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DIFFERENTIAL EFFECTS ON REACTION TIME, ACCURACY AND
SIGNAL DETECTION

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HEMISPHERIC ASYMMETRY IN VISUO-SPATIAL PROCESSING: DIFFERENTIAL EFFECTS ON REACTION TIME, ACCURACY AND SIGNAL DETECTION.

by

BETTY KOSS

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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ABSTRACT

HEMISPHERIC ASYMMETRY IN VISUO-SPATIAL PROCESSING: DIFFERENTIAL EFFECTS ON REACTION TIME, ACCURACY AND SIGNAL DETECTION.

by

Betty Koss

Adviser: Professor Doreen Berman.

An investigation was carried out to study the relative influence of perceptual sensitivity and decisional strategies on cerebral asymmetry in recognition of slopes. The variables looked at were the stimulus condition and visual field stimulated, as well as the eye and hand utilized in the task. The dependent variables included the reaction time for correct responses, percentage of accurate responses and two signal detection measures based on rating scales. The stimuli were black rectangles positioned in different orientations in the left or right visual field. They were presented to six right handed male subjects under two stimulus conditions. In stimulus condition vertical-oblique (V-O), rectangles were oriented either 90 degrees or 95 degrees from the horizontal, whereas in stimulus condition oblique-oblique (O-O), rectangles were oriented either 95 degrees or 100 degrees from the horizontal. For both conditions, the subject's task was to respond to the presentation of the stimulus oriented 95 degrees from horizontal.

Hemispheric asymmetries were reflected differently by the various laterality indices. With accuracy, an overall superiority for the right hemisphere was observed, along with an advantage for stimulus condition V-0 and for the right eye. In comparison, with reaction time for correct responses, none of the main effects reached significance, but there was a highly significant interaction between visual field and stimulus condition. Also, stimulus condition 0-0 was processed faster in the right visual field of the right eye than in the left visual field. Results from signal detection analysis extended the findings of RT analysis by showing that the superior performance noted when stimulus condition 0-0 was projected to the right visual field of the right eye was dependent on decisional biases and not hemispheric superiority. The results are contrasted with those obtained by Umilta et al. (1974).

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Je dédie cette dissertation à Gregory qui a accepté, sans bien comprendre, ces heures d'interminables absences et de présence douteuse, et à toi Robert, dont la patience fut inlassable et le devouement sans borne.

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CHAPTER 1

INTRODUCTION

The topic of laterality of function has enjoyed extensive popularity within the last decade. Asymmetry in human cerebral functioning has been linked to the development of language (Molfese, Freeman & Palermo, 1975), and thereby contrasted to the bilateral cerebral equipotentiality commonly, though not universally, found in infrahuman brains (Chapple, 1977; Dewson, 1977; Hamilton, 1977). Lateralized cerebral asymmetry has also been studied in relation to anatomical asymmetries of the brain (Geschwind & Levitsky, 1968; Wada, Clark & Hamm, 1975), development and heredity (Collins, 1975; Levy, 1974), differential organization of the brain in males and females (Buffery & Gray, 1972; Kimura, 1969, 1973) and hand preference (Hecaen & Piercy, 1956; Rasmussen & Milner, 1975).

Despite a proliferation of research evidenced by the many symposia and review volumes on this topic (e.g. Dimond & Beaumont, 1974; Dimond & Blizard, 1977; Harnard,S., Doty, R. W., Goldstein, L., Jaynes, J., & Krauthamer, 1977; Kinsbourne, 1978), there is a great deal of uncertainty regarding the exact nature and extent of functional asymmetries and the locus of their hemispheric representation. The left hemisphere is generally considered to be the locus for linguistic capabilities, for analytic and sequential processing and is thought to be dominant for most cognitive processes (Milner, 1974). There is considerably less information regarding the role of the right hemisphere which was, until recently, thought of as the mute, passive companion to the dominant left hemisphere (Sperry, 1974). The right hemisphere is now often considered to be more competent than the left hemisphere for holistic tasks (Levy, 1974; Sperry, 1974), for musical abilities (Milner, 1962; Kimura, 1964), emotions (Dimond, Farrington & Johnson, 1976), facial recognition (Young & Ellis, 1976) and spatial representation (De Renzi, 1978). There is mixed evidence however regarding the sole representation of these functions in the right hemisphere (Bever & Chiarello, 1974; Marzi, Brizzolara, Rizzolatti, Umilta & Berlucchi, 1974; White, 1971; Yin, 1970).

