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Margaret Jean Durnford

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VISUAL FIELD DIFFERENCES IN VISUAL-SPATIAL PERCEPTION

by

Margaret Jean Durnford

Department of Psychology

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ABSTRACT

Under conditions of successive, tachistoscopic presentations to the left and right visual fields, normal adults perceive certain visual-spatial stimuli more accurately in the left visual field. Such superior perception in the left visual field is assumed to reflect right hemisphere lateralization of spatial abilities. Perception found to be more accurate in the left visual field involved perception of orientation and perception of depth, but not perception of pattern.

Thus, the slope of short slanted lines was more accurately judged in the left visual field than in the right. It was assumed that perception of such stimuli was dependent upon a right hemisphere system involved in processing the orientational content of visual input. Orientation defined by the upright or inverted position of line drawings of familiar objects did not differentially engage left or right hemisphere systems, nor did perception of long slanted lines when the subject's judgment of slope was a motor response involving adjustment of a moveable line.

It was suggested that tasks which involved perception of pattern (familiar objects, patterned matrices, pairs of lines), did not produce perceptual asymmetries. Since it is known that perception of patterned stimuli is asymmetrically represented at the level of the temporal lobes, it was concluded, in agreement with Kimura (in press) that the tachistoscopic procedure, as used here, seems to sample only the visual functions of regions close to the primary receiving area.

Perception in the left visual field was also found to be superior on a three-dimensional depth task when viewed binocularly but not when viewed monocularly, indicating that the binocular depth cues provided the information producing the asymmetry. A subsequent stereoscopic task examining binocular disparity showed that fusion of left- and right-eye images at a central level was again superior when the two images were presented to the left visual field. It was concluded that the disparate input from the two eyes was one source of input more efficiently utilized in depth perception by the right hemisphere than by the left.

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INTRODUCTION

This thesis examines some visual abilities in man with special emphasis on aspects of spatial perception such as perception of orientation of a line and perception of depth. Much of the relevant information concerning neural representation of these abilities is based on clinical observations of performance deficits associated with cerebral damage. It is assumed that perceptual deficits which consistently accompany damage to a given brain area provide information about the function served by the damaged region. The examination begins, therefore, with a review of the clinical evidence of perceptual deficits suffered by patients with localized brain lesions. Following the survey of clinical evidence, contributions provided by the study of perception in normal subjects are examined.

Perceptual Disabilities Related to Cortical Lesions

Different parts of the brain appear to subserve somewhat different functions. Thus, abnormalities of space perception differ as a function of the site of the lesion. This difference has been demonstrated by Teuber and Mishkin (1954). They reported that patients with lesions located in the anterior region of the brain made larger errors than patients with lesions in the posterior region of the brain on a task involving the integration of visual and postural cues. This task required the patient to set a luminous line to the vertical position while the body was tilted. In a visual-visual form of this task, the line appeared against an obliquely striped background and the patient once again was required to set the line to vertical. While the anterior group made larger errors on the visual-postural form of the task, the posterior group made larger errors (not statistically significant) on the visual-visual form of the task. The reversal in pattern of errors for the two groups due to the change in the nature of the task shows that the parietal and frontal regions of the brain function differently in spatial abilities.

Other spatial disturbances following parietal and frontal lesions support the suggestion by Teuber and Mishkin (1954) that frontal and parietal regions have different roles in spatial ability. Early reports of disturbances in spatial perception following bilateral lesions of the parietal lobes are referred to by Paterson and Zangwill (1944) and Piercy (1964). Among the disorders noted was visual disorientation, a form of defective localization of objects in space described by Holmes (1918). Also noted as symptoms of parietal lobe disfunction were difficulties in route finding, apraxia for dressing, and disabilities of construction, manipulation, and drawing. In a few cases, such as one reported by Riddoch (1917), depth perception was lost. As Riddoch described it, the patient was completely incapable of appreciating depth or thickness, and all objects appeared bidimensional. A sphere, for example, appeared as a circle, a chair appeared flat, and a person appeared as a flat cardboard figure.

Following frontal lesions or caudate nucleus lesions, on the other hand, the spatial deficits are of a different nature. Caudate nucleus lesions are included here because of the close anatomical relationship of this structure to the frontal cortex (Rosvold and Szwarcbart, 1964). Cats, rats, and monkeys with damage to the frontal area or the caudate nucleus show impaired performance on tasks possessing spatial aspects such as spatial alternation (Mishkin, Vest, Waxler, and Rosvold, 1969), egocentric orientation (Potegal, 1969), and adaptation to prisms (Bossom, 1965, 1968). Examination of the process underlying adaptation to prisms provides an example of frontal lobe contributions to spatial perception. Held and Bossom (1961) and Held and Rekosh (1963) have shown that visual feedback accompanying self-produced movement (i.e., moving the limb and seeing it move) is necessary if adaptation to prisms is to occur in man. Since frontal (and caudate nucleus) lesions effectively retard the recovery of accurate reaching in prism-wearing monkeys (Bossom, 1965), it is concluded that the frontal area is involved in processing the information necessary for prism adaptation and that this information is derived from visual cues produced during voluntary movement (Bossom, 1968).

It can be seen, therefore, that there is a motor element involved in the spatial deficits associated with frontal lesions. An analysis of the process underlying frontal lobe symptoms in man led Teuber (1964) to suggest that frontal structures and some of the basal ganglia are involved in sensorimotor coordination associated with voluntary movement. Sensorimotor coordination refers to the corollary discharge, which presets central receptor structures for predictable changes in input that will result from voluntary movement, and which occurs simultaneously with impulses to the effectors.

Thus, it can be seen that different neural structures are involved in different aspects of spatial perception. The parietal lobe contributions to spatial abilities are probably more purely perceptual in nature. They seem to involve perception of relative external position in both two- and three-dimensional space. The frontal lobe contributions, on the other hand, involve a motor element and also involve egocentric orientation (i.e., body position). Since the perceptual aspect is of major importance in this thesis, functions of the parietal lobe will be further examined. The available evidence indicates that, in addition to differences between frontal and parietal areas, the left and right parietal areas in man function asymmetrically in visual-spatial perception.

Functional Hemispheric Differences

For language abilities, asymmetry in function between the left and right hemispheres has long been recognized. Investigators in the eighteen hundreds such as Broca, Dax, Jackson, and Wernicke (see Geschwind, 1963) pointed out the critical involvement of the left hemisphere in aphasic disorders. Numerous investigators have since substantiated and expanded the idea that the left hemisphere plays a major role in all forms of language and ideational behavior (see Millikan and Darley, 1967) while the right hemisphere plays only a minor role in these functions (Sperry, 1968).

Mention of the right hemisphere's involvement in visual-spatial abilities also appeared in the literature at a very early date. Piercy (1964) provides a review of some of the early clinical references to right hemisphere involvement in perceptual abilities. As early as 1874, Hughlings Jackson presented a paper on the duality of the brain. Jackson used the term "imperception" to refer to the defects in visual recognition and visual memory accompanying right posterior damage. Following Jackson's observations, periodic references to the right hemisphere's involvement in spatial perception continued to appear in the literature as Piercy's review indicates. Notable among these were the reports of Hebb (1939) and Brain (1941). Benton (1970) points out that the early observations were scattered in time and often not published in widely circulated journals. As a result, they failed to exert their full impact and the right hemisphere continued to be popularly thought of as minor and subservient to the left. It is now becoming clear, however, that the right hemisphere is also specialized and plays a more critical role than the left in certain abilities. In addition, the evidence indicates that a difference exists within the right hemisphere between the contributions of the parietal and temporal regions to the perception of visual stimuli.

Paterson and Zangwill (1944) present detailed observations of visual-spatial disorders following brain injury to the parieto-occipital area of the right cerebral hemisphere. In the first case reported, they noted impaired localization of objects in space and errors in estimating the distance of test objects. They also reported distorted reproduction of irregular groups of dots presented tachistoscopically which, once again, could be interpreted to reflect problems with spatial position. The patient showed no problems perceiving pictures or interpreting pictorial material but in his drawing the patient showed abnormal representation of perspective and depth, confusion of planes, errors in relative size, etc. Impairment in block design, stick design, and assembly tests were also reported.

This brief summary of the observations by Paterson and Zangwill (1944) represents only a sampling of the relevant detail provided by their report. In its entirety, the report produced compelling evidence for a reliance of visual-spatial organization on the parieto-occipital area of the right hemisphere. Additional evidence is recorded by McFie, Piercy, and Zangwill (1950). Once again, orientational problems were noted. Topographical disorientation, including inability to sketch maps of familiar areas or find one's way around in familiar surroundings, was common in cases of right parietal or occipital damage. Visual disorientation in the form of inability to set a rod to vertical or horizontal was also noted in some cases.

Hécaen, Penfield, Bertrand and Malmo (1956) have made similar observations of spatial disturbances in patients with right hemisphere lesions. They noted difficulties in spatial orientation, alteration of the visual coordinates, and loss of topographical memory. In addition, they noted that the parieto-temporal-occipital region was involved in the cases they studied and the areas common to all excisions included the supramarginal gyrus, part of the angular gyrus, and the posterior part of the first temporal convolution. The parietal region has again been implicated in a recent report by Butters and Barton (1970). Severe parietal lobe damage produced behavioral deficits on tasks requiring horizontal or vertical rotations of familiar objects or unfamiliar patterns. The right parietal group was impaired relative to the left parietal group only on the familiar objects task which required the patients to choose a photograph of a village scene which matched a three-dimensional model of the village viewed from a position at which the patient was not seated. Butters and Barton (1970) conclude that reversible operations in space (imaginal rotations, changing perspective) are more dependent upon the right hemisphere than the left.

The evidence cited above supports the suggestion by McFie et al. (1950) that a division of labor exists between the left and right hemispheres and that the right hemisphere plays a special role in visual-spatial perception. Their observation, however, did not include a control group of patients with damage to similar areas in the left hemisphere, thus preventing a conclusive statement on this issue. In addition, reports existed in the literature (see Piercy, 1964) attributing similar disabilities to bilateral and left posterior lesions of the parietal areas. McFie and Zangwill (1960) resolved this issue by studying patients with left-sided lesions of the posterior parietal region. They found that spatial disabilities shown by the left-sided cases were clearly distinguishable from those reported for the right-sided cases. In their words:

> ...the outstanding difference between the groups with left and right-sided lesions is in the associated manifestations of conceptual spatial impairment....Failure on tests requiring a relatively small amount of manipulation, in contrast to considerable understanding of spatial properties, was almost invariable in the right-sided series, but rarely encountered in the left-sided group.
>
> (McFie and Zangwill, 1960, p. 256)

Warrington, James, and Kinsbourne (1966) confirm this distinction between disabilities associated with left- and right-sided lesions.

They found that patients with right-sided lesions made errors incorporating spatial information into their drawings. This was evidenced by errors of proportion and articulation of parts of the drawing. Patients with left-sided lesions had difficulty planning the drawing process and tended to produce a simplified version of the model.

An extremely convincing body of evidence supporting hemispheric specialization has been provided by investigating performance of patients with commissural sections. Commissural section refers to complete division of the commissures connecting the two cerebral hemispheres including the corpus callosum, the anterior and hippocampal commissures, and in some cases the massa intermedia (Bogen and Vogel, 1962). Originally, the technique was used with experimental animals to investigate the function of the corpus callosum (Sperry, 1964) but in man it is performed to contain epileptic convulsions (Bogen and Vogel, 1962). The finding of these investigations relevant to the present discussion concerns the visual perception of human subjects who have had hemispheric disconnections. This technique permits functions to be localized according to side but not according to anterior or posterior location.

In visual perception, it is known that the right visual field, that is the portion of the visual field to the right of fixation, is represented in the left visual receiving area of the brain. Conversely, the left visual field is represented in the right visual receiving area. Figure 1 shows a simplified diagram of the optic pathways and the contralateral representation of half the visual field in each visual receiving cortex (Gatz, 1966). When the left and right hemispheres

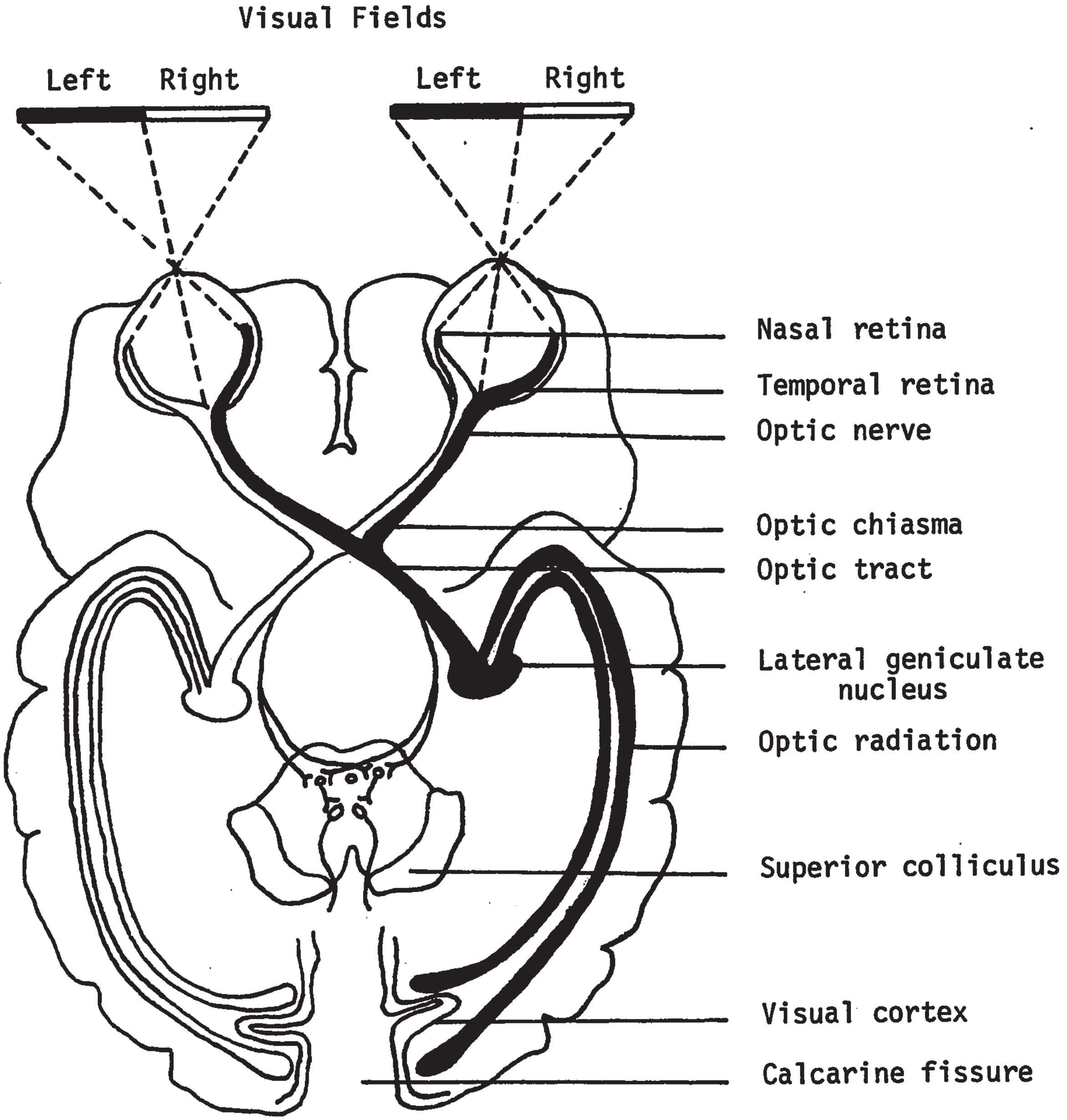


Figure 1: The optic pathways and the representation of the left and right visual fields in the contralateral visual cortex (modified from Gatz, 1966, p. 85)

are surgically disconnected, input arriving at one hemisphere is not transmitted to the other side as in the case of the normal brain with intact corpus callosum. If the eyes are centrally fixated and no head movements are permitted, information about what appears in the right visual field is only available to the left cerebral hemisphere and the right has no direct knowledge of it.

