significant that, on pointing trials, Perenin and Jeannerod (1975) report that subjects always turned their eyes to the target position each time it had to be localized. Thus, pointing responses may have represented manual alignments with the direction of gaze rather than praxic components of secondary visual processes.

Finally, for methodological reasons, the assertion that a dissociation has been demonstrated between visual information used for the control of visual orienting and that used for stimulus identification is questionable. This is the case for the movement studies described in the preceding in which observers could accurately "guess" the location of a flashed target in a "blind" field with a motor response but, in no instance, were observers also required to localize targets with a forced-choice perceptual "guess." In fact, Barbur, Ruddock, & Waterfield (1980) have shown that patients with visual scotomas are better able to perceptually localize a visual target appearing within a blind area than they are able to report its occurrence. Unfortunately, these authors did not measure eye movements to subthreshold visual targets. Thus, it cannot be concluded that accurate eye movements into blind visual areas necessarily require perceptual information.

Reports by Trevarthen and Sperry (1973) of the cross-integration of "ambient" visual half-fields, but not "focal" half-fields in commissurotomy patients raise similar questions. These authors provide impressive evidence of perceptual access to both visual half-fields in these patients when stimuli appear in the far periphery. They contrast this performance, however, with established findings of a perceptual disconnection of the visual half-fields in and around the fovea rather than recreating their stimulus conditions with focal visual targets. Thus, it cannot be determined whether their findings reflect intact visual processes that are limited to ambient visual space, whether cross-integration occurs for some visual stimuli but not for others, or whether these patients represent instances in which the delayed emergence of a form of perceptual access to both visual half-fields coincided with the testing period (see Gazzaniga, Sidtis, Volpe, Smylie, Holtzman, & Wilson, 1982).

Studies of Spatial Orientation

The data described in the following were collected from two commissurotomy patients in an attempt to examine the relationship between spatial orientation and explicit stimulus identification in more detail. Initially, we assessed performance at perceptual tasks that required the manipulation of the locus of visual attention. We attempted to measure attentional control separately from motor control by using a paradigm that measured the capacity to manipulate spatial attention independent of overt orienting movements. We then contrasted the ability of these patients to orient to visual targets with their ability to explicitly identify the same stimuli. Our results imply that, whereas the control of orienting is relatively unaffected by callosal section, profound limitations in the capacity to identify visual targets are present. Finally, we assessed the extent to which visual information that is available for attentional control also is available for directed motor responses.

Attentional Control and the Commissurotomy Patient

A subset of commissurotomy patients are unable to perform perceptual comparisons of stimuli briefly presented on both sides of the visual midline, such as whether two stimuli are the same or different (see Gazzaniga, 1970; Gazzaniga and LeDoux, 1978). This occurs because direct visual input to each hemisphere is predominantly contralateral; ipsilateral information is provided only indirectly through the interconnections between the hemispheres via the corpus callosum. Therefore, for example, because speech is a left hemisphere function, visual stimuli presented to the right hemisphere via left visual field exposure typically cannot be named by the commissurotomy patient. However, though mute, the right hemisphere can direct the left hand to retrieve the correct stimulus from an array of objects placed in front of the patient.

Such observations raise several possibilities concerning the commitment of attentional resources for a cognitive task. One possibility is that sectioning the callosum provides each hemisphere with its own private resource pool. If so, one might expect that the commissurotomy patient would show enhanced performance at dual tasks, one of which is lateralized to one hemisphere and the other to the other hemisphere. There is some evidence for such enhancement (Gazzaniga and Young, 1967); but in general, performance is rarely superior to that of normal observers (Kreuter, Kinsbourne, & Trevarthen, 1972; Teng & Sperry, 1974), and facilitation effects tend to reflect reduced interference between two tasks rather than an increase in overall information-processing capacity (Ellenberg & Sperry, 1980; Gazzaniga & Hillyard, 1973; Springer & Gazzaniga, 1975). Observations reported by Holtzman and Gazzaniga (1982) suggest that, whereas the separated hemispheres do not share access to a common data base, thus accounting for the absence of perceptual interference between the hemispheres, they do utilize common processing resources, which, under conditions of bilateral stimulation, are distributed between the hemispheres.