The purpose of this thesis is to clarify some of the issues pertaining to asymmetry of visuo-spatial processing. The relevant literature on asymmetrical processing of spatial tasks will be reviewed in both patients and normal subjects, and the main models of lateralization of function will be discussed and contrasted before the rationale and the design of this experiment are presented.

Review of the Literature on Asymmetries of Spatial Functions

Evidence for asymmetry of spatial functions comes from clinical observation of patients with unilateral cerebral lesions, studies of split-brain patients and from lateralized tachistoscopic presentation of stimuli to normal subjects.

Patients

Unilateral lesions. In contrast to the accumulation of clinical evidence on the prominent role of the left hemisphere in language, deficits following lesions of the right hemisphere have been harder to pinpoint. Right hemisphere lesions have generally been related to disorders of visual perception and of the analysis of spatial properties of inner and external space (De Renzi & Faglioni, 1967; Piercy, 1964; Warrington, 1970). This generalization is based on the observation that patients with right posterior hemisphere lesions frequently show disturbances in orientation, and topographical memory loss. They also do worse than other groups on tasks of rapid visual identification, picture comprehension and picture arrangement (Ettlinger, 1960; Milner, 1968; Warrington & James, 1967). McFie and Zangwill (1960) have demonstrated inaccurate perception of horizontality and verticality in patients with right hemisphere lesions. Drawings made by patients with right sided lesions are typically tilted, or show mirror reversal, crowding or spatial distortions (Critchley, 1953/1971). The patients apparently are unable to go beyond a "piecemeal approach" (Paterson & Zangwill, 1944).

Spatial deficits are usually considered to be more frequent with right sided than with left sided lesions although the evidence is mixed. For instance, unilateral neglect of the contralateral hemispace is more often associated with right than left hemisphere damage (Battersby, Bender, Pollack & Kahn, 1956; Costa, Vaughan, Horwitz & Ritter, 1969; De Renzi & Faglioni, 1967; Hecaen & de Ajuriaguerra, 1956). Unilateral neglect is also expressed by a deficit of body image often accompanied by belief that the left limbs are missing (hemisomatognosia) and lack of awareness or denial of disability (anosognosia) (Friedland & Weinstein, 1977; Weinstein & Kahn, 1955). Multiple theories have been proposed to explain the rarity of unilateral neglect with left hemisphere damage. Battersby et al. (1956) explored the possibility that aphasia obscured the manifestation of neglect after left hemisphere damage. De Renzi, Faglioni and Scotti (1970) have postulated a "mutilated representation of space" as the basic cognitive deficit. According to this view, neglect is more prevalent with right sided lesions because the right hemisphere is considered to be the locus of visuospatial processing. Alternatively, neglect may be associated with right hemisphere damage because this hemisphere may be endowed with the representation of body image (McFie, Piercy & Zangwill, 1950).

Another interesting deficit related to spatial organization which has been reported in patients with right hemisphere lesions is prosopagnosia. Prosopagnosia is characterized by a difficulty in recognition and identification of familiar faces. In extreme cases the affected person is incapable of recognizing his own face in the mirror (Bornstein, 1963). Such cases are extremely rare and, in fact, the existence of such a dysfunction has been seriously doubted by Critchley (1953/1971). Using quantitative methods, however, Milner (1968) showed that right hemisphere patients were indeed poorer in recognition of faces. However, what factors make face perception more dependent on the right hemisphere than the left is not yet elucidated.

Constructional apraxia, a defect of visual control of normal activity, was originally considered to be due to a lesion in the left hemisphere (Kleist, 1934). Nevertheless, following Paterson and Zangwill's paper (1944), most studies have supported the hypothesis that the more severe constructional disabilies are seen with patients with right hemisphere lesions (Arrigoni & De Renzi, 1964; Benton, 1962 (cited by Benton, 1979); Piercy, Hecaen & de Ajuriaguerra, 1960). However, a thorough review of the literature led Critchley (1953/1971) to conclude that the evidence for a right hemisphere localization of constructional apraxia was not sufficient, that both left and right parietal lobes were important for spatial skills. In this regard, Benton and Fogel (1962) and Arrigoni and De Renzi (1964) demonstrated the presence of constructional disturbances after damage to either hemisphere, although right hemisphere lesions produced quantitatively greater deficits.