Words presented to the right visual field (Sperry, 1968) were easily named because they had access to the left (language) hemisphere. Words presented to the left visual field, however, elicited no identifying response. An object name in the left visual field could not be reported but the subject could search out the object from a group of objects using his left hand (the hand under control of the right hemisphere which had "seen" the word). Thus, the right hemisphere comprehended the written word but could not express it. Nevertheless, it should be pointed out that the left hemisphere was much better even on this form of the task.

Of major importance to the present argument was the finding that the right hemisphere (indicated by the left hand's performance) was superior to the left hemisphere (indicated by the right hand's performance) on tasks such as drawing spatial relations and block design (Bogen and Gazzaniga, 1965) supporting earlier conclusions that the right hemisphere is dominant for visual-spatial functions of this nature. Thus, the two cerebral hemispheres function asymmetrically in spatial perception and the right hemisphere plays a more significant role than the left. Emphasis, here, has been on visual perception but it should also be mentioned that the spatial system of the right hemisphere applies to tactual as well as visual perception (De Renzi and Scotti, 1969; Milner, 1965).

It was suggested earlier that the contributions of the right temporal lobe were thought to differ from those of the parietal or occipital lobes. Tasks such as recognition of faces (Milner, 1968; Warrington and James, 1967b), and recognition of nonsense patterns (Kimura, 1963) show greater deficits following right as compared to left temporal lobe damage. Thus, temporal areas, as well as parieto-occipital areas show the asymmetry of function between the left and right hemispheres for certain aspects of visual perception. For temporal areas, it appears that the tasks, successful in showing asymmetry of function generally involve pattern perception and memory.

For parieto-occipital areas, it would appear that one critical aspect of the visual input is its orientational content. In every study of posterior damage to the right hemisphere, some form of disorientation in external space was noted. These included distortion of the visual coordinates (Hécaen et al., 1956; McFie et al., 1950), errors in localizing objects in space, over- and under-estimation of distance, (Paterson and Zangwill, 1944) and problems imagining spatial arrangements from another perspective (Butters and Barton, 1970). All of these reports suggest that information on spatial position is processed more efficiently by the right hemisphere.

The fact that errors have been reported in the estimation of distance suggests that the right hemisphere mechanism for spatial position pertains to the third dimension as well. Riddoch (1917), it will be recalled, reported a clear case of loss of three-dimensional vision and Paterson and Zangwill (1944) have referred to similar evidence, but bilateral damage made it impossible to localize this function according to side. The case reported by Riddoch had damage caused by a bullet which entered the left frontal area and came to rest just inside the skull near the right occipital pole. Definite evidence has recently been provided by Carmon and Bechtoldt (1969) that the right hemisphere is dominant for stereoscopic vision. They found that patients with right-hemisphere lesions made more errors and had longer latencies on a stereoscopic depth perception task than the left hemisphere group. It appears, therefore, that the right hemisphere's specialized organization of spatial orientation and position will also include position in the third dimension.

It is clear that a better knowledge of hemispheric specialization would be a basic step towards understanding neurological and psychological organization of perceptual input. The clinical approach has provided much of the available knowledge in this area but the problems associated with this approach are well recognized. Vascular disorders, missile wounds, neoplasms, etc. can produce changes in tissue or function at sites remote from the focus of the apparent pathology. Fortunately, several techniques are available which permit examination of hemispheric specialization in normal subjects. One approach which has not yet been deeply explored involves the study of evoked potentials. Beck (1970) has recently reported that visual evoked potentials recorded from the central scalp area are greater in amplitude and stability from the right hemisphere than from the left. This was the case for normal adults and for bright children but not for dull or mongoloid children. At present, the meaning of amplitude differences in evoked potentials is not clear as Beck (1970) himself admits. He does suggest, however, that less efficient brains do not show hemispheric asymmetry as evidenced by his recordings from dull and mongoloid children.

Perceptual Asymmetries

A more firmly established technique for examining hemispheric asymmetry in normal adults has been provided by the investigators of lateral perceptual asymmetries. It was pointed out in the review of hemispheric disconnection studies that the right and left visual fields are separately represented in the contralateral visual receiving areas of the brain. Also reviewed was the evidence that the two cerebral hemispheres in man are known to be differentially specialized in function. Under certain conditions, this asymmetry in function can be detected in normal adults. Language processing, it will be recalled, is clearly a left hemisphere function (Millikan and Darley, 1967) and this left hemisphere specialization is reflected in perceptual performance. When language material is presented tachistoscopically in either the left or right visual field, recognition is more accurate in the right visual field (Heron, 1957; Mishkin and Forgays, 1952; Terrace, 1959). It should be noted that these investigators did not infer hemispheric asymmetry from lateral perceptual asymmetry as suggested here. The earlier explanations of this phenomenon are discussed below but later research has shown that a cerebral dominance interpretation (Kimura, 1961) is necessary to account for much of the data on lateral asymmetries observed in visual perception. It is assumed that letters or words presented tachistoscopically to the right visual field transmit information to the left visual receiving area and thus have readier access to the language hemisphere than does similar information arriving at the right visual receiving area. The validity of this interpretation will become evident as the literature on this topic is reviewed.

Most of the studies to be discussed in relation to visual field differences involve one of two tachistoscopic procedures of presentation. The tachistoscope is particularly useful in these investigations because it allows central fixation, restricts head movements, and thus makes it possible to know that stimuli in a given location on the screen actually appear in a specific portion of the subject's visual field.

A right-field superiority for the perception of words and letters is only obtained using the procedure of random successive presentations. This means the stimulus appears randomly either to the left or to the right of centre on any one trial. An alternative procedure involves simultaneous presentations in which case the stimulus material appears in both the left and right visual fields on the same trial. It has been consistently reported (Bryden and Rainey, 1963; Glanville and Dallenbach, 1929; Harcum, 1964; Heron, 1957; Kimura, 1959) that a left-field superiority for the recognition of words and letters is found using the simultaneous procedure.

Initially, visual field differences were explained in terms of acquired reading habits. Mishkin and Forgays (1952) suggested that successively presented words and letters were more easily recognized in the right visual field because of selective retinal training produced during reading experience. They concluded that reading selectively trains regions of the left hemiretina because the eyes, while fixating the word being read, always see the next word to be read to the right. They thus suggested a more efficient neural organization in the left cerebral hemisphere for English words, based on reading experience.

Heron (1957) pointed out that Mishkin and Forgay's hypothesis would not adequately explain the fact that left-field superiority occurred when the words or letters were exposed simultaneously to both fields. To deal with this problem, he offered an explanation in terms of post-exposure attentional processes which corresponded to the two main types of eye movements that occur while reading English--a dominant movement to the extreme left of the printed line and then shorter movements to the right. On successive presentations, when material is to the left of fixation, these two types of movements are in opposition but when material is to the right, the two tendencies operate in the same direction, thus producing a right-field superiority. Scanning, of course, was of the stimulus trace rather than of the actual stimulus because of the brief exposure time.

This explanation adequately accounted for right-field superiority under successive conditions (material in either the left or right visual field) and left-field superiority for simultaneous conditions. In the latter case, the dominant movement to the left of the stimulus array would predict superior recognition of the stimuli in the left field. In addition, this interpretation applied successfully to a report by Anderson (1946, cited in Heron, 1957) that under conditions of _simultaneous presentations_ bilingual subjects recognized more English letters to the left of fixation and more Hebrew letters to the right of fixation. Hebrew, of course, requires right-to-left scanning.

Subsequent comparisons of English and Hebrew (or Yiddish) with <u>successive presentations</u> in the left and right visual fields cast doubt on the suggestion that experience with reading produces a left-field superiority under conditions of successive presentations. Mishkin and Forgays (1952) reported that bilingual subjects recognized more English words to the right of fixation but showed no significant field differences for Hebrew words. Orbach (1952) made a similar report of right-field superiority for English and no difference for Jewish words. Only when he selected those subjects who had learned "Jewish" as their first language did he find left-field superiority for Jewish words. These same subjects recognized more English words in the right field.

A problem common to these early studies since they were not concerned with the role of cerebral dominance was the fact that they did not report handedness information as an indicator of cerebral dominance for speech. It is known that a left-handed group has a higher incidence of right hemisphere or bilateral speech representation than does a right-handed group (Milner, Branch, and Rasmussen, 1964). Assuming that right-field superiority for the recognition of words reflects left hemisphere dominance for processing language input, no clear left or right visual field superiority could be predicted for a left-handed group which would include instances of left, right or bilateral speech representation.

It is quite probable that Orbach's (1952) group included left-handed subjects. The fact that he later re-examined the issue (Orbach, 1967), taking care to examine the performance of left- and right-handed subjects, suggests that he became aware of this problem in his earlier data. In this later study, the performance of the left-handed group is, in fact, similar to the performance of the group who had learned Jewish first in his earlier report. Barton, Goodglass and Shai (1965) had suggested that the directional scanning requirements of Hebrew were not the determinants of visual field differences. They presented vertically arranged Hebrew words in an attempt to remove the right-to-left directional aspects from the stimuli and found right-field superiority under these conditions. Other investigators (Bryden, 1970; Goodglass and Barton, 1963) agree that vertical displays of letters, which minimize the conflict in scanning tendencies suggested by Heron (1957) still produce a right-field superiority for letter or word recognition. Bryden (1970) noted a more pronounced right-field superiority for horizontal than for vertical arrays and concluded that scanning effects could accentuate right-field superiority but could not solely account for it.

Orbach's (1967) findings also made it clear that a cerebral dominance interpretation of visual field differences was necessary to account for the data. Right-handers showed a right-field superiority for both Hebrew and English words. Left-handers showed a less pronounced right-field superiority for the recognition of English words than did right-handers and they also showed left-field superiority for the recognition of Hebrew. Performance by the left-handers in both languages indicates that directional aspects of the stimuli can influence recognition accuracy in the left and right visual fields when a consistent cerebral dominance factor is not operating. The fact that right-handed subjects recognized more Hebrew in the right visual field indicates that cerebral dominance is a more influential factor in visual field differences than are the directional aspects of the stimuli.

The left-field superiority reported under conditions of simultaneous presentations indicates that something other than cerebral dominance is operating but even here it is not clear that reading habits are solely responsible. Braine (1968) has shown that Israelis, who learn a right-to-left scanning pattern in reading, also show the left-to-right scanning pattern which has been attributed to learned reading habits peculiar to English. Further, the left-to-right scan does not occur solely for words and letters. It has been shown to apply much more generally for types of sequential displays such as geometric forms (Braine, 1968; Bryden, 1960), number sequences (Bryden, Dick, and Mewhort, 1968), picture arrangements (Braine, 1968), and horizontal arrays of filled and unfilled circles (Harcum, Hartman, and Smith, 1963). Braine (1968) explained such scanning tendencies as a "side of pattern effect" resulting from a tendency to attend to the left side of the pattern first. Such scanning tendencies, instead of being a product of reading experience, might be neurologically determined and could, themselves, be related to hemispheric lateralization (Braine, 1968).

The necessity of a cerebral dominance interpretation of visual field differences for successive presentations is decidedly evident in studies employing nonlanguage visual stimuli. In all subsequent studies referred to here, it may be assumed that successive presentations were used. Evidence of right hemisphere dominance (left-field superiority) for visual-spatial processes obtained from normal adults has been provided by Kimura (1966, 1969). Normal adults are better able to localize a dot when presented tachistoscopically to the left visual field than when presented to the right visual field (Kimura, 1969). Dot enumeration and enumeration of geometric designs are also better in the left visual field (Kimura, 1966). It has been suggested that the spatial aspect of this task involves "holding" the dots in their spatial positions in order to count them (Kirmura, 1970). These tasks with spatial components result in superior performance in the visual field contralateral to the hemisphere thought to be specialized for visual-spatial perception.

Contradictory evidence exists concerning the occurrence of field differences in the recognition of stimuli involving pattern or shape such as line drawings of familiar objects and geometric forms. Wyke and Ettlinger (1961) and Bryden and Rainey (1963) have both reported greater accuracy in the right visual field for recognition of line drawings of familiar objects. Numerous studies by Kimura (personal communication) in which care was taken to eliminate directional biases in the line drawings (by including mirror image drawings) have failed to replicate the reported field differences for outline drawings. Geometric forms (Bryden, 1960; Bryden and Rainey, 1963; Heron, 1957; Terrace, 1959) and nonsense figures (Kimura, 1966) were reported to produce no visual field differences. Fisher (1968), however, reported a clear left-field superiority for the recognition of geometric forms. The explanation of this inconsistency is not evident.

Present Investigation

The experiments that follow examine visual perception for normal adults in the left and right visual fields. Tasks designed specifically to investigate the perception of orientation and depth are included. In addition, several tasks which involve spatial position and possibly pattern are examined. It was the aim of this investigation to further clarify the specialized role of the right hemisphere in visual-spatial perception. More accurate perception of stimuli in the left as compared to right visual field will be assumed to reflect right hemisphere processing of the perceptual input. Systematic examination of the characteristics of the stimuli will then be undertaken in an attempt to isolate the qualities of the stimulus material dependent upon the right hemisphere for such processing.