Hemispheric disconnection effects also raise questions concerning the control of spatial orientation following commissural section. For example, do the hemispheres have independent orienting systems? How do the hemispheres interact in specifying the locus of attention? Because each hemisphere receives unilateral visual information and is capable of stimulus acquisition, storage, and retrieval as well as of the initiation of directed movement, it might be expected that as a consequence, coordinated behavior outside the laboratory would be severely disrupted. If, for example, a single hemisphere dominated behavior, a state of unilateral neglect would be anticipated. On the other hand, if the hemispheres vied for the control of behavior, instances of response competition would be expected, with the hemispheres attempting to direct the patient toward disparate goals. In fact, instances of both response competition and unilateral neglect occur very infrequently. Instead, commissurotomy patients are able to direct action within the environment with little overt difficulty or hesitation (e.g., walk, run, avoid obstacles, and in one instance operate a motorcycle; see Gazzaniga, 1970).

These observations suggested to us that, although visual information is not transferred between brain areas subserving explicit stimulus identification, the hemispheres use visual information from both hemifields for the control of selective visual attention. Such integration could account for the absence of overt indications of visual neglect and response competition in commissurotomy patients as well as the overall integrity of coordinated visual-motor behavior within the normal environment.

In order to test this hypothesis, we needed a means of manipulating visual attention and measuring its spatial locus. The method we used for these purposes was based on a "facilitation" paradigm originally developed by Posner and his colleagues (see Posner, 1980; Posner, Snyder, & Davidson, 1980). These authors determined that the response latency to a peripheral visual target is reduced when observers have prior information regarding its spatial locus, even when eye movements to the cued location are prohibited. Presumably, the spatial cue allows observers to direct their attention to the appropriate location prior to the onset of the target. In the present context, this paradigm was used to measure the extent to which such attentional cues affected performance under a variety of conditions. We determined that, despite the perceptual segregation of the visual fields for explicit stimulus identification in split-brain patients, the separated hemispheres are not strictly independent in the control of spatial orientation. These patients rely on a common orienting system that serves to maintain a single focus of attention, a system that makes use of visual information from both hemifields.

Commissurotomy Does Not Result in Dual Attentional Systems

In our first experiment, we employed a facilitation paradigm to examine whether the hemispheres can simultaneously orient to different spatial locations

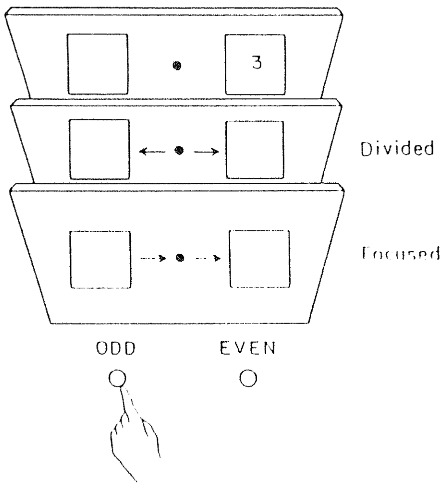

Figure 10.1 Spatial cues for the focused and divided attention trials. On each trial, the spatial cue appeared for 150 msec, followed by a 1.5-second lapse, and then the target appeared again for 150 msec. For description of additional trials, see text.

within the visual environment. Although there are data to indicate that normal observers can distribute attentional resources over a relatively small area (Jonides, 1980; Shaw & Shaw, 1977), for the stimulus conditions used here, it has been determined that normal observers are unable to direct attention simultaneously to disparate points in space (Posner *et al.*, 1980). If, unlike the performance of normal observers, each hemisphere of the commissurotomy patient has its own orienting system, orienting to disparate spatial locations would be possible.