Other forms of spatial deficit may be left brain originated. An example would be left-right disorientation, characterized by inability to tell the right from the left hand. Patients may show confusion for right-left orientation on all parts of their anatomy, on photographs, on inanimate human representations and also may make mistakes in external space. Left-right disorientation is considered part of Gerstmann's syndrome, along with bilateral finger agnosia, agraphia and dyscalculia (Gerstmann, 1940). Although the occurence of these four signs together has been infrequent enough to induce scepticism regarding their value as a clinically significant entity, all authors agree on the localizing value of these signs. Gerstmann's syndrome is always related to left hemisphere lesions (Lishman, 1978). As a spatial deficit, left-right disorientation by itself warrants some comments. It is remarkable, Critchley (1953/1971) argued, that "this disorientation applies only, or at any rate mainly, to lateral dimension in space" (p.214). No difficulty is seen with similar spatial concepts such as "up versus down", "above and below" or "front and rear". This restriction in disorientation to only left and right suggested to Critchley that this was a true confusion in spatial orientation and not a simple semantic disturbance.

Several authors have recently suggested that the differences between the two hemispheres may be qualitative, rather than quantitative, with spatial abilities being more focalized in the left hemisphere and more diffuse in the right hemisphere (Benson & Barton, 1970; De Renzi & Faglioni, 1967; McFie & Zangwill,1960). Others, although agreeing with the idea of qualitative differences between the cerebral hemispheres, found the opposite relationship (Piercy et al., 1960). Yet others, such as Bisiach, Nichelli and Spinnler (1976), questioned whether there are differences between left and right hemisphere lesions at all. They divided a brain-damaged population into left versus right and anterior versus posterior lesions. The perceptual deficits were more marked in the group with posterior lesions than in the group with anterior lesions, with no significant differences between the left and right hemispheres. The important variable appeared to be the anterior versus posterior placement of the lesion, rather than the traditional left-right hemispheric dichotomy. Thus, although the exact nature of hemisphere involvement in spatial orientation is still imperfectly understood, both hemispheres seem to have a considerable capacity for spatial processing. Disorders of visual perception and visuo-spatial analysis are more frequent and more severe, however, with right than with left hemisphere lesions.

Split-brain. Another way to study the respective roles of the cerebral hemispheres emerged with the split-brain technique. A treatment for intractable epilepsy, this technique consists in the surgical disconnection of the two cerebral hemispheres by severance of the corpus callosum. The interest of studies on split-brain patients resides in the fact that after surgery, the two hemispheres are capable of functioning independently of each other, although the unity of behavior is apparently respected. Studies of disconnected minor hemisphere function suggest that at the basic level of perception of line orientation and direction of movement the right hemisphere predominates (Nebes, 1974). The right hemisphere appears also to be more concerned with spatially related wholes, in contrast to the left hemisphere which is more concerned with details of tasks to which verbal labels can be applied (Levy, Trevarthen & Sperry, 1972; Zaidel & Sperry, 1973). Sperry (1974) summarized the findings from commisurotomized patients in the following way:

> There is a "strong lateralization and dominance for speech, writing and calculation in the disconnected left hemisphere in right handed patients. The language dominant hemisphere is also the more aggressive, executive, leading hemisphere in the control of the motor system. The mute, minor hemisphere by contrast seems to be carried along, much as a silent passenger.
> . . . Though predominantly mute and generally inferior in all performances involving language or linguistic or mathematical reasoning, the minor hemisphere is nevertheless clearly the superior member for certain types of tasks.
> . . . They involve the apprehension and processing of spatial patterns, relations and transformations" (p.11).