METHOD AND RESULTS

General Method

Certain procedural details apply to all experiments reported in this thesis. Rather than repeatedly state them in each individual experiment, they are summarized here as background information for the experiments that follow.

Subjects

Male and female college students from summer and winter classes at the University of Western Ontario served as subjects. Handedness information was available from questionnaires filled out by most students when they volunteered as subjects. In addition, the subjects were questioned at the end of each experiment concerning the hand used for: writing, throwing a ball, cutting with scissors, holding a knife, brushing the teeth, etc. With the exception of Experiment 1 which included four left-handed males, all subjects were right-handed.

The subjects who participated ranged in age from 17 years to 30 years with a mean age of 21.5 years. Mean ages for the individual experiments ranged from 20.0 years to 24.4 years.

Apparatus

Model T-2B-1, a two-channel Gerbrands Harvard Tachistoscope, and Model T-3B-1, a three-channel Gerbrands Harvard Tachistoscope were used.

Both are mirror tachistoscopes which permit timed exposures of each channel to the nearest msec. as well as controlled time delays between activation of channels.

The distance from the subject's eyes to the viewing screen in the Model T-2B-1 is 24 inches and the distance from the centre of the field to the outer edge of the field is 3.75 inches allowing a maximum visual angle of approximately 9 degrees when the eyes are centrally fixated. The corresponding viewing distance in the Model T-3B-1 is 33 inches with a maximum visual angle of approximately 6½ degrees (3.75 inches) because of the longer viewing distance.

Procedure

All experiments followed the procedure of successive random tachistoscopic presentations to the left or right visual fields. In successive presentations, as described in the Introduction, the stimulus appears either to the left or to the right of the centre on any one trial.

In all experiments the subject fixated a central point in the illuminated pre-exposure field and after a ready signal the stimulus was presented briefly to the left or right of the fixation point. Throughout the course of each experiment, the subject was frequently reminded of the importance of the central fixation point. Exposure duration was always less than 150 msec. to prevent the possibility of eye movements during stimulus presentation (Crovitz and Daves, 1962). Actual exposure durations used are given in the description of each individual experiment. If it appeared obvious during the practice session that the exposure time for a task would result in near 100 per cent or near 0 per cent accuracy for a given subject, minor adjustments in exposure duration were introduced. This occurred rarely and whenever it did, care was taken to see that differences in exposure time were not responsible for performance differences on any of the variables under investigation.

Practice sessions preceded all experimental sessions to familiarize the subject with the procedure and to assure the experimenter that the instructions were understood. Rest periods were given systematically half way through the series of trials and also whenever subjects requested them.

Sighting dominance information was collected for each subject and in all cases the data were examined for differences in left- and right-visual field performance between left- and right-eye dominant subjects. Eye dominance was established by asking the subject to sight a target on the wall through a small hole in the centre of a 9" x 11" card while holding the card in both hands. The eye chosen for sighting the target was recorded as the dominant eye (Walls, 1951).

Among the 280 right-handed subjects who were involved in the experiments reported here, it was found that 78 per cent of the females were right-eyed and 22 per cent left-eyed, while 83 per cent of the males were right-eyed and 17 per cent left-eyed. The higher percentage of left-eyed females compared to left-eyed males in a right-handed group agrees with a similar observation by Kimura (1969). Since the visual field data showed no systematic relation to eye dominance, it is not mentioned again throughout the remainder of the thesis.

Sex differences were also examined throughout the thesis. Hobson

(1947) reported that males exceeded females on the Space factor of the Primary Mental Abilities Tests (Thurstone, 1938). It was of interest here to see whether male superiority as measured by the Space factor would be evident at a basic perceptual level.

Experiment 1

Familiar Objects in an Upright or Inverted Orientation

Several of the clinical reports cited in the Introduction suggest that orientational aspects of visual-spatial perception are right hemisphere dependent (Butters and Barton, 1970; Hécaen et al., 1956; McFie et al., 1950). The first experiment reported here examines the perception of stimuli judged to possess orientational information.

Method

Subjects

Thirty-two college students (16 male, 16 female) were tested. Four of the males were left-handed and all other subjects were right-handed.

Apparatus

The Model T-2B-1 Gerbrands Harvard Tachistoscope was used.

Procedure

Line drawings were prepared of 64 familiar objects judged to have orientational qualities (i.e., definite right side up or upside-down orientations). Two objects were drawn, one above the other, on each stimulus card and both members of the pair were either in an upright or inverted orientation. Both stimuli were placed to the left or right of the centre such that the distance from fixation to the outer edge of the stimulus array was 1.75 inches, representing a visual angle of approximately 4 degrees. The line drawings were designed to fit within an area of one square inch. Figure 2 provides sample stimuli.

Eight sets of drawings were prepared, four to counterbalance for side of presentation (left, right) and orientation (upright, inverted). The remaining four sets were mirror image drawings of the first four with side of presentation and object orientation counterbalanced in the same manner. It was considered necessary to include mirror image drawings because viewing a drawing from left to right or from right to left (as is the case when the eyes are centrally fixated and the stimuli appear to left or right of centre) may influence the ease of recognition (Takala, 1951, cited in Braine, 1968).

The stimuli were then rearranged into sets so that each set had an equal number of upright and inverted stimuli, an equal number of left- and right-field stimuli, and an equal number of mirror image and normal drawings. A given pair of drawings appeared only once in a set and within the eight sets the pair appeared once in each of the eight conditions mentioned.

The subject was instructed that drawings of two familiar objects would flash briefly (50 msec.) on the screen in either an upright or inverted position and that his task was to name the objects. Sixteen trials per field with two objects per trial permitted a maximum score of 32 for each field and within each field, 16 for upright figures and 16 for inverted figures.

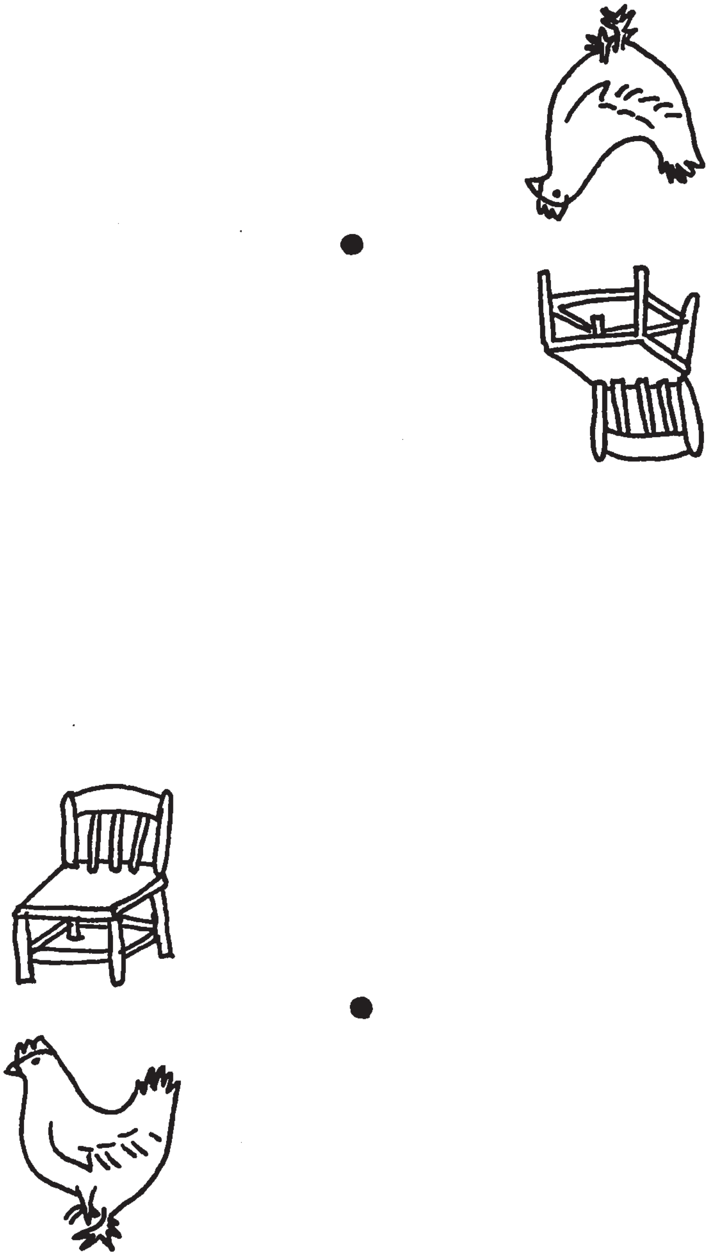


Figure 2: Sample pair of line drawings of familiar objects shown in an inverted, mirror image position in the right field and in an upright, normal position in the left field (Experiment 1)

Results

The data were analyzed using a 2 x 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measures, field (left, right) and orientation (upright, inverted). Means for each of these factors are presented in Table 1 and the summary of the analysis is provided in Appendix A-1. The mean recognition score for females ($\overline{X}$ = 22.18) did not differ significantly from that of males ($\overline{X}$ = 18.63), nor did the number of drawings recognized in the left field ($\overline{X}$ = 10.22) differ from the number recognized in the right field ($\overline{X}$ = 10.19). Drawings of familiar objects were, however, more often recognized in an upright position than in an inverted position ($\overline{X}$ = 13.41, and $\overline{X}$ = 7.00 respectively; $\underline{F}$ = 86.60, $\underline{df}$ = 1,30, $\underline{p} < .001$) as would be expected from similar reports (Braine, 1965). Orientation of the objects did not produce a visual field difference.

Experiment 2

Perception of Line Slant

To further investigate the perception of orientation, it was next decided to examine the perception of line slant in the left and right visual fields.

Method

Subjects

Twenty-eight right-handed college students (14 male, 14 female) served as subjects.

TABLE 1

Mean Recognition Scores for Familiar Objects in an Upright or Inverted Orientation (Experiment 1)

	Means and Standard Deviations				
	Left	SD	Right	SD	Total
Males (M)	9.32		9.31		18.63
Upright	6.38	2.44	6.56	1.66	12.94
Inverted	2.94	1.29	2.75	1.20	5.69
Females (F)	11.12		11.06		22.18
Upright	7.12	2.31	6.75	2.60	13.87
Inverted	4.00	1.73	4.31	2.00	8.31
M and F	10.22		10.19		
Upright	6.75		6.66		13.41
Inverted	3.47		3.53		7.00

Summary of Analysis of Variance

Field: F = 0.01, df = 1,30
Sex: F = 2.83, df = 1,30
Orientation: F = 86.60, df = 1,30, $p < .001$
No significant interactions

Note: For complete analysis of variance summary see Appendix A-1.

Apparatus

The Model T-2B-1 Gerbrands Harvard Tachistoscope was used.

Procedure

A black line, 1½ inches long (approximately 3 degrees, 35 minutes at the eye) of angles 20, 30, 45, 60, or 70 degrees was viewed by the subject for 20 msec. Each line radiated from the central fixation point but was located one inch (2 degrees, 23 minutes at the eye) from fixation. The five angles each appeared once in each of the four quadrants, giving a total of 20 trials.

After viewing the stimulus line, the subject was asked to set a moveable dial so that the line on the dial corresponded in slope to the line he had viewed tachistoscopically. The dial was positioned directly in front of the subject above the eye-piece of the tachistoscope. When the subject was satisfied that he had set the dial accurately, he responded by reading the number at which the pointer was set (or if it was between gradations, the closest number). The numbers around the periphery of the dial were randomly arranged to avoid (if possible) having the subject think in terms of 90 degrees, 180 degrees, etc. There were 152 gradations around the dial, each separated by 2.5 degrees.

The magnitude of error for each judgment of slope was calculated by determining the difference in degrees between the actual slope of the line presented and the subject's representation of it. Mean error scores were then calculated for each of the four quadrants.

Results

The mean degrees of error for the judgments of slope in each quadrant is presented in Table 2. These errors were analyzed using a 2 x 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of each repeated measure, field (left, right) and location (top, bottom). The summary of this analysis is provided in Appendix A-2.

It was found that females made significantly larger errors on this task than males ($\overline{X} = 9.60$ and $\overline{X} = 6.65$ respectively; F = 10.75, df = 1,26, $p < .01$). The significant interaction between field of presentation and location in upper or lower quadrant (F = 10.28, df = 1,26, $p < .01$) is shown graphically in Figure 3. When interpreted by a Newman-Keuls a posteriori test of differences between ordered means (Appendix B-1), it was found that the errors in the bottom left quadrant ($\overline{X} = 10.42$) were significantly larger than the errors in the other three quadrants ($\overline{X} = 6.96$, $\overline{X} = 7.46$, $\overline{X} = 7.66$). Inspection of Figure 3 shows clearly that this interaction accounts for the other two main effects, field (F = 6.75, df = 1,26, $p < .05$) and location in the top or bottom quadrants (F = 9.01, df = 1,26, $p < .01$).

Thus, perception of line slant as investigated here yielded a curious inaccuracy in the bottom left quadrant. Several aspects of the task were, however, considered to be unsatisfactory. It was thought, for example, that the manual response introduced variation that was not relevant to the subject's perception of line slant. In addition, the subjects were all right-handed and naturally used their preferred hand to adjust the dial. It is not known what effect this would produce in the left and right quadrants. The long lines were also considered to be unsatisfactory because they extended too far toward the frames of

TABLE 2

Mean Degrees Error in the Perception of Line Slant in the Left and Right Visual Fields (Experiment 2)

	Means and Standard Deviations				Combined
	Left	SD	Right	SD	Means
Males (M)	6.96		6.34		6.65
Upper Quadrant	5.21	1.98	6.50	2.08	5.86
Lower Quadrant	8.71	3.62	6.18	1.69	7.44
Females (F)	10.42		8.78		9.60
Upper Quadrant	8.71	3.45	8.82	4.18	8.76
Lower Quadrant	12.14	4.66	8.75	3.03	10.44
M and F	8.69		7.56		8.12
Upper Quadrant	6.96		7.66		7.31
Lower Quadrant	10.42		7.46		8.94

Summary of Analysis of Variance

Field: $F = 6.75$, $df = 1,26$, $p < .05$
Sex: $F = 10.75$, $df = 1,26$, $p < .01$
Location: $F = 9.01$, $df = 1,26$, $p < .01$
Field X Location: $F = 10.28$, $df = 1,26$, $p < .01$
No other significant interactions

Note: For complete analysis of variance summary see Appendix A-2.