The background visual display for this study, generated by a microprocessor and displayed on a video monitor, is depicted in Figure 10.1. It consisted of two 3° square boxes, presented 7° on either side of a central dot on which the observer fixated at all times. On each trial, a target digit briefly appeared in one of the boxes and the observer indicated with a forced-choice key press whether the digit was even or odd. On each trial one of four spatial cue configurations briefly appeared 1.5 seconds before the onset of the target. On "focused attention" trials (approximately 44% of the total trials), two arrows—one in each field—pointed to the box in which the target would appear; on "divided attention" trials (22%), the arrows pointed in opposite directions; on neutral-cue trials (22%), two noninformative *X*s appeared in place of the arrows; and on invalid cue trials (11%), two arrows pointed to the wrong box.

If the separated hemispheres have completely independent attentional systems, response latencies on focused and divided-attention trials should be similarly

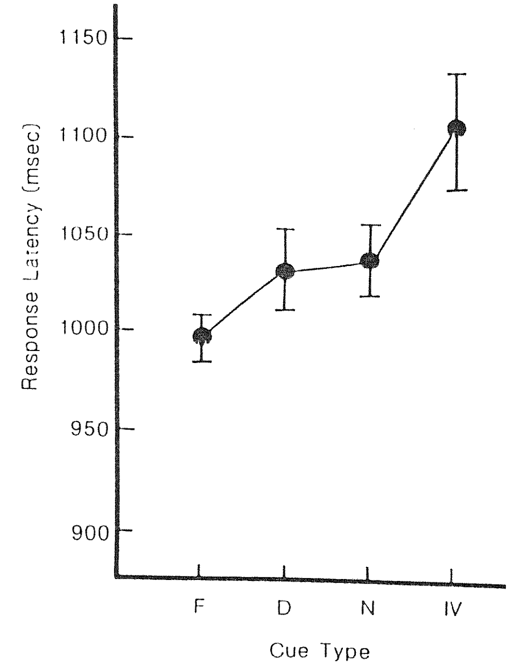

Figure 10.2 Average response latencies (± 1 standard error) for (F) Focused-attention, (D) Divided-attention, (N) Neutral-cue, and (IV) Invalid-cue trials. All data were collected from commissurotomy patient JW.

facilitated. If spatial attention is restricted to one area, then performance on divided-attention trials should more closely resemble performance on neutral-cue trials.

The results of 720 total trials collected from patient JW are summarized in Figure 10.2. Approximately 6% of the trials were rejected from the analysis because of an incorrect response or a response latency in excess of 2.5 seconds. It can be seen that performance on divided-attention trials was most similar to performance on neutral-cue trials. These results imply that commissurotomy does not result in separate orienting systems that can be manipulated independently and concurrently by each hemisphere. Thus, like neurologically intact observers, split-brain patients are unable to prepare for events in two spatially disparate locations; that is, their attention is unifocal. This may be one factor that minimizes the potential for interhemisphere rivalry in these patients.

If attention is unifocal, the question then arises as to how attention is directed when the hemispheres receive conflicting spatial cues (e.g., on divided-attention trials). One possibility is that, on each such trial, a decision is made to orient to either the left or right box. When the target appears in the attended location, response latencies would be similar to those on focused-cue trials; when it appears in the unattended location, latencies would be similar to those on invalid-cue trials. Under such circumstances, the decision regarding where to direct attention would be consistent with the spatial cue from either the left or right visual half-field, with a single hemisphere dominating behavior on each trial.

This interpretation would predict that the sum of these two distributions of latencies would produce a third distribution with a mean intermediate between that for focused- and invalid-cue trials, and the data appearing in Figure 10.2 show just this. It would also predict that the variability of the latency distribution for divided-attention trials would exceed that for both focused and invalid-cue trials. This was not the case: the variability of the response latencies on divided-attention trials (*s.d.* = 253 msec) was *less* than that for both focused- and invalid-cue trials (*s.d.* = 271 msec and 310 msec, respectively). Thus, in both instances, this difference is opposite to the increase in variability that would occur if divided-attention trials were comprised of a combination of focused- and invalid-cue trials. On the other hand, the variability on divided-attention and neutral-cue trials was quite similar (*s.d.* = 253 msec and 248 msec, respectively). Thus, it appears that, on the whole, divided-attention and neutral-cue trials were regarded by JW as equally uninformative.