In addition, according to Levy (1974),

> "The right side of the brain is extremely poorly organized for temporal analysis, abstract conceptualization, detailed feature detection,linguistic coding and phonological analysis. The analyzing, conceptualizing, talkative left hemisphere . . . provides only an ill-defined spatial coordinate system, visual images fragmented and synthetic processes which . . . extract only a small fraction of the information contained in the visual stimulus" (p.167).

In summary, research from split-brain patients suggests that there is a basic difference in general functioning between the two hemispheres. The left hemisphere is characterized in terms of complex analytic processing whereas the right hemisphere is characterized by simple gestalt or holistic organization (Bogen & Vogel, 1962; Gazzaniga, 1970; Geschwind & Kaplan, 1962; Levy, 1969).

Normal Subjects

In normal subjects, most of the current knowledge on lateral differences comes from data obtained from tachistoscopic presentation of visual stimuli, dichotic listening and electrophysiological recording. Of these techniques, one of the most significant is visual tachistoscopic presentation. Consequently, this technique was employed in the present experiment and in the following discussion only studies involving visual tachistoscopic presentation are reviewed.

There are ongoing controversies regarding the mechanisms and nature of hemispheric specialization in the normal brain. Primarily based on the literature coming from tachistoscopic presentation, the organization of cerebral asymmetries is variously attributed to acquired reading habits, to structural differences between the hemispheres, to the informational content of the task, and to attentional factors. These models of lateral differences, which need not be mutually exclusive, are reviewed below.

Models of Lateralization of Function

Acquired Habits

Mishkin and Forgays (1952) have been credited with the first report of differential performance following stimulus presentation in the left and right visual fields (LVF and RVF). They found, for right handers, better recognition for English words flashed to the right than to the left of a central fixation point (RVF) and better recognition for Yiddish words flashed to the left than the right of the fixation point (LVF). The authors interpreted their results in terms of a more effective neural organization developed in the corresponding hemisphere, acquired through opposite reading habits. Heron (1957) supported this view, even though his results were in direct opposition to those of Mishkin and Forgays. The discrepancy was attributed to procedural differences, namely Heron's use of bilateral instead of unilateral stimulus presentation. To reconcile the two findings, Heron proposed the existence of a "postexposural scanning mechanism" reading a rapidly decaying memory trace. According to this interpretation, bilateral presentation of English words would lead to a better performance for stimuli presented in the LVF than for stimuli presented in the RVF, since readings of the postexposural memory trace would go from left to right, based on acquired reading habits. Orbach (1967) obtained slightly different results with the same paradigm. When English and Hebrew words were presented to Hebrew speaking subjects, English was invariably recognized better in the RVF than in the LVF. However right and left-handers differed in their recognition of Hebrew words: right handers recognized more Hebrew words in the RVF whereas left handers recognized more Hebrew words in the LVF. On this basis, Orbach questioned the generality of an interpretation based on acquired habits and suggested instead that in addition to directional scanning and structural features of the two languages, cerebral dominance might have played an important role in influencing the differential recognition of words in the two VF.