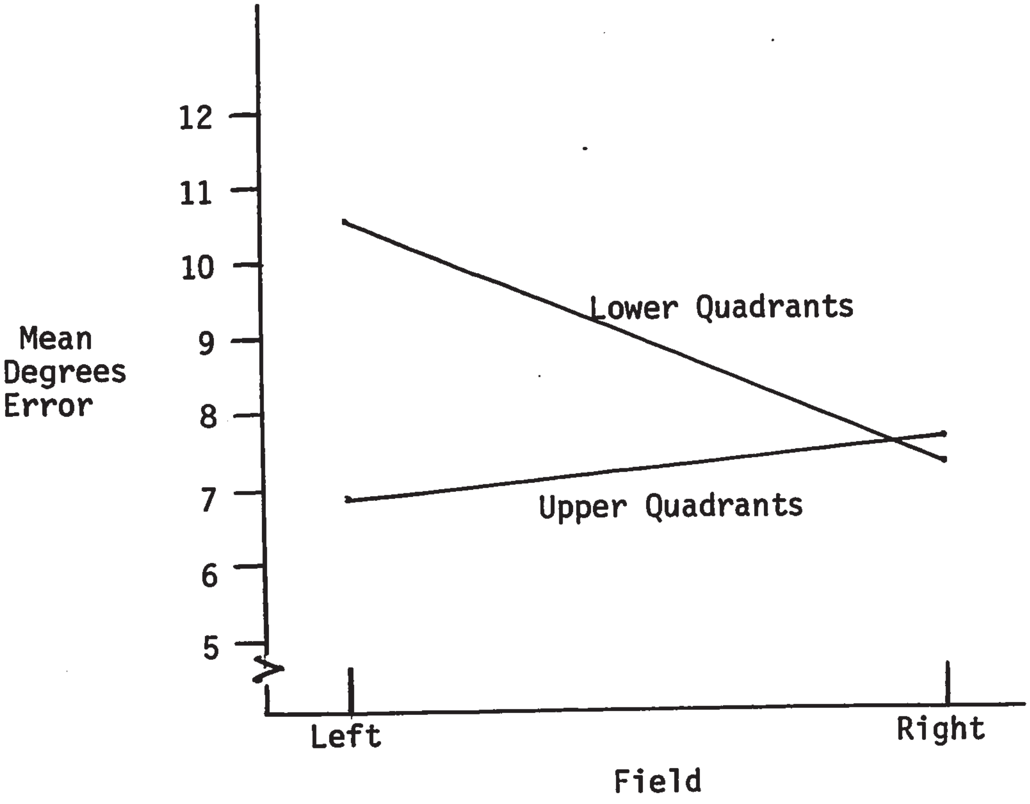


Figure 3: Degrees of error associated with the representation of slant in the upper and lower quadrants of the left and right visual fields (Experiment 2)

the tachistoscope which could serve as cues for horizontal and vertical coordinates.

Experiment 3

Perception of Line Slant

To eliminate the problems encountered in Experiment 2, perception of line slant was re-examined using much shorter lines and a method which avoided a manual response.

Method

Subjects

Twenty-two right-handed college students (11 male, 11 female) participated.

Apparatus

The Model T-3B-1 Gerbrands Harvard Tachistoscope was used.

Procedure

Slanted lines (Letraset 8E), one-eighth inch in length, subtending a visual angle of approximately 13 minutes of arc at the eye, were exposed one at a time for 40 msec. in the left or right visual field. The lines ranged in slant from 15 degrees to 165 degrees (90 degrees omitted) varying in 15 degree steps. The 15 degree difference in choices (1/16 inch) represents a difference of approximately 6½ minutes of arc at the retina. The slopes in the left visual field were mirror images of the slopes in the right visual field so that all lines sloped away from fixation. In the left visual field, therefore, the slopes 15, 30, 45, 60, and 75 degrees each appeared four times, once at each of four distances from fixation (1.0, 1.5, 2.0, and 2.5 inches) along the horizontal axis. The visual angles corresponding to these distances are approximately 1.7, 2.6, 3.5, and 4.4 degrees respectively. Right visual field stimuli were arranged in an identical fashion giving a maximum of 20 presentations per field.

Following the stimulus presentation and a 700 msec. delay to avoid backward masking (Haber, 1968), a multiple-choice response card containing the entire range of stimulus lines was viewed tachistoscopially for four seconds. Figure 4 shows the horizontal arrangement of the choices on the response card. From this card, the subject was asked to choose the line whose slope matched the one previously viewed. He simply reported the number of the line chosen. A graded accuracy score, ranging from 4 to 0 was assigned depending upon the degree of discrepancy between the slope of the stimulus line and the slope of the line chosen as its match. A perfect match would score 4, a choice ± 15 degrees away from the stimulus would score 3, etc. Using this scoring procedure, the 20 trials in each visual field permitted a maximum score of 80 per field.

Results

The data were examined using a 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measure, field (left, right). Mean graded accuracy scores for perception of line slant in the left and right visual fields are presented in Table 3.

Figure 4: Horizontal arrangement of response choices (Experiment 3)

TABLE 3

Mean Graded Accuracy Scores for the Perception of Line Slant in the Left and Right Visual Fields (Experiment 3)

	Means and Standard Deviations				
	Left	SD	Right	SD	Total
Males (M)	70.00	3.16	68.09	3.69	138.09
Females (F)	69.91	3.57	66.64	4.43	136.55
M and F	69.95		67.36		

Summary of Analysis of Variance

Field: F = 10.22, df = 1,20, $p < .01$
Sex: F = 0.28, df = 1,20
No significant interaction

Note: For complete analysis of variance summary see Appendix A-3

The analysis (summarized in Appendix A-3) indicated that a difference exists between left- and right-field accuracy of perception of slope ($F = 10.22$, $df = 1,20$, $p < .01$). Table 3 shows that the mean graded accuracy score for judgments in the left field ($\overline{X} = 69.95$) was significantly higher than in the right field ($\overline{X} = 67.36$). In terms of degrees, these scores represent a mean error of 7.5 degrees in the left visual field and 9.5 degrees in the right visual field. No sex differences were evident ($F = 0.28$, $df = 1,20$).

Experiment 4

Perception of Line Slant

Experiment 3 indicated that perception of short slanted lines was more accurate in the left visual field. There existed the possibility, due to the left-to-right arrangement of the response choices (Figure 4), that a bias had been introduced in favor of the left field. It is well known that scanning tendencies are in a left-to-right direction (Braine, 1969). Thus, the left-field stimuli would be identified earlier in the scan of choices than the right-field stimuli.

To rule out this possibility, a replication of the experiment is presented below in which directional biases were avoided in both stimulus and response line arrangements.

Method

Subjects

Twenty right-handed summer school students (10 male, 10 female) participated. These same subjects later participated in Experiment 7.

Apparatus

The Model T-3B-1 Gerbrands Harvard Tachistoscope was used.

Procedure

The procedure and stimuli were identical to Experiment 3 with the following exceptions. Ninety degree lines were included in the series and all 11 stimulus slopes (15, 30, 45, ..., 140, and 165 degrees) appeared in both visual fields. Each slanted line appeared in two positions (1 inch and 2 inches from fixation or 1 degree 45 minutes and 3 degrees 28 minutes), rather than in four positions as in the previous experiment. This gave a total of 22 presentations per field and using the graded accuracy scoring procedure, a maximum score of 88 per field. The response choices were arranged vertically from top to bottom on the multiple choice response card as shown in Figure 5. The vertical arrangement of choices and the presentation of each slope equally often in the left and right fields made scanning tendencies no more beneficial to one field than to the other.

Results

The data were analyzed in a 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measure, field (left, right). The means for each of these factors are presented in Table 4 and the summary of the analysis appears in Appendix A-4. Once again, as in Experiment 3, there was a significant main effect due to field of presentation ($\underline{F} = 5.82$, $\underline{df} = 1,18$, $\underline{p} < .05$) and no interaction or difference involving sex. Mean left-field accuracy for the

Figure 5: Vertical arrangement of response choices (Experiment 4)

TABLE 4

Mean Graded Accuracy Scores for the Perception of Line Slant in the Left and Right Visual Fields (Experiment 4)

	Means and Standard Deviations Left	SD	Right	SD	Total
Males (M)	75.20	6.71	72.80	12.25	148.00
Females (F)	74.20	4.94	69.30	8.22	143.50
M and F	74.70		71.05		145.74

Summary of Analysis of Variance

Field: F = 5.82, df = 1,18, $p < .05$
Sex: F = 0.37, df = 1,18
No significant interaction

Note: For complete analysis of variance summary see Appendix A-4.

perception of slope was significantly greater than mean right-field accuracy as the means in Table 4 indicate ($\overline{X} = 74.70$ and $\overline{X} = 71.05$ respectively). In terms of degrees, these scores represent a mean error of 9.1 degrees in the left visual field and 11.6 degrees in the right visual field. In terms of maximum scores obtainable, the overall accuracy level with the vertical arrangement of response choices was 83 per cent compared to 86 per cent with the horizontal arrangement. It can be noted from an examination of the standard deviations presented in Tables 3 and 4 that larger variation in responding occurred when the response choices were vertically arranged.

An additional analysis was undertaken to examine the accuracy of judgments for vertical lines (90 degrees) compared to the accuracy for oblique lines (± 45 degrees). These particular lines are represented in Figure 5 by choices 6 (vertical) and 3 and 9 (oblique). A mean graded accuracy score with a maximum of 4 was calculated for this comparison. The analysis of variance, summarized in Appendix A-5, involved field (left, right) and type of line (vertical, oblique).

It was found that vertical lines were perceived more accurately than oblique lines ($\underline{F} = 15.74$, $\underline{df} = 1,19$, $\underline{p} < .001$). The mean graded accuracy score for judgments of vertical lines was 3.55 compared to 3.16 for oblique lines. The judgments in the left field ($\overline{X} = 3.50$) were superior to those in the right field ($\overline{X} = 3.21$) even on these selected trials ($\underline{F} = 5.21$, $\underline{df} = 1,19$, $\underline{p} < .05$).

Experiment 4 provides a convincing replication of the findings in Experiment 3. It must be concluded on the basis of these two studies that there is superior accuracy for perception of slope in the left visual field and that this is not a product of left-to-right scanning tendencies. In addition, perception of vertical lines is more accurate than perception of oblique lines.

Male superiority for reproduction of slant (Experiment 2) when a motor response was required was not evident when a visual selection of response choices was utilized (Experiments 3 and 4).

Experiment 5

Detection of Short Lines

Detectibility of short lines in the left and right visual fields was next examined to see whether left-field superiority for lines occurred only when slope was reported. Experiment 5, which consists of six tasks, was undertaken to establish whether or not detection differences existed for one-eighth inch lines in the left and right visual fields.

Method

<u>Subjects and Apparatus</u>

Table 5 provides information concerning the number and sex of subjects participating in each experiment as well as the apparatus used.

<u>Procedure</u>

Short lines, one-eighth inch in length, were presented using an ascending threshold technique. The stimulus was repeatedly exposed at durations which increased in 1 msec. steps from a point below threshold (established during practice trials) until the subject indicated that

TABLE 5

Description of Stimuli and Procedural Conditions for Detection Tasks
(Experiment 5)

Task	T-Scope	N	Total Trials	Stimulus Description	Positions and Angles	Subject's Response
I	T-2B-1	9M[1] 13F	24	1/8" H,V,O[2] lines hand drawn	2L,2R[3] $3^{\circ}30'$	Quadrant Lower L, Lower R, etc.
II	T-2B-1	10M 10F	24	1/8" H,V,O lines hand drawn (new set)	2L,2R $3^{\circ}15'$	Yes, No
III	T-2B-1	10M 10F	24	1/8" H,V,O lines Letraset 8E	4L,4R $3^{\circ}15'$ $4^{\circ}20'$	Yes, No
IV	T-3B-1	10M 10F	36 & 4 Blank	1/8" H,V,O lines Letraset 8E	6L,6R $1^{\circ}45'$, $2^{\circ}36'$ $3^{\circ}28'$, $3^{\circ}54'$	Right, Left
V	T-3B-1	5M 9F	28 & 4 Blank	1/8" O lines Letraset 8E	14L,14R $2^{\circ}35'$ $3^{\circ}30'$	Right, Left
VI	T-2B-1	10M 12F	32	1/8" and 1/16" diameter dots	4L,4R $3^{\circ}15'$ $4^{\circ}20'$	Quadrant Lower L, Lower R, etc.

[1] M, F - Male, Female

[2] H,V,O - Horizontal, Vertical, and Oblique lines

[3] L, R - Left, Right

he had detected the line. The required response upon detection varied in the different tasks because it was suspected that some modes of response required spatial localization which could be partially responsible for field differences (Kimura, 1969). The dot detection task (Task VI) was also introduced to clarify the contributions of positional information to visual field differences.

The subject's response in each task is listed in Table 5, as is information on stimulus position, visual angle, and number of trials. Figure 6 provides an example of the left- and right-field positions and corresponding visual angles for one of the tasks. Blank trials, where no stimulus was present for detection, were included in Tasks IV and V as a check on the reliability of the subject's responses. Only one subject gave detection responses on blank trials and his data were discarded. The subjects were told prior to the experiment that blank trials would be included.

Average thresholds for detection in the left and right visual fields were calculated for each task. Whenever horizontal, vertical, and oblique lines (H, V, O) were presented in the same task, mean thresholds for the left and right fields were calculated for each type of line separately.