One possible explanation for these data is that visual information from both hemifields was used to direct the locus of attention. On divided-attention trials, when *conflicting* and therefore uninformative spatial cues were presented to the two hemifields, JW adopted an allocation strategy identical to that used on neutral-cue trials in which *consistent* and uninformative spatial cues were presented. This interpretation would predict that because bilateral visual information is available for attentional control, the hemifield in which the spatial cue appears would not differentially effect response latencies. Our next experiment verified this prediction.

Attention Can Be Directed Across the Visual Midline

This experiment examined whether the hemispheres cooperate in the manipulation of the locus of attention. Specifically, we asked whether a spatial cue presented to one hemisphere can be used to direct attention into the sensory field corresponding to the other hemisphere, that is, across the visual midline. The background visual display and temporal parameters for this study were identical to those described in the preceding. As in the prior experiment, central fixation was maintained throughout each trial, a target digit appeared in one of the boxes, and an odd–even discrimination was required. As can be seen in Figure 10.3, however, a different set of cue configurations was used. On directionally cued trials, a single arrow appeared either in the left or right visual field. Valid within-field and between-field cue trials (approximately 66% of the total trials) were those in which the cue and target appeared in the same visual field or different fields, respectively; on neutral-cue trials (17%), the cue consisted of two *X*s; and invalid-cue trials (17%) were those in which the target appeared in the uncued location. Thus, between-field trials required the observer to orient to a spatial location that presumably lacked sensory representation in the visual cortex of the cued hemisphere.

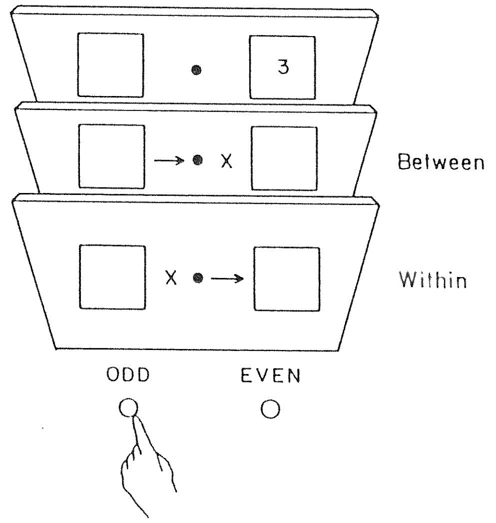

Figure 10.3 Valid spatial cues for within-field and between-field trials. For description of additional trials, see text.

The average of 352 total trials collected from patients JW and PS are summarized in Figure 10.4. Approximately 10% of the trials were rejected from the analysis because of an incorrect response or a response latency in excess of 2.5 seconds for JW or 2.0 seconds for PS. The similarity of performance on within-field and between-field trials indicates that either hemisphere can direct attention into either visual half-field. Despite this, the performance of both patients did not exceed chance when they were required to indicate whether two arrows, one in each visual field, pointed in the same or different directions.

Thus, information about a stimulus presented to one hemisphere, in this case the spatial location of an impending target, facilitates processing of that stimulus by the other hemisphere. Because in this study the target could only appear in one location in each field, however, we could not conclude that our findings reflected a shift in attention across the midline to a specific location. Similar results also would be expected if the primed hemisphere were globally activated and, thus, more sensitive to any stimulus appearing in its sensory field.

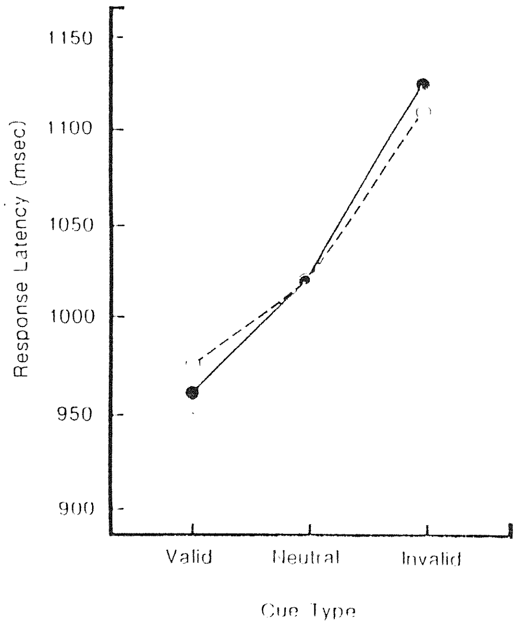

Figure 10.4 Average response latencies for within field (solid line) and between-field (dashed line) trials for each spatial cue type. Data from commissurotomy patients JW and PS are averaged, with each given equal weight.