Structural Differences

Kimura (1966) extended the concept of cerebral dominance by positing that perceptual asymmetries are the result of basic processing differences between the cerebral hemispheres. Following the neurological tradition, she proposed that the left hemisphere was specialized for handling material of a verbal nature. The right hemisphere was considered to be better for processing of non-verbal stimuli along a visuo-spatial dimension. This view has enjoyed wide acceptance and currently prevails over the hypothesis that acquired habits cause asymmetries in visual perception. An abundance of present day research makes it apparent that, as Kimura suggested, verbal material produces a differential accuracy favoring the RVF. This finding holds across a variety of methodological variations (see Bryden, 1965, 1966; Kimura, 1966; McKeever & Huling, 1970; White, 1969 and others). Lateral differences favoring the LVF are less commonly found and appear more variable. Kimura (1961, 1966, 1969) found LVF superiority for the enumeration and localization of dots. Similar results have been reported by Davidoff (1977), Filbey and Gazzaniga (1969) and Jeeves and Dixon (1970). Greater efficiency for stimuli presented in the LVF has also been demonstrated for tasks such as stereoscopic depth perception (Carmon & Bechtold, 1969; Durnford & Kimura,1971), recognition of faces (Geffen, Bradshaw & Wallace, 1971; Rizzolatti, Umilta & Berlucchi, 1971; Young & Ellis, 1976) and recognition of slanted lines (Atkinson & Egeth, 1973; Kimura & Durnford, 1974; Umilta, Rizzolatti, Marzi, Zamboni, Franzini, Camarda & Berlucchi, 1973, 1974). These findings fit well with the hypothesis of a right hemisphere specialization for visuo-spatial stimuli. However, notable exceptions have weakened the interpretation of cerebral asymmetry based on the nature of the stimulus. Several studies using stimuli of a clearly visuo-spatial nature, such as geometric nonsense or random forms or curved lines, failed to reveal VF differences (Bryden, 1960; Bryden & Rainey, 1963; Heron, 1957; Longden, Ellis & Iversen, 1976; Terrace, 1959). Furthermore, Kimura's reports of LVF superiority for dot localization were not replicated by two groups of researchers (Bryden, 1976; Pohl, Butters & Goodglass, 1972). In addition, outline drawings of familiar objects have yielded a RVF superiority (Bryden & Rainey, 1963; Wycke & Ettlinger, 1961), while discrimination of line orientation has been shown to produce more accurate performance in the RVF under certain conditions (White, 1971). Even face recognition, reputedly the most robust stimulus to elicit LVF superiority (Geffen et al., 1971; Rizzolatti,et al., 1971; Yin, 1970; Young & Ellis, 1976), has on occasion yielded opposite VF supremacy. Patterson and Bradshaw (1975) obtained RVF superiority when they presented schematic faces which varied from memory items by only one of three possible features. Similarly, increasing familiarity with novel stimuli (e.g. unknown faces) has produced shifts from right toward left hemisphere superiority (Marzi et al., 1974; Umilta, Bagnara & Simion, 1978).

Shifts or reversals in VF superiorities can also occur for verbal materials. Several studies have indicated that a RVF superiority could be annulled by varying the number of letters of an array

(Bryden, 1966), the spacing between the letters (Hayashi & Bryden, 1967), or the type face used (Bryden & Allard, 1976). Similarly, the RVF advantage commonly obtained with verbal matching disappeared or reversed itself to a LVF superiority when a physical identity strategy was required for the matching (Cohen, 1972; Geffen, Bradshaw & Nettleton, 1972; Gibson, Dimond & Gazzaniga, 1972).

It thus seems that an interpretation of cerebral asymmetry based on the type of stimulus to be processed is not entirely satisfactory. One difficulty in relating cerebral asymmetry to the processing of various types of materials resides in the equivocality of the definition of "verbal" versus "non verbal". Indeed, verbal labels can easily be attached to such non-verbal stimuli as simple geometric forms, familiar objects or simple spatial orientations. It is thus not uncommon for stimuli to belong to both the verbal and the non-verbal categories.

Information-Processing

The study of commisurotomized patients has brought forth the view that the two hemispheres use distinct and independent processing mechanisms and that the nature of the processing rather than the type of stimulus is the factor determining lateral differences. The model of hemispheric specialization based on the split-brain preparation proposes a processing dichotomy in terms of an analytic versus holistic type of processing, respectively the domain of the left and right hemispheres.

This concept has enjoyed wide popularity and many authors have attempted to redefine the idea of a processing dichotomy in their own terms. Egeth and Epstein (1972) proposed a dichotomy in terms of similarity or dissimilarity of judgments. The authors view the left hemisphere as superior for processing similar stimuli and the right hemisphere as best for processing stimuli dissimilar in nature. This position has been adopted by Hock (1973) and Taylor (1976). Most data, however, seem to point in the opposite direction, with the left hemisphere generally considered superior for dissimilarity judgments and the right hemisphere superior for similarity judgments (Atkinson & Egeth, 1973; Bradshaw, Gates & Patterson, 1976; Cohen, 1972; Davis & Schmit, 1971, 1973; Geffen et al., 1972; Patterson & Bradshaw, 1975).

Other dichotomies have been proposed, such as that the hemispheres differentially utilize pictorial versus verbal encoding strategies (Moscovitch, 1976) or temporal versus spatial capabilities (Ben Dov & Carmon,1976; Efron, 1963a, 1963b) or focal versus diffuse neural organization (Semmes, 1968). Alternatively, the left hemisphere has been considered to act as a serial processor in contrast to the right hemisphere which functions as a parallel processor (Geffen et al., 1972; Cohen, 1975). None of these dichotomies alone seem to encompass satisfactorily the variety of performance asymmetries reported in the literature. New data is constantly being published which pose diffficulties for any single duality proposed.