Results

The mean detection thresholds for each task appear in Tables 6 and 7. Since sex was in no case a significant variable, all means presented are collapsed across sex. The _F_ ratios associated with these means were obtained from analysis of variance, the summaries of which are found in

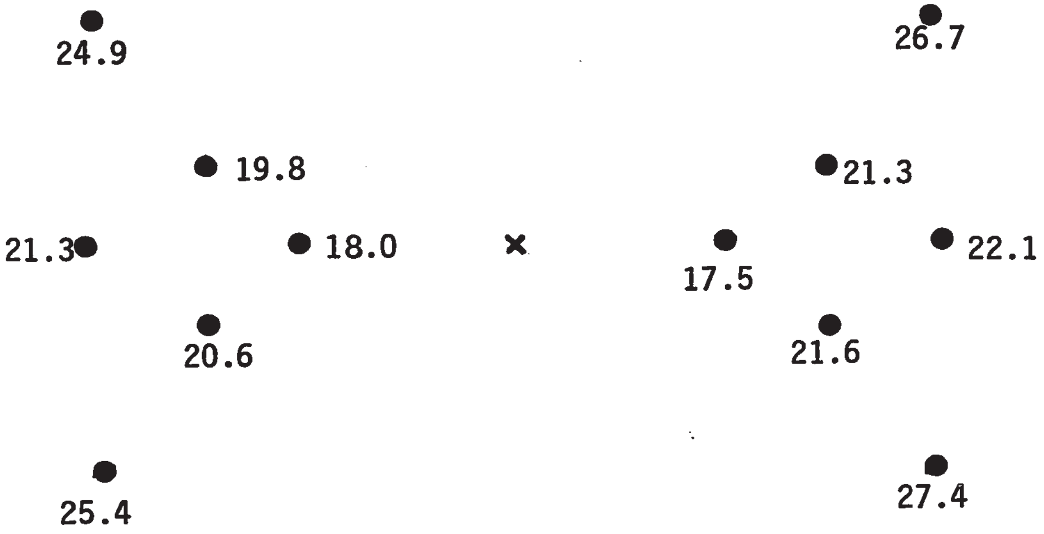


Figure 6: Mean detection thresholds (msec.) for horizontal, vertical, and oblique lines at six different positions in each visual field. Beginning at the top in either field, the visual angles from fixation are $3^{\circ}54'$, $2^{\circ}36'$, $1^{\circ}45'$, $3^{\circ}28'$, and $3^{\circ}54'$. (Experiment 5, Task IV)

Appendices A-6 to A-11. Tasks I, II, III, and IV each involved a 2 x 2 x 3 analysis with two levels of sex (male, female), two levels of the repeated measure field (left, right), and three levels of the repeated measure type of line (H, V, O). Since no sex differences were found in the first four analyses, nor were they evident in the data for the last two tasks, sex as a variable was omitted from the analyses of Tasks V and VI data. The only variable of interest in Task V (oblique lines) and Task VI (dots) was field (left, right).

Main Effect: Field.--Comparison of the mean thresholds for left- and right-field detection of short lines (Table 6) indicates that left-field superiority for detection occurs under some conditions and not under others. Examination of the procedural differences given in Table 5 suggests that both position of the stimulus and type of stimulus material are critical in determining whether or not field differences in detection thresholds occur. It can be noted from Tables 5 and 6 that the largest field difference occurred when only two positions per field were involved and when the subject was required to localize lines in quadrants (Task I, detection of H, V, O lines). As more positions per field were used (Tasks IV and V), the field difference was reduced or disappeared. Figure 6 shows that small changes in visual angle have marked effects on the magnitude of detection thresholds. A direct relationship exists between distance from fixation and detection threshold in both fields.

Dot detection (Task VI) did not result in field differences when only two positions per field were used, indicating that a variety of slanted lines as stimuli also contribute to the field differences found on these tasks.

TABLE 6

Mean Thresholds (msec.) for the Detection of Lines in the Left and Right Visual Fields (Experiment 5)

Task	Stimuli	Means (msec.) Left	Right	F Ratio	df	p
I	H,V,0	11.20	13.61	21.53	1,20	<.001
II	H,V,0	13.51	14.35	3.17	1,18	<.10
	0	13.86	15.49	5.05	2,36	<.05
III	H,V,0	11.38	12.64	15.52	1,18	<.001
IV*	H,V,0	21.70	22.83	3.55	1,18	<.10
V	0	18.16	18.04	0.12	1,13	NS
VI	Dots	6.99	7.26	1.44	1,21	NS

*Higher thresholds for Tasks IV and V result from the greater distances from eyes to stimulus in the Model T-3B-1 (33 inches) compared to the Model T-2B-1 (24 inches).

Main Effect: Type of Line.--Thresholds for the detection of horizontal, vertical, and oblique lines were available for the first four tasks. These means and the associated F ratios are provided in Table 7. Significant differences in detection thresholds as a function of type of line were subsequently examined with a Newman-Keuls analysis of differences between ordered means. These analyses and the means involved appear in Appendices B-2 to B-4 inclusive. The results of these analyses, presented in Table 7, show that no consistency in magnitude of threshold as a function of type of line was evident.

Interactions: Field and Type of Line.--In two of the analyses (Appendices A-6 and A-7), an interaction resulted between the field of presentation and the type of line presented for detection. Both of these interactions were investigated with a Newman-Keuls test of differences between ordered means. These analyses and the means involved are presented in Appendices B-5 and B-6. All means referred to here represent thresholds in msec. In the first case (Task I; $F = 10.94$, $df = 2{,}40$, $p < .01$), the interaction was produced by the fact that all left-field thresholds did not differ from all right-field thresholds. The left-field threshold for vertical lines ($\overline{X} = 11.85$), for example, did not differ from the right-field threshold for horizontal lines ($\overline{X} = 12.08$). The important left-right differences were all significant (Newman-Keuls, $p < .05$). Left vertical ($\overline{X} = 11.85$) differed from right vertical ($\overline{X} = 15.68$), left horizontal ($\overline{X} = 10.90$) differed from right horizontal ($\overline{X} = 12.08$), and left oblique ($\overline{X} = 10.85$) differed from right oblique ($\overline{X} = 13.06$).

TABLE 7

Detection Thresholds (msec.) as a Function
of Type of Line
(Experiment 5)

Task	Type of Line Means H	 V	 O	F Ratio	Newman-Keuls Analysis
I	11.49	13.77	11.95	10.68***	V > H,O*
II	13.76	13.36	14.68	6.31**	O > H,V*
III	12.04	12.12	11.96	0.07	NS
IV	22.77	22.33	21.66	4.30*	H > O*

*** $p < .001$

** $p < .01$

* $p < .05$

The field by type of line interaction found in Task II ($\underline{F}$ = 5.05, $\underline{df}$ = 2,36, $\underline{p} < .05$) is explained in Table 6. The only left- and right-field thresholds to differ significantly were those for oblique lines ($\overline{X}$ left = 13.86, $\overline{X}$ right = 15.49). Appendix B-6 presents the Newman-Keuls analysis of the means involved in this interaction.

Experiment 6

Judgments of Parallel-Nonparallel

A final experiment examining slanted lines as stimuli involved judgments of whether or not a pair of lines was parallel.

Method

Subjects

Thirty right-handed college students (15 male, 15 female) participated.

Apparatus

The Model T-2B-1 Gerbrands Harvard Tachistoscope was used.

Procedure

A pair of black lines one-half inch in length and 5/8 inch apart were viewed for 20 msec. One-half of the pairs were parallel and one-half were approximately 3/32 inch off parallel (or 14 minutes of arc at this viewing distance). The pairs sloped away from the central fixation point at slopes of 20, 30, 45, or 55 degrees. All four quadrants were used so that the lines radiated from points 1½ inches above or below and left or right of fixation. A set, similar in length, separation, and slope radiated from points 3/4 inch from fixation. The visual angles corresponding to these distances (3/4 inch and 1½ inches) from fixation to closest edge of the stimulus lines were 2 degrees and 4 degrees.

Sixteen trials were presented in each visual field and the subject responded "Same" or "Different" depending upon whether he judged both lines of the pair to be of the same slope. The maximum score in each field was 16.

Results

Examination of the data presented in Table 8 indicated no differences between sexes ($\bar{X}$ males = 24.94, $\bar{X}$ females = 26.20), fields ($\bar{X}$ left = 13.07, $\bar{X}$ right = 12.50) or quadrants ($\bar{X}$ upper left = 6.60, $\bar{X}$ upper right = 6.43, $\bar{X}$ lower left = 6.47, and $\bar{X}$ lower right = 6.06). These data were analyzed using a 2 x 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measures, field (left, right), and location (upper, lower). The summary of this analysis, appearing in Appendix A-12, revealed no significant main effects or interactions.

To investigate the possibility that the stimulus conditions had not been optimal in this task, additional subjects (N = 20) were tested on a similar task using shorter lines, larger separations between lines, and varied distances from fixation. This did not, however, change the pattern of the results. Judging whether or not two lines were parallel was as accurate when the lines appeared in the right visual field as when they appeared in the left visual field.

TABLE 8

Mean Correct Judgments of Parallel-Nonparallel in the Left and Right Visual Fields (Experiment 6)

	Means and Standard Deviations				
	Left	SD	Right	SD	Total
Males (M)	12.87		12.34		25.21
Upper Quadrant	6.40	0.73	6.47	1.13	12.87
Lower Quadrant	6.47	0.94	5.87	1.41	12.34
Females (F)	13.47		12.73		26.20
Upper Quadrant	6.80	0.93	6.40	0.86	13.20
Lower Quadrant	6.67	0.87	6.33	1.58	13.00
M and F	13.17		12.53		25.70
Upper Quadrant	6.60		6.43		13.03
Lower Quadrant	6.57		6.10		12.67

Summary of Analysis of Variance

Field: F = 2.84, df = 1,28
Sex: F = 1.09, df = 1,28
Location: F = 0.80, df = 1,28
No significant interactions

Note: For complete analysis of variance summary see Appendix A-12.

Experiment 7

Perception of Patterned Matrices

A visual-spatial task of an entirely different nature was next examined. It was thought useful to employ a task involving spatial pattern or design similar in nature to block design which has been shown to be impaired after right hemisphere damage (Paterson and Zangwill, 1944; Warrington and James, 1967a).

Method

<u>Subjects</u>

Twenty right-handed summer school students (10 male, 10 female) served as subjects. These were the same subjects who served in Experiment 4 and in all cases this task was presented second. An additional eight right-handed males had been previously tested on this task giving a total of 28 subjects (18 male, 10 female).

<u>Apparatus</u>

The Model T-2B-1 Gerbrands Harvard Tachistoscope was used.

<u>Procedure</u>

The subject was instructed that a 3 x 3 matrix would flash briefly on the screen and three of the nine squares would be black. On his response booklet of blank matrices, he was simply to place an X in each of the three squares that had appeared black. The stimulus was viewed for 20 msec. (30 msec. for the first eight males). The stimulus itself was a 3/4 inch square, placed 1 inch left or right of fixation and 3/8 inch above (Figure 7), and subtended a visual angle of

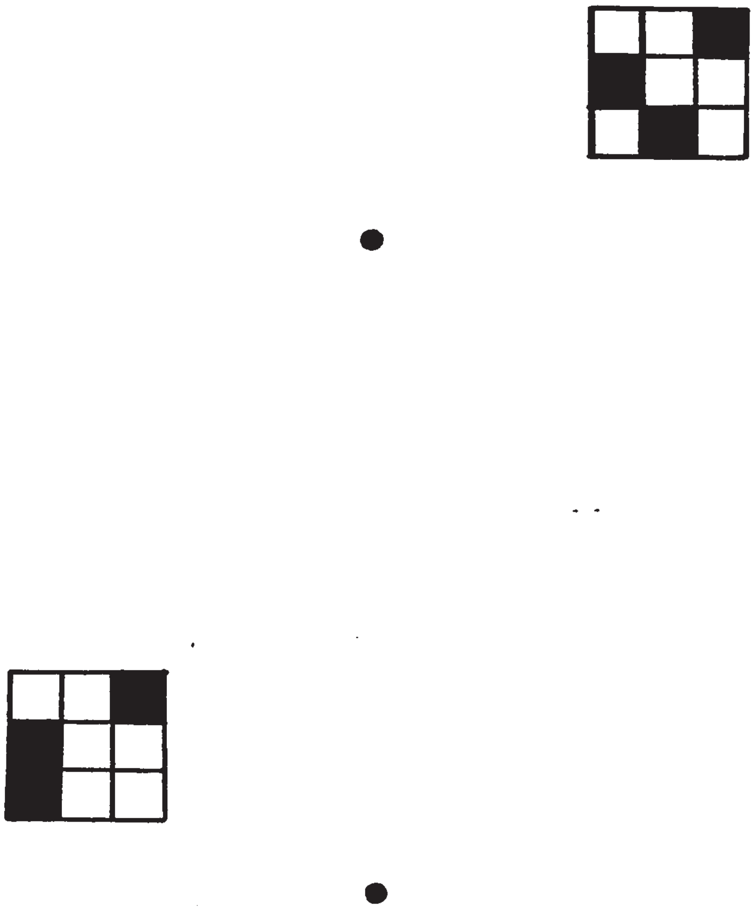


Figure 7: Sample patterned matrices (Experiment 7)

approximately 1 degree, 47 minutes. Fixation to the closest edge of the matrix subtended a visual angle of 2 degrees, 20 minutes. To match the difficulty level of the left- and right-field stimuli, the eight patterns in the left visual field were mirror images of the eight in the right. A score of 1 was given for each X correctly placed allowing a maximum score of 24 in each visual field.

Results

Inspection of the means presented in Table 9 clearly indicated that no field differences existed on this task. To verify this, a *t* test for differences between correlated means was calculated ($t = 0.13$, 26 *df*). The apparent difference in means for males ($\overline{X} = 30.3$) and females ($\overline{X} = 28.6$) resulted because the first eight males viewed the matrices longer.

Experiment 8

Binocular Perception of Depth

The final aspect of visual-spatial perception examined in this thesis is the perception of depth. This experiment investigated binocular perception of three-dimensional depth in the left and right visual fields.

Method

Subjects

Twenty-two right-handed college students (11 male, 11 female) participated.

TABLE 9

Mean Accuracy for the Perception of Patterned Matrices in the Left and Right Visual Fields (Experiment 7)

		Means and Standard Deviations				
	N	Left	SD	Right	SD	Total
Males (M)	18*	15.2	3.84	15.1	2.44	30.3
Females (F)	10	14.0	1.84	14.6	1.74	28.6
M and F	28	14.6		14.8		

*8 out of 18 males were given a 10 msec. longer exposure time than other subjects.

Apparatus

A back attachment as shown in Figure 8 was placed on the exposure field of the Model T-2B-1 Gerbrands Harvard Tachistoscope to permit three-dimensional viewing. The back attachment consisted of a depth box (12" x 12" x 14½") in which were placed two vertical rods, one centrally located and stationary and the other mounted on one of two sliding tracks 2¼" to the left or right of centre. A black mask with a centrally positioned one inch slit extending its width was placed directly in front of the depth box.

Procedure

The subject was required to raise a shutter over the tachistoscope's eye-piece before each presentation and to say "ready" when he was fixating the central dot. The shutter was necessary to prevent the subject from seeing the experimenter set the rods into position when the back of the depth box was open to change the settings. The adjustable rod was set in a prearranged random order, 7, 14, 21, or 28 mm. in front or behind the central rod and approximately 4 degrees to the left or right. A presentation consisted of a 90 msec. exposure of the segments of the two vertical rods visible binocularly through the one inch slit over the exposure field. The subject judged whether the central rod was closer or farther than the other. He then dropped the shutter and the experimenter reset the adjustable rod. The maximum number of correct responses per field was 32.