Interfield Performance Is Specific to the Cued Location

In order to determine whether attentional priming was specific to the cued location, we increased the number of cells in each field. In this study (see Holtzman, Sidtis, Volpe, Wilson & Gazzaniga, 1981, for a detailed description), the background display consisted of a 3 × 3 cell grid presented on each side of a central fixation stimulus (see Figure 10.5). As in the prior studies, on each trial the observer indicated with a manual response whether a digit appearing in one of the cells was odd or even. On within-field trials, the digit was always preceded by a spatial cue that appeared either in the cell in which the target appeared (valid cue); in a different cell in the same grid (invalid cue); or superimposed on the central fixation stimulus (neutral cue). In order to examine interfield performance, we modified our procedure: Rather than specifying the actual location of the target, the valid cue appeared, instead, in the homologous cell in the opposite grid. Analogously, the invalid cue appeared in a different relative position in the opposite grid. Thus for these between-field trials, the efficacy of the cue required visual information concerning specific spatial locations in both visual hemifields.

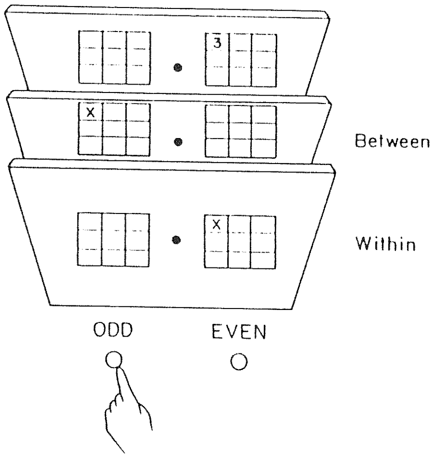

Figure 10.5 Example of valid-cue trial in within-field and between-field trials. For description of additional trials, see text.

The average of 544 trials collected from JW and PS are summarized in Figure 10.6. Approximately 11% of the trials were rejected from the analysis because of an incorrect response or a latency in excess of 2.5 seconds for JW or 2.0 seconds for PS. It can be seen that, on the average, response latencies were shortest when the observer knew where the target would appear (valid-cue trials), and longest when they expected it elsewhere (invalid-cue trials). This occurred on within-field trials in which the target and cue appeared in the same visual half-field and, thus, the efficacy of the spatial cue did not require perceptual access to both visual half-fields. However, similar results were also obtained for between-field trials, indicating that the spatial cue was effective even when the target subsequently appeared in the opposite hemifield.

Of particular interest is the detrimental effect on response latency of the invalid cue on between-field trials, which implies that when attention is directed across the midline, it is specific to the target's location and not simply directed in general to the contralateral visual half-field. If attention were directed diffusely, that is, if the opposite hemisphere were simply globally activated, then response latencies on valid-cue trials would not differ from those on invalid-cue trials. Our results are quite to the contrary: Performance on these two types of trials shows contrasting effects relative to the neutral cue trials. Thus, interhemispheric priming cannot be explained simply in terms of global activation, but must reflect a shift in attention across the midline to a specific spatial location.