Moscovitch (1979) has proposed an information-processing model according to which hemispheric asymmetries vary at different stages of the information processing sequence and diverge most clearly at the later, higher-order, categorical stages. In agreement with this model, right hemispheric asymmetries are not usually reported for the detection of low-level features such as the perception of curvature (Longden et al., 1976) or the detection of unstructured patches of light (Bradshaw & Perriment, 1970; Berlucchi, Heron, Hyman, Rizzolatti & Umilta, 1971; Gazzaniga, 1970).

If Moscovitch's theory is correct, lateral differences ought to be a function of task difficulty, and memory load. There is some evidence to support this view. Fontenot (1973) demonstrated a LVF superiority in the recognition of random shapes of high complexity with low verbal association value. Accuracy of identification of low complexity shapes did not differ between fields. Thus, only when a certain level of difficulty was exceeded did a right hemispheric superiority appear. Similar findings have been reported by Umilta et al. (1978), who noted faster reaction time (RT) in the RVF than the LVF both for simple geometric figures and for simple, barely codable, nonsense patterns. Nonetheless, a LVF superiority was found when complex geometrical figures (such as 11-sided polygons) were used. The authors concluded that the left hemisphere was dominant when the task encompassed a few very clear cut details, with or without verbal labels. When there was need for detailed configurational analysis, however, the right hemisphere apparently prevailed.

In an attempt to dissociate codability and difficulty, Berlucchi, Brizzolara, Marzi, Rizzolatti & Umilta (1979) demonstrated a right hemisphere superiority for reading aloud the time shown on clockfaces. The authors speculated that reading of clockfaces represented a difficult, although familiar and highly verbalizable, visuospatial task. Presumably, verbal encoding must be preceded by processing of the visual input in the right hemisphere, suggesting that the hemispheres differ in their ability to deal with visuospatial information at an early stage of processing. A different view has been espoused by Hellige and Webster (1979) who found that the right hemisphere was superior for feature extraction, even with verbal material, while the left hemisphere was more efficient at later stages of processing. This view of superior "preprocessing" in the right hemisphere is also shared by others (Bryden & Allard, 1976; Moscovitch et al., 1976; Rizzolatti & Buchtel, 1977).

In support of the idea that the hemispheres differ in terms of memory and encoding, several studies have indicated that imposing a delay prior to recognition or recall enhanced hemispheric asymmetries for the identification of many stimuli. For instance, Dee and Fontenot (1973) have shown that, with complex figures of low verbal association, a variable delay between stimulus onset and response significantly affected lateralized performance. A superiority in the LVF appeared only for the longer delays. Similarly, Moscovitch et al. (1976) found that perceptual asymmetries for faces occurred at a late stage of stimulus analysis. A consistent LVF advantage was noted only when there was a delay of at least 100 milliseconds (ms) between the stimulus and the response. The initial absence of a LVF superiority led to the hypothesis of a short-lived bilateral visual trace equally accessible to both hemispheres. To confirm this hypothesis, Moscovitch and his coworkers introduced a visual masking paradigm during the stimulus-response interval, thereby degrading the short term trace. Under this condition, the right hemisphere advantage was observed even at the shortest intervals. Although not strictly within the realm of short-term memory, Bevilacqua, Capitani, Luzzati and Spinnler (1979) confirmed the importance of delay, using a task involving recognition of complex abstract visual patterns. Complex scrawls were used as stimuli with five time delays (0, 5, 15, 30 and 60 seconds) before the response. With up to a 30 second delay, targets projected to the left hemisphere were better recognized than those projected to the right hemisphere. The asymmetry was greatest at a 15 second delay. Stimuli projected to the right hemisphere induced a significantly higher recognition rate than when projected to the left hemisphere only for the longest retention interval of 60 seconds.

Laterality also shifts as a function of memory load. In a letter classification task, Klatzky and Atkinson (1971) observed an advantage