It should be noted here that the fixation point was actually closer to the subjects' eyes than the rods in the depth box. The variable rods, at their different settings appeared approximately 5.0 to

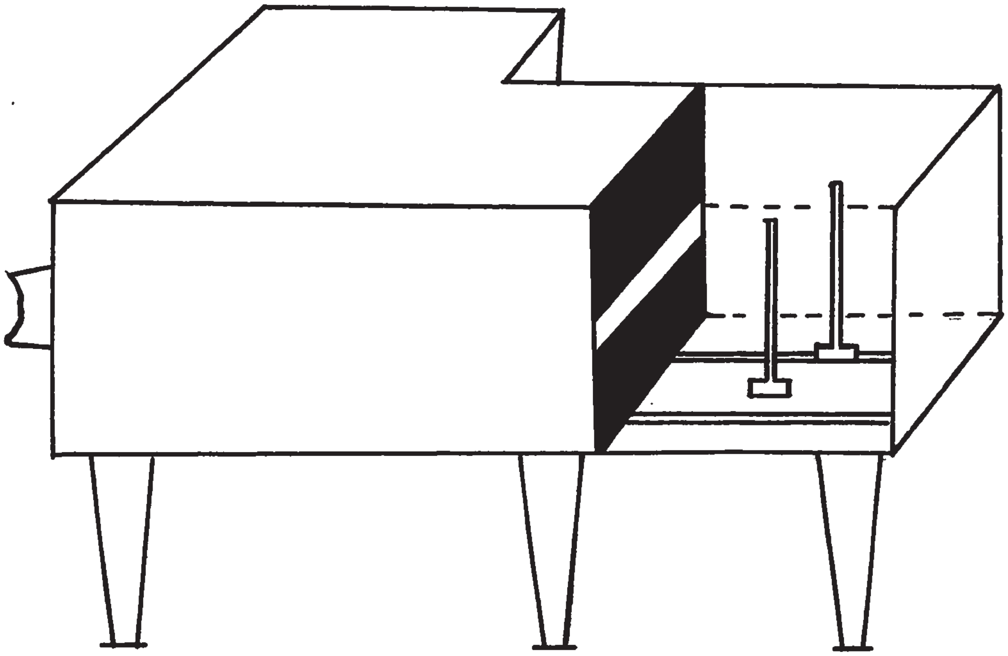


Figure 8: Arrangement of adjustable rods for three-dimensional viewing

7.25 inches farther back than the fixation point. Since the 90 msec. exposure would not permit accommodation, it must be assumed that some degree of blurring of the stimulus rods was present.

Results

The data were analyzed using a 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measure, field (left, right). The mean number of correct judgments in the left and right visual fields for both males and females are presented in Table 10. The analysis of this data, summarized in Appendix A-13, showed that there were no sex differences on this task but that accuracy of judgments in the left and right visual fields differed significantly ($\underline{F} = 4.93$, $\underline{df} = 1,20$, $\underline{p} < .05$). The subjects made more correct judgments in the left visual field ($\overline{X} = 20.36$) than in the right visual field ($\overline{X} = 18.59$) on this depth perception task.

Experiment 9

Monocular Perception of Depth

In the three-dimensional viewing conditions of Experiment 8, both monocular and binocular cues to depth were present. Experiment 9 reexamines performance on this task to see whether monocular cues alone were involved in the field difference.

TABLE 10

Binocular Judgments of Three-Dimensional Depth in the Left and Right Visual Fields
(Experiment 8)

	Means and Standard Deviations Left	SD	Right	SD	Total
Males (M)	20.54	2.43	18.00	2.45	38.54
Females (F)	20.18	2.58	19.18	3.47	39.36
M and F	20.36		18.59		

Summary of Analysis of Variance

Field: F = 4.93, df = 1,20, $p < .05$
Sex: F = 0.18, df = 1,20
No significant interaction

Note: For complete analysis of variance summary see Appendix A-13.

Method

Subjects

Twenty right-handed college students (10 male, 10 female) participated.

Apparatus

The apparatus used in this experiment was identical to that used in Experiment 8.

Procedure

The subject's task was also similar to that of Experiment 8 except that the rods were viewed monocularly for 100 msec. and the distances between rods were larger (1, 2, 3, and 4 inches). These changes were introduced to equate the difficulty level of the monocular task to that of the binocular task.

For a given subject, half of the trials were viewed with the left eye and half with the right eye. Use of the left or right eye first was counterbalanced across subjects. The subject kept both eyes open but one eye's view was blocked due to the presence of a black strip behind that eye-piece. Once again, the maximum possible score per field was 32.

Results

A three-way analysis of variance with two repeated measures was used to examine the data. This analysis involved two levels of sex (male, female) and two levels of each repeated measure, field (left, right) and eye (left, right). These data are presented in Table 11. The summary of the analysis, appearing in Appendix A-14, shows no significant main effects or interactions. The mean correct left- and

TABLE 11

Monocular Judgments of Three-Dimensional Depth in the Left and Right Visual Fields (Experiment 9)

	Means and Standard Deviations Left	SD	Right	SD	Total
Males (M)	19.50		19.60		39.10
Left Eye	9.80	1.78	10.20	2.23	20.00
Right Eye	9.70	1.76	9.40	1.68	19.10
Females (F)	19.30		18.50		37.80
Left Eye	9.60	2.69	8.90	2.07	18.50
Right Eye	9.70	1.95	9.60	2.42	19.30
M and F	19.40		19.05		38.45
Left Eye	9.70		9.55		19.25
Right Eye	9.70		9.50		19.20

Summary of Analysis of Variance

Field: F = 0.13, df = 1,18
Sex: F = 0.12, df = 1,18
Eye: F = 0.10, df = 1,18
No significant interactions

Note: For complete analysis of variance summary see Appendix A-14.

right-field judgments were 19.40 and 19.05 respectively, indicating that the monocular task was comparable to the binocular task in overall difficulty. The exclusion of binocular cues, however, eliminated the field differences previously found for depth discrimination judgments in the left and right visual fields.

Experiment 10

Perception of Random Dot Stereograms

Experiments 8 and 9 indicated that the binocular depth cues were responsible for the superior perception of depth in the left visual field. This next experiment was designed to examine the most powerful binocular depth cue, binocular disparity. No other binocular or monocular cues were present in this task.

Method

Subjects

Twenty right-handed college students (10 male, 10 female) participated.

Apparatus

The Model T-3B-1 Gerbrands Harvard Tachistoscope was modified with the aid of polaroid filters for stereoscopic viewing. The polaroid material had light transmission average of 35 per cent and crossed transmission of 2 per cent. Insertion of the polaroid material over the eye-pieces and two of the viewing channels made it possible for the right eye to view one channel and the left eye to view the other channel.

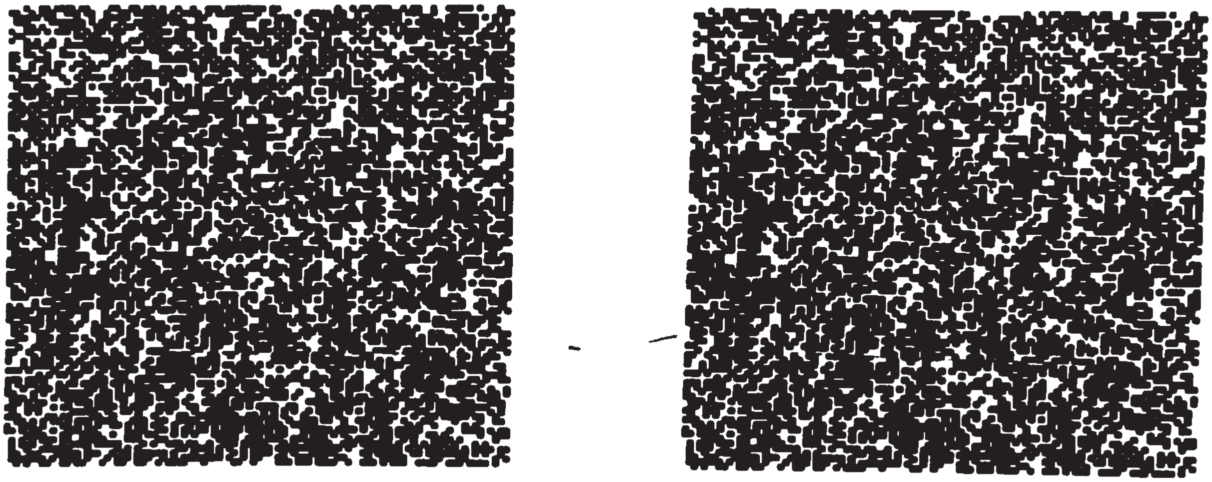
The third channel, containing the fixation point, was seen by both eyes.

Procedure

Ten random dot stereogram pairs were constructed from duplicates of material taken from Julesz (1968). An example of the material used is given in Figure 9. When one member of the pair is viewed, no discernible pattern is present. When both members of the pair are viewed stereoscopically, however, a central form appears in front of the background due to the fusion of similar areas.

Construction of the pairs involved mounting geometric forms cut from identical black and white sections onto identical black and white backgrounds. These were then photographed. The form on the right eye's member of the pair was shifted horizontally 17 minutes of arc farther left than the form on the left eye's member of the pair. This mimics the normal disparity of left- and right-eye views produced by the lateral separation of the two eyes. The closest edge of the stimulus form was 2 degrees left or right of fixation.

The two channels containing the left-eye pattern and the right-eye pattern were activated simultaneously for a period of 100 or 120 msec., depending upon the subject's performance during practice trials. The practice session for this experiment was quite extensive. An entire set of the ten stimuli with the left- and right-eye patterns appearing in the centre of the exposure field was shown to the subject for unlimited exposure time. This was done to arrive at mutually agreeable names for the ten geometric forms (square, circle, star, X, rectangle,



Left-eye View

Right-eye View

Figure 9: Random dot stereogram pair--triangle (Experiment 10)

triangle, diamond, inverted triangle, vertical rectangle, ellipse) and also to eliminate subjects (N = 2) who had poor binocular fusion under optimal conditions. This same set of stimuli was then presented at 100 msec. to accustom the subject to the brief exposure time to be used during the experiment and to eliminate the practice effect which is quite marked with this type of material.

The subject's task during the practice and experimental trials was to name the geometric form. Forty experimental trials were presented, 20 in the left visual field and 20 in the right visual field.

Results

The data were analyzed using a 2 x 2 analysis of variance with two levels of sex (male, female) and two levels of the repeated measure, field (left, right). The mean number of forms correctly identified in the left and right visual fields for males and females appears in Table 12. The summary of the analysis may be seen in Appendix A-15. Once again, males and females showed no difference in performance on this task. Performance in the left and right visual fields, however, did differ significantly. Mean recognition of forms in the left visual field ($\bar{X} = 10.05$) was greater ($\underline{F} = 7.25$, $\underline{df} = 1,18$, $\underline{p} < .05$) than in the right visual field ($\bar{X} = 7.80$).

Summary of Results

Variations in orientation, defined by the upright or inverted position of line drawings of familiar objects (Experiment 1) did not produce visual-field differences in accuracy of recognition. Objects

TABLE 12

Perception of Random Dot Stereograms in the Left and Right Visual Fields
(Experiment 10)

	Means and Standard Deviations				
	Left	SD	Right	SD	Total
Males (M)	9.60	1.68	7.50	2.73	17.10
Females (F)	10.50	2.60	8.10	3.42	18.60
M and F	10.05		7.80		17.85

Summary of Analysis of Variance

Field: F = 7.25, df = 1,18, $p < .05$
Sex: F = 0.62, df = 1,18
No significant interaction

Note: For complete analysis of variance summary see Appendix A-15.

in the inverted orientation were more difficult to recognize than those in the upright orientation regardless of field of presentation.

Perception of orientation, defined by slope of short lines (1/8 inch) was found to be superior in the left visual field. Two separate experiments (Experiments 3 and 4) yielded this same result. Regardless of the arrangement of response choices (Figures 4 and 5) judgments of slope were more accurate in the left visual field when the response involved visual selection of a line with matching slope. It was also found that perception of slope was more accurate for lines of 90 degree orientation than for lines of ±45 degree orientation.

The experiment using longer lines (1½ inches) did not reveal the superior perception of slope in the left visual field found for short lines (Experiment 2). Long lines were more inaccurately reproduced in the bottom quadrant of the left visual field when a motor response was used to set the slope of the line. This was the only task in which sex differences were evident. Males adjusted the slope of the line on a moveable dial more accurately than did females. This finding is possibly related to a report by Witkins (1949) that women make larger errors than men in adjusting a rod to the vertical position under various conditions of field or body tilt.

Detection thresholds (Experiment 5) for horizontal, vertical, and oblique lines (1/8 inch in length) were found to be lower in the left visual field on three of five detection tasks. In these three tasks, the lines appeared in a relatively small number of left- and right-field positions. In the remaining two tasks, which produced no field differences in detection thresholds, lines were more widely positioned. Detection thresholds for dots in the left and right visual fields did not show the field differences found for lines in these positions. No consistent threshold differences as a function of type of line were found.

Judgments of whether two slanted lines were parallel (Experiment 6) were no more accurate following left-field presentation than following right-field presentation. Similarly, recall of patterned matrices (Experiment 7) did not differ as a function of field of presentation.

Binocular perception of depth under three-dimensional viewing conditions (Experiment 8) differed in the left and right visual fields. The subjects were able to judge the position of a variable rod, relative to a stationary rod, more accurately in the left visual field than in the right. This same task under monocular viewing conditions (Experiment 9) yielded no differences between perception in the left and right visual fields. An additional task involving binocular disparity as the only depth cue (Experiment 10) resulted in superior perception in the left visual field.

DISCUSSION

The present study has shown that certain visual stimuli, when presented successively to the left or right visual field are perceived more accurately in the left visual field. Such perceptual asymmetry has been related to functional differences between the left and right cerebral hemispheres (Kimura, 1961). Superior perception of stimuli in the right visual field reflects left-hemisphere specialization while superior perception in the left visual field reflects right-hemisphere specialization. Each visual half-field is represented in the contralateral visual receiving area of the brain and it is assumed that visual input is processed more efficiently if it is received directly by the hemisphere which is specialized for its processing. Language materials (words and letters) are more accurately perceived in the right visual field, the field represented in the visual receiving area of the language hemisphere. Similarly, the available evidence concerning tasks which involve spatial relations indicates that these are more accurately perceived in the left visual field, the field represented in the hemisphere specialized for spatial abilities (see Kimura, 1969).