The ability of commissurotomy patients to integrate the visual half-fields for the control of attention in this task was in dramatic contrast to their inability to perform explicit interfield visual comparisons. This was made clear when the

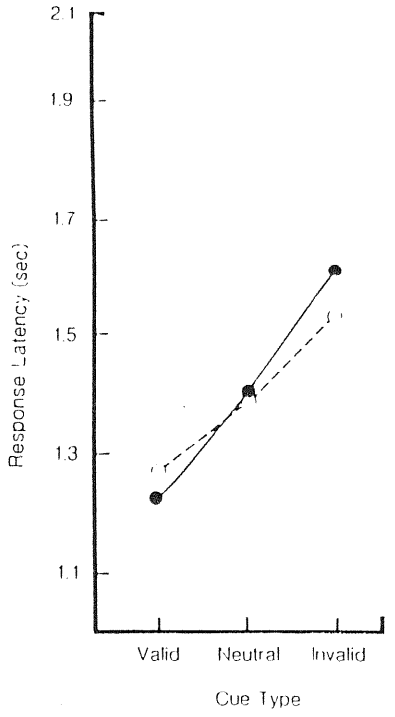

Figure 10.6 Average response latencies for within-field (solid line) and between-field (dashed line) trials for each spatial cue type. Data from commissurotomy patients PS and JW are averaged, with each given equal weight.

same stimuli were used in a task that required an explicit comparison of two spatial positions. In essence, we asked observers to compare the spatial location of the target and cue by responding "same," with the appropriate key press, if the target and cue fell in the same or homologous cells, and by responding "different" in all other conditions. On the whole, observers were accurate in their judgments under within-field conditions in which the target and cue fell in the same visual half-field (88% correct) but inaccurate under between-field conditions in which a comparison across the visual midline was required (60% correct). A further analysis of the error data revealed that observers were not utilizing a crude form of spatial information from both fields that may have facilitated performance in the priming task but that was not sufficiently precise for accurate interfield comparisons. Thus, bilateral visual information that was available for attentional control proved to be unavailable for explicit stimulus localization.

TABLE 10.1

Percentage of Correct Localizations of a Visual Target with a Pointing Response by Commissurotomy Patients

Target location	Percentage correct	
	No eye movements	Eye movements
Within field	80	100
Between field	44	80

Attentional Control and Motor Control

Subsequently, we asked whether bilateral visual information is also available for motor responses to visual targets. Our pilot data regarding this question reveal that commissurotomy patients may have access to such information for oculomotor control, but that deficits in performance arise when visual information from the two fields must be integrated for the control of limb praxis.

In order to facilitate comparison between these observations and our priming studies, our experimental paradigm used in this context was very similar to that described in the preceding. The same two grids appeared on either side of a fixation stimulus; and, on each trial, an *X* appeared in one of the cells. The observer was required either to point to the cell in which the target appeared (within-field trials) or to point to the homologous cell in the opposite grid (between-field trials). For the first set of trials, the observer was required to maintain central fixation throughout each trial; on the second set, eye movements were allowed.

The percentage of trials in which the cued cell was accurately localized appear in Table 10.1, averaged for our two observers and collapsed across hand and visual half-field. Each value is based on approximately 20 trials for each observer.

It can be seen that these patients accurately localized the cued cell under conditions in which the target and cue fell in the same visual half-field and under conditions in which they fell in opposite fields and eye movements were allowed. They performed poorly, however, on those between-field trials in which central fixation was required. Although performance on these trials exceeded chance, these findings seem to imply that, at best, commissurotomy patients have only limited access to bilateral visual information for praxic control. Nevertheless, these results are in dramatic contrast to the availability of such information for the orienting of attention. The interesting question regarding these data is whether, when eye movements are allowed on between-field trials, the initial saccadic eye movement is accurate to the homologous cell in the opposite grid. If it is, this would imply that bilateral visual information for motor control under such circumstances is specific to the oculomotor system. This question is currently under investigation in our laboratory.

Finally, we ran an additional study in which the observers directed their manual responses within a metal reproduction of two lateralized 5 × 5 grids that appeared on the display screen. This 15- × 15-cm metal frame was placed in front of the subject and was thoroughly explored tactually and visually prior to testing. The patient was instructed to move his or her index finger to the location in the metal grid that corresponded to the location of the *X* that appeared on the screen. On each trial, the patient fixated the central dot and *X* flashed randomly in any one of 48 positions (24 possible locations in each grid on the display screen). The subjects began each trial with the index finger of either hand within the center cell of the metal grid. The grid and the tested hand were kept out of view, and the patient's forearm was fastened to the table to prevent proximal movement. Because control of the distal musculature involved in this task is strictly lateralized to the hemisphere contralateral to the responding hand (see Volpe, Sidtis, Holtzman, Wilson, & Gazzaniga, 1982), this procedure allowed us to assess the performance of each hemisphere when the target stimulus was presented to the ipsilateral or contralateral visual field.