Perception of Orientation

In the present study, varying orientation, as defined by the upright or inverted position of line drawings, did not engage the hypothesized right hemisphere mechanisms responsible for processing orientational aspects of visual input. Line drawings of familiar objects are, of course, complicated patterned stimuli and it might be expected that qualities of these stimuli, other than their orientational qualities, might determine how the brain processes them. When other stimuli were presented which possessed orientation as their key characteristic, perception was found to be more accurate in the left visual field. Perception of line slant, therefore, was assumed to be dependent upon right hemisphere mechanisms concerned with processing orientational content of perceptual input.

This finding of left-field superiority for the perception of slope was qualified to the extent that it could not be demonstrated for long lines when a motor response was required from the subject. In fact, an inexplicable inaccuracy in the bottom left quadrant was found. The problems associated with this form of the task were discussed in the Method Section. Generally, it was thought that variables other than the perception of slope (such as motor response variability, hand used for responding, and visual cues provided by the frames of the tachistoscope) influenced the subject's responses. In the studies on short lines, the frames were less useful as horizontal and vertical cues and with no motor response required, the orientational content of short lines was more accurately perceived in the visual field contralateral to the right hemisphere, thus reflecting that hemisphere's special functions.

The possibility that the left-field superiority for the perception of slant might have been due to differences in detectibility of short lines in the left and right visual fields was also explored. This possibility appears unlikely on the basis of the magnitude of the difference between the exposure duration used in the perception of slant studies and the detection thresholds found for similar stimuli. For example, Figure 6 shows that some of the lines presented for detection were at positions and angles (1°45' and 3°38') identical to those used in the third perception of slant study (Experiment 4). The mean detection threshold for lines in these positions was found to be approximately 20 msec. The 40 msec. exposure duration used in the perception of slant studies, therefore, is well above the detectibility threshold.

Quite apart from establishing that detectibility differences were not producing the field differences in the perception of slope, it was of interest to see whether visual field asymmetrics for detection of lines existed. In spite of the apparent simplicity of establishing this information and the numerous attempts to do so (Experiment 5, Tasks I to VI), no clear answer to this problem emerged. It was found that both position of stimulus material and type of stimulus material were critical in determining whether or not field differences in detection thresholds occurred. Location cues, available when the lines were not placed in a wide variety of right- or left-field positions were probably utilized in aid of detection. As more positions per field were introduced, the field differences decreased or disappeared. The left-field superiority on some of the "detection" tasks, therefore, might have been partially an artifact of the location characteristics, an effect predictable from the knowledge that localization is better in the left visual field (Kimura, 1969).

Nevertheless, dot detection thresholds (Experiment 5, Task VI) did not differ in the left and right visual fields when the same location characteristics were available. If location alone was totally responsible for the field differences found for lines, similar differences would have occurred for dots. It is probable, then, that short-line stimuli have lower detection thresholds in the left visual field than in the right. It may not be useful with these stimuli to make a distinction between detection of a slanted line and perception of the slope of such a line. Both may occur simultaneously. In support of this, the subjects reported confidently at the end of the experiment that on the majority of detection responses they could also have reported the slant of the line. Thus, the data for detection of short lines may not provide any information beyond that established by perception of orientation tasks and location tasks.

It was also noted in the detection studies of Experiment 5 that thresholds differed as a function of the type of line presented (i.e., horizontal, vertical, oblique) but that no consistent pattern was evident (see Table 7). In the first instance, the vertical lines, and in the second, the oblique lines, had higher thresholds than the other two types. It is possible that minor variations in blackness, length, or width of the stimulus lines were responsible for these differences. This is extremely plausible in the first two instances of type of line differences where lines were hand drawn with pen and ink. Awareness of such problems led to the use of Letraset in later preparations of stimulus materials and the type of line difference disappeared in the next task. The author has no explanation for their reappearance in the final task involving horizontal, vertical, and oblique lines.

Evidence in the literature indicates that changes in the orientation of a stimulus line influence the accuracy of perception of that line. Orientations of ±45 degrees are more inaccurately perceived than horizontal or vertical orientations (Andrews, 1965; Leibowitz, 1955; Marsh and Krauskopf, 1970; Nachmias, 1960; Shlaer, 1937). In regards to threshold procedures, Marsh and Krauskopf (1970) reported threshold differences as a function of orientational differences for short dim lines (10 minutes of arc at the eye). Higher detection thresholds were obtained for oblique lines than for vertical or horizontal lines. As line length increased (40 minutes) and brightness increased, differences in threshold as a function of orientation disappeared. No such differences in detection thresholds as a function of orientation were evident in the present investigation. Brightness as a variable, however, was not manipulated in the present detection studies. Both pre-exposure and exposure fields were fully illuminated. A further dissimilar point was the fact that Marsh and Krauskopf (1970) examined perception in the central part of the field while the present detection tasks involved perception to the left and right of centre. If peripheral detection has the same characteristics as central detection, one would have expected oblique lines to have higher thresholds than horizontal or vertical lines--given that the lines were sufficiently short. In the present detection tasks, retinal size of the lines was approximately 18 minutes of arc in the first three tasks involving horizontal, vertical, and oblique lines and 13 minutes of arc in the final such task, thus placing the lines within the range reported to give threshold differences. Either the brightness variable or the difference between central and peripheral viewing may account for these different results.

The effects of orientation on accuracy of perception were very evident in the perception of slant (Experiment 4). The slope of 90 degree lines was perceived significantly more accurately than the slope of lines with orientations of ±45 degrees. This finding is in complete agreement with previous reports in the literature. Andrews (1965), for example, reported that mean error for resolution of slant for short lines (6 minutes x 1 minute at the eye) in the central fovea ranged from 0.15 degrees to 0.3 degrees. Perception of orientation of the stimulus line varied systematically as the orientation of the stimulus was changed and was more accurate when the stimulus line was horizontal or vertical than when it was at ±45 degrees. Leibowitz (1955) has also reported changes in the accuracy of perception as a function of orientation of the stimulus on a vernier acuity task. Vernier acuity requires judgments of whether two halves of a line are continuous or offset. He found that orientations 45 degrees from horizontal or vertical increased the variability of vernier acuity by 20 per cent. Similarly, grating acuity (Shlaer, 1937) and fine-line acuity (Nachmias, 1960) vary as a function of stimulus orientation.

Thus, the accuracy with which a line is perceived can be influenced by changing its orientation. It would be expected, therefore, that at some level in the visual system differential activity dependent upon stimulus orientation must occur. Hubel and Wiesel (1962) have shown that this is the case in the cat's striate cortex. Cells were found which responded specifically to particular orientations of short black or white lines. Andrews (1965) suggests that similar units are present in the human visual system and that those tuned to orientations near the horizontal or vertical are more selective (respond to a narrower range of angles) than those units tuned to orientations of ±45 degrees. Such selectivity in responding would account for the reported changes in accuracy of stimulus perception as a function of changes in orientation. On the basis of the present studies, it may be added that the processing of orientational information becomes asymmetrically organized at some level in man's nervous system.

Slanted lines in pairs (Experiment 6), although still possessing orientational information, are apparently not processed by the visual system primarily on the basis of their orientational information. The requirements of this task, of course, were different from those of the perception of slope of a single slanted line. No absolute judgments of slant were made. The fact that judgments of whether two short lines were parallel did not produce visual field differences indicates that this task did not differentially engage left or right hemisphere systems as did perception of slant. Subjectively, it appears that judgments of parallel are made on the basis of noticeable differences between the spaces separating the end points of the lines (i.e., whether one pair of end points appears closer together than the other two). Thus, the entire configuration formed by the pair of lines and the space between them enters into the perceptual judgment and the orientation of each member of the line pair is not necessarily the basis for judgment.

Perception of Pattern

If the judgment of parallel can be made on the basis of the overall configuration of the stimulus, it is not surprising that visual field differences were not found, since form perception does not appear to produce field differences. In relation to this issue, Kimura (in press) has suggested that the tachistoscopic procedure, as used here, only samples activity of regions close to the primary visual receiving area. With normal adults, the tachistoscopic procedure does not yield visual field differences on tasks such as recognition of faces (Kimura, personal communication) and recognition of nonsense figures (Kimura, 1966). Both of these tasks, however, are known to be more severely impaired following damage to the right temporal lobe than to the left (Kimura, 1963; Milner, 1968; Warrington and James, 1967b). Thus, the tachistoscopic procedure is apparently not sensitive to the visual functions of the temporal lobes. As noted in the Introduction, the visual functions of the temporal lobe seem to involve pattern perception or memory for pattern and it was found that those tasks in the present investigation involving pattern showed no differences for perception in the left and right fields. That is, judgments of whether lines were parallel (Experiment 6), recall of patterned matrices (Experiment 7), and perception of line drawings (Experiment 1) did not show field differences.

It should be noted that evidence exists in the literature which appears to conflict with the above stated conclusions on neural processing of pattern information. These studies, however, have not clearly demonstrated that the pattern aspect of the task was the basis of the asymmetry. Using the tachistoscopic procedure, McKeever and Huling (1970) found left-field superiority for accuracy of drawing dotted designs but not for solid-line designs. The fact that solid-line designs failed to produce the visual field asymmetry found for dotted designs eliminates design as the underlying cause of the asymmetry. Unfortunately, McKeever and Huling (1970) do not state the method used by the judges to assess accuracy of drawing. Accuracy might include the number of dots reproduced in the design, the relative spacing, or both. If accuracy scores were influenced by the number of dots reproduced, the results might have been a product of the enumeration aspect of the task. It is known that dot enumeration is better in the left visual field (Kimura, 1966) and this is possibly the explanation of the left-field superiority on the "pattern" task.

Schell and Sachs (1970) have also reported left-field superiority on a task involving pattern perception. The subjects recognized block designs more accurately in the left visual field than in the right. Stimulus exposure, however, was over 600 msec., thus introducing the possibility of eye movements. The patterned matrices described in Experiment 7 were basically a simple version of a block design and these stimuli, presented at exposure durations too brief to allow eye movement, showed no visual field differences.

On the basis of the present investigation, and previous evidence, therefore, it must be concluded that pattern aspects of visual perception have not been shown to produce left-field superiority. This conclusion, in conjunction with the present findings on line slant, suggests that pattern and orientation engage different right hemisphere systems, both involved in the perception of external space. Lack of field differences for pattern tasks indicates that pattern does not engage the same right hemisphere system that was involved in the perception of line orientation since asymmetries were detectible there. Other visual-spatial tasks employed here, however, indicated that the perception of depth was subserved by the system overlapping that for perception of orientation.

Perception of Depth

Binocular perception of depth was superior in the left visual field suggesting that right hemisphere specialization for perception of position or location applies to location in the third dimension as well. Since monocular viewing produced no visual field differences, depth cues discriminable monocularly apparently do not differentially engage perceptual systems of the left or right hemisphere. This conclusion, of course, only pertains to the cues available in this experiment. Movement parallax as a monocular depth cue could not operate since the head was motionless. This particular cue, therefore, cannot be eliminated as a source of perceptual asymmetries. A number of other monocular cues to depth, however, were available in this viewing situation. Actual size of the retinal image, for example, varied as a function of distance. In this case, only the width of the retinal images was free to vary since the vertical lengths were held constant by the one inch slit through which the subject viewed the rods. Accommodation and the resulting blur in retinal images due to differences in distances of the rods would provide information for spatial discrimination. Patterns of light and shade on the rods could also serve as a depth cue.

Since these monocular cues to depth did not result in visual field differences, they may be eliminated as sources of information utilized more efficiently by the right hemisphere than by the left. It may be concluded that the binocular cues provided the source of such information. This conclusion was confirmed by the results of a task in which binocular disparity was the only depth cue available. Random dot stereograms viewed stereoscopically in the left or right visual fields were reported more accurately when they appeared in the left visual field. Accurate report on this task required fusion of the disparate portions of the random dot patterns. Thus, disparate binocular input is more effectively utilized by the right hemisphere than by the left.

A neural basis for encoding binocular disparity may be present at the level of the cat's striate cortex (Barlow, Blakemore, and Pettigrew, 1967; Blakemore, 1970; Nikara, Bishop, and Pettigrew, 1968). Over seventy percent of the cells in the visual cortex of both cat and monkey are influenced by stimulating either eye (Hubel and Wiesel, 1962, 1968). These binocular neurons respond to specific disparities of the images on the two retinae and the optimal disparity varies from cell to cell (Barlow et al., 1967; Nikara et al., 1968). Thus, systems of coding both depth and stimulus orientation (Hubel and Wiesel, 1962, 1968) are present at the level of the visual receiving cortex in cats and monkeys.

The asymmetries in the perception of orientation and depth established by the present thesis in man may possibly arise at the level of the primary receiving area, since means of processing such information are clearly evident there in other animals. On the other hand, parts of the right hemisphere may simply utilize information from the primary receiving area more efficiently than the left hemisphere. If these asymmetries do arise at levels beyond the primary receiving areas, the evidence most strongly implicates the parietal and occipital regions of the right hemisphere.

In conclusion, this thesis has provided evidence of asymmetries in two aspects of visual-spatial perception. Perception of line slant and perception of depth are both superior in the left visual field, the field represented in the visual receiving area of the right hemisphere. Since earlier evidence indicated that the right hemisphere plays a special role in processing visual-spatial input, the assumption that perceptual asymmetries reflect hemispheric asymmetries is supported by these data. The data suggest that specific aspects of visual-spatial input more dependent upon the right hemisphere than the left include orientational content and information based on binocular disparity.

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APPENDIX A

Analysis of Variance Tables

Appendix A-1	Familiar Objects: Experiment 1
Appendix A-2	Slant: Experiment 2
Appendix A-3	Slant: Experiment 3
Appendix A-4	Slant: Experiment 4
Appendix A-5	Slant: Experiment 4
Appendix A-6	Detection: Experiment 5, Task I
Appendix A-7	Detection: Experiment 5, Task II
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Appendix A-1

Analysis of Variance for the Perception of Upright or Inverted Line Drawings of Familiar Objects in the Left and Right Visual Fields (Experiment 1)

Source	SS	df	MS	F
Between Ss	294.430	31		
Sex (Male, Female)	25.383	1	25.383	2.83
Ss Within	269.047	30	8.968	
Within Ss	561.250	96		
Field (Left, Right)	0.008	1	0.008	0.01
Sex x Field	0.008	1	0.008	0.01
Field x Ss	34.734	30	1.158	
Orientation (Up., Inv.)	328.320	1	328.320	86.60***
Sex x Orientation	5.695	1	5.695	1.50
Orientation x Ss	113.734	30	3.791	
Field x Orientation	0.195	1	0.195	0.08
Sex x Field x Orient.	2.258	1	2.258	0.89
Field x Orient. x Ss	76.297	30	2.543	
Total	855.680	127		

*** $p < .001$

Appendix A-2

Analysis of Variance for the Perception of Line Slant in the Left and Right Visual Fields (Experiment 2)

Source	SS	df	MS	F
Between Ss	835.810	27		
Sex (Male, Female)	244.556	1	244.556	10.75**
Ss Within	591.254	26	22.741	
Within Ss	803.562	84		
Field (Left, Right)	36.002	1	36.002	6.75*
Sex x Field	7.252	1	7.252	1.36
Field x Ss	138.683	26	5.334	
Location (Upper, Lower)	74.752	1	74.752	9.01**
Sex x Location	0.056	1	0.056	0.01
Location x Ss	215.630	26	8.293	
Field x Location	93.806	1	93.806	10.28**
Sex x Field x Location	0.181	1	0.181	0.02
Field X Location x Ss	237.201	26	9.123	
Total	1639.373	111		

** $p < .01$

* $p < .05$

Appendix A-3

Analysis of Variance for the Perception of Slant in the Left and Right Visual Fields (Experiment 3)

Source	SS	df	MS	F
Between Ss	484.386	21		
Sex (Male, Female)	6.568	1	6.568	0.28
Ss Within	477.818	20	23.891	
Within Ss	223.500	22		
Field (Left, Right)	73.841	1	73.841	10.22**
Sex x Field	5.114	1	5.114	0.71
Field x Ss	144.546	20	7.227	
Total	707.886	43		

** $p < .01$

Appendix A-4

Analysis of Variance for the Perception of Slant in the Left and Right Visual Fields (Experiment 4)

Source	SS	df	MS	F
Between Ss	2517.875	19		
Sex (Male, Female)	50.625	1	50.625	0.37
Ss Within	2467.250	18	137.069	
Within Ss	560.500	20		
Field (Left, Right)	133.225	1	133.225	5.82*
Sex x Field	15.625	1	15.625	0.68
Field x Ss	411.650	18	22.870	
Total	3078.375	39		

* $p < .05$

Appendix A-5

Analysis of Variance for Accuracy of Perception of Vertical and Oblique Lines in the Left and Right Visual Fields (Experiment 4)

Source	SS	df	MS	F
Between Ss	11.222	19		
Within Ss	18.000	60		
Field (Left, Right)	1.653	1	1.653	5.20*
Field x Ss	6.034	19	0.318	
Type of Line (V,O)	3.003	1	3.003	15.75***
Type of Line x Ss	3.622	19	0.191	
Field x Type of Line	0.253	1	0.253	1.400
Field x Line x Ss	3.434	19	0.181	
Total	29.222	79		

*** $p < .001$

* $p < .05$

Appendix A-6

Analysis of Variance for the Detection of Slanted Lines in the Left and Right Visual Fields (Experiment 5, Task I)

Source	SS	df	MS	F
Sex (Male, Female)	129.507	1	129.507	1.73
S	1498.147	20	74.907	
Field (Left, Right)	190.921	1	190.921	21.52***
Sex x Field	2.506	1	2.506	0.28
Field x S	177.416	20	8.871	
Type of Line (H,V,O)	127.503	2	63.751	10.68***
Sex x Type of Line	32.454	2	16.227	2.72
Type of Line x S	238.751	40	5.969	
Field x Type of Line	39.222	2	19.611	10.94***
Sex x Field x Line	6.047	2	3.023	1.68
Field x Line x S	71.730	40	1.793	

*** $p < .001$

Appendix A-7

Analysis of Variance for the Detection of Lines in the Left and Right Visual Fields (Experiment 5, Task II)

Source	SS	df	MS	F
Between Ss	2330.422	19		
Sex (Male, Female)	75.400	1	76.400	0.61
Ss Within	2254.022	18	125.223	
Within Ss	353.573	100		
Field (Left, Right)	21.463	1	21.463	3.17
Sex x Field	3.250	1	3.250	0.48
Field x Ss	121.734	18	6.763	
Type of Line (H,V,O)	36.291	2	18.145	6.31**
Sex x Type of Line	13.520	2	6.760	2.35
Type of Line x Ss	103.544	36	2.876	
Field x Type of Line	11.470	2	5.735	5.05*
Sex x Field X Line	1.382	2	0.691	0.61
Field x Line x Ss	40.919	36	1.137	
Total	2683.995	119		

** $p < .01$

* $p < .05$

Appendix A-8

Analysis of Variance for the Detection of Lines in the Left and Right Visual Fields (Experiment 5, Task III)

Source	SS	df	MS	F
Between Ss	1773.956	19		
Sex (Male, Female)	83.751	1	83.751	0.89
Ss Within	1690.205	18	93.900	
Within Ss	175.594	100		
Field (Left, Right)	47.817	1	47.817	15.52**
Sex x Field	1.576	1	1.576	0.51
Field x Ss	55.451	18	3.081	
Type of Line (H,V,O)	0.145	2	0.072	0.07
Sex x Type of Line	0.164	2	0.082	0.08
Type of Line x Ss	38.629	36	1.073	
Field x Type of Line	0.303	2	0.152	0.18
Sex x Field x Line	1.389	2	0.694	0.83
Field x Line x Ss	30.121	36	0.837	
Total	1949.550	119		

** $p < .01$

Appendix A-9

Analysis of Variance for the Detection of Lines in the Left and Right Visual Fields (Experiment 5, Task IV)

Source	SS	df	MS	F
Between Ss	7716.218	19		
Sex (Male, Female)	96.517	1	96.517	0.23
Ss Within	7619.701	18	423.317	
Within Ss	494.371	100		
Field (Left, Right)	38.104	1	38.104	3.55
Sex x Field	26.395	1	26.395	2.46
Field x Ss	193.279	18	10.738	
Type of Line (H,V,O)	24.932	2	12.466	4.30*
Sex x Type of Line	10.679	2	5.340	1.84
Type of Line x Ss	104.476	36	2.902	
Field x Type of Line	3.501	2	1.751	0.71
Sex x Field x Line	4.529	2	2.264	0.92
Field x Line x Ss	88.476	36	2.458	
Total	8210.588	119		

* $p < .05$

Appendix A-10

Analysis of Variance for the Detection of Oblique Lines in the Left and Right Visual Fields (Experiment 5, Task V)

Source	SS	df	MS	F
Between Ss	356.306	13		
Within Ss	9.352	14		
Field (Left, Right)	0.088	1	0.088	0.12
Residual	9.264	13	0.713	
Total	365.658	27		

Appendix A-11

Analysis of Variance for the Detection of Dots in the Left and Right Visual Fields (Experiment 5, Task VI)

Source	SS	df	MS	F
Between Ss	141.864	21		
Within Ss	11.731	22		
Field (Left, Right)	0.751	1	0.751	1.44
Residual	10.980	21	0.523	
Total	153.595	43		

Appendix A-12

Analysis of Variance for Judgments of Parallel-Nonparallel in the Left and Right Visual Fields (Experiment 6)

Source	SS	df	MS	F
Between Ss	50.075	29		
Sex (Male, Female)	1.875	1	1.875	1.09
Ss Within	48.200	28	1.721	
Within Ss	101.250	90		
Field (Left, Right)	3.008	1	3.008	2.84
Sex x Field	0.075	1	0.075	0.07
Field x Ss	29.667	28	1.060	
Location (Upper, Lower)	1.008	1	1.008	0.80
Sex x Location	0.208	1	0.208	0.16
Location x Ss	35.533	28	1.269	
Field x Location	0.675	1	0.675	0.63
Sex x Field x Location	1.008	1	1.008	0.94
Field x Location x Ss	30.067	28	1.074	
Total	151.325	119		

Appendix A-13

Analysis of Variance for Accuracy of Binocular Depth Perception in the Left and Right Visual Fields (Experiment 8)

Source	SS	df	MS	F
Between Ss	203.477	21		
Sex (Male, Female)	1.841	1	1.841	0.18
Ss Within	201.636	20	10.082	
Within Ss	181.500	22		
Field (Left, Right)	34.568	1	34.568	4.93*
Sex x Field	6.568	1	6.568	0.94
Field x Ss	140.364	20	7.018	
Total	384.977	43		

* $p < .05$

Appendix A-14

Analysis of Variance for Accuracy of Monocular Depth Perception in the Left and Right Visual Fields (Experiment 9)

Source	SS	df	MS	F
Between Ss	183.738	19		
Sex (Male, Female)	2.112	1	2.112	0.21
Ss Within	181.625	18	10.090	
Within Ss	177.250	60		
Field (Left, Right)	0.612	1	0.612	0.13
Sex x Field	1.012	1	1.012	0.21
Field x Ss	85.125	18	4.729	
Eye (Left, Right)	0.012	1	0.012	0.01
Sex x Eye	3.612	1	3.612	1.66
Eye x Ss	39.125	18	2.174	
Field x Eye	0.012	1	0.012	0.01
Sex x Field x Eye	2.112	1	2.112	0.83
Field x Eye x Ss	45.625	18	2.535	
Total	360.988	79		

Appendix A-15

Analysis of Variance for Recognition of Random Dot Stereogram Patterns in the Left and Right Visual Fields (Experiment 10)

Source	SS	df	MS	F
Between Ss	170.275	19		
Sex (Male, Female)	5.625	1	5.625	0.62
Ss Within	164.650	18	9.147	
Within Ss	176.500	20		
Field (Left, Right)	50.625	1	50.625	7.25*
Sex x Field	0.225	1	0.225	0.03
Field x Ss	125.650	18	6.981	
Total	346.775	39		

* $p < .05$

APPENDIX B

Newman-Keuls Analyses

Appendix B-1	Field x Location Interaction: Experiment 2
Appendix B-2	Type of Line Main Effect: Experiment 5, Task I
Appendix B-3	Type of Line Main Effect: Experiment 5, Task II
Appendix B-4	Type of Line Main Effect: Experiment 5, Task IV
Appendix B-5	Field x Type of Line Interaction: Experiment 5, Task I
Appendix B-6	Field x Type of Line Interaction: Experiment 5, Task II

Appendix B-1

Newman-Keuls Analysis of the Interaction Between Visual Field and Location of Stimulus in the Upper or Lower Quadrant (Experiment 2)

Ordered Mean Error (Degrees) in the Representation of Slant in Each Quadrant

		UL 6.9	LR 7.4	UR 7.6	LL 10.4
UL	6.9	-	.5	.7	3.5*
LR	7.4		-	.2	3.0*
UR	7.6			-	2.8*
LL	10.4				-

* $p < .05$

(UL = Upper Left, LR = Lower Right, etc.)

Critical Difference

r	df	Critical Difference
2	24	2.92 (.57) = 1.7
3	24	3.53 (.57) = 2.0
4	24	3.90 (.57) = 2.2

Appendix B-2

Newman-Keuls Analysis of Differences in Detection Thresholds as a Function of Type of Line (Experiment 5, Task I)

Ordered Mean Thresholds (msec.) for Detection of Horizontal, Vertical, and Oblique Lines (H,V,O)

	H 11.49	O 11.95	V 13.77
H 11.49	-	.5	2.3*
O 11.95		-	1.8*
V 13.77			-

* $p < .05$

Critical Difference

$\underline{r}$	df	Critical Difference
2	40	2.86 (.37) = 1.1
3	40	3.44 (.37) = 1.3

Note: $\underline{r}$ = number of steps between ordered means

Appendix B-3

Newman-Keuls Analysis of Differences in Detection Thresholds as a Function of Type of Line (Experiment 5, Task II)

Ordered Mean Thresholds (msec.) for Detection of Horizontal, Vertical, and Oblique Lines (H,V,O)

	V 13.36	H 13.76	O 14.68
V 13.36	-	.40	1.32*
H 13.76		-	.92*
O 14.68			-

* $p < .05$

Critical Difference

r	df	Critical Difference
2	30	2.89 (.27) = .77
3	30	3.49 (.27) = .94

Note: r = number of steps between ordered means

Appendix B-4

Newman-Keuls Analysis of Differences in Detection Thresholds as a Function of Type of Line (Experiment 5, Task IV)

Ordered Mean Thresholds (msec.) for Detection of Horizontal, Vertical, and Oblique Lines (H,V,O)

		O 21.66	V 22.33	H 22.77
O	21.66	-	.67	1.11*
V	22.33		-	.44
H	22.77			-

* $p < .05$

Critical Difference

r	df	Critical Difference
2	30	2.89 (.27) = .78
3	30	3.49 (.27) = .94

Note: r = number of steps between ordered means

Appendix B-5

Newman-Keuls Analysis of the Interaction Between Visual Field and Type of Stimulus Line (Experiment 5, Task I)

Ordered Mean Thresholds (msec.) for Detection of Horizontal, Vertical, and Oblique Lines (H,V,O) in the Left and Right (L,R) Visual Fields

		LO 10.85	LH 10.90	LV 11.85	RH 12.08	RO 13.06	RV 15.68
LO	10.85	-	.05	1.00*	1.23*	2.21*	4.85*
LH	10.90		-	.95*	1.18*	2.16*	4.78*
LV	11.85			-	.23	1.21*	3.83*
RH	12.08				-	.98*	3.60*
RO	13.06					-	2.62*
RV	15.68						-

* $p < .05$

Critical Difference

<u>r</u>	<u>df</u>	Critical Difference
2	40	2.86 (.29) = .83
3	40	3.44 (.29) = 1.00
4	40	3.79 (.29) = 1.10
5	40	4.04 (.29) = 1.17
6	40	4.23 (.29) = 1.23

Note: <u>r</u> = number of steps between ordered means

Appendix B-6

Newman-Keuls Analysis of the Interaction Between Visual Field and Type of Stimulus Line (Experiment 5, Task II)

Ordered Mean Thresholds (msec.) for Detection of Horizontal, Vertical, and Oblique Lines (H,V,O) in the Left and Right (L,R) Visual Fields

		VL 12.96	HL 13.70	VR 13.76	HR 13.81	OL 13.86	OR 15.49
VL	12.96	-	.74	.80	.85	.90	2.53*
HL	13.70		-	.06	.11	.16	1.79*
VR	13.76			-	.05	.10	1.73*
HR	13.81				-	.05	1.68*
OL	13.86					-	1.63*
OR	15.49						-

* $p < .05$

Critical Difference

_r_	df	Critical Difference
2	30	2.89 (.24) = .69
3	30	3.49 (.24) = .84
4	30	3.84 (.24) = .92
5	30	4.10 (.24) = .98
6	30	4.30 (.24) = 1.03

Note: _r_ = number of steps between ordered means