A total of 124 trials were collected. Both observers showed significant impairments in performance in the ipsilateral condition: When the visual target appeared in the hemifield contralateral to the responding hand, PS and JW were accurate in their responses on 73% of the trials; when it appeared in the ipsilateral field, their performance fell to 25%. Analogous to the previous study, these results indicate that the hemispheres are severely impaired at directing a manual response based on visual information presented to the ipsilateral visual half-field.

Conclusions

In conclusion, our findings provide evidence that different kinds of visual information are used for attentional control and stimulus identification. When the connections between the hemispheres are severed, significant impairments in the perceptual integration of the visual hemifields results. Most likely, such integration depends on visual cortex because it is typically disrupted when callosal section or damage disconnects visual cortex (Gazzaniga & Freedman, 1973; Levine & Calvanio, 1980; Maspes, 1948; Siditis, Volpe, Holtzman, Wilson, & Gazzaniga, 1981; Sugishita, Iwata, Toyokura, Yoshioka, & Yamada, 1978) but not when the lesion is restricted to the anterior callosum, in which case occipital interconnections are spared (Gazzaniga, Risse, Springer, Clark, & Wilson, 1975; Geschwind & Kaplan, 1962; Gordon, Bogen, & Sperry, 1971; Sweet, 1941). Likewise, it would seem that manual responses to visual targets depend on visual cortex as well, because our findings indicate that such performance is also disrupted by callosal section. It remains to be determined whether, as in the case of patients with visual scotomas due to occipital lesions, interfield manual localization in commissurotomy patients would improve with prolonged practice.

In contrast, callosal section appears to have only minimal consequences on the control of selective attention. If, as the clinical data would suggest, the control of visual attention depends on parietal cortex, our data imply that a bilateral representation of the visual world within parietal cortex is preserved following cerebral disconnection. It is tempting to speculate that such information is provided directly through secondary visual pathways via the superior colliculus and pulvinar. Other explanations remain to be considered, however, including the potential for interhemispheric transfer via the anterior commissure, interactions between the occipital cortices via subcortical pathways, and the possible role of spatial memory in the control of orienting.

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11

Selective- and Sustained-Attention Tasks: Individual and Group Differences

D. R. Davies, D. M. Jones, and Ann Taylor

Introduction

Since the resurgence of interest in the topic of attention, which began in the late 1940s, several different paradigms utilizing a variety of psychological and physiological measures have been employed in the investigation of attentional processes. Researchers concerned with selective and sustained attention have tended to draw on a small range of task categories, somewhat wider in the case of selective attention than in that of sustained attention, and the performance of tasks within this range has been regarded as an index of the ability of subjects to focus, divide, or maintain their attention.

Individual differences in the performance of selective- and sustained-attention tasks are considerable; and, as Hoyer and Plude (1980) have observed, current information-processing models "leave room for differential psychologists to fill in the data on interindividual differences and intraindividual change" (p. 235). Whether or not the abilities involved in selecting relevant from irrelevant information and in maintaining attention over long periods of time are related to other abilities, such as general intelligence, or to characteristics such as sex, personality, and age is of practical interest to psychologists concerned with the development of selection and training procedures; and various measures of the ability to attend selectively have been employed with some success in predictive studies of driver and pilot performance (Gopher & Kahneman, 1971; Kahneman, Ben-Ishai, & Lotan, 1973; Mihal & Barrett, 1976). More fundamentally, individual differences in performance may be used as a "crucible" in nomothetic theory construction (Underwood, 1975); although, until fairly recently, theory construction in the areas of selective and sustained attention has taken little account of individual differences, perhaps because (for selective-attention tasks at least) there is a paucity of basic data concerning the range of individual variation in performance, the reliabilities of the tasks themselves, and the extent to which performance scores in different tasks intercorrelate. There are, however, some indications that individual differences in the performance of tasks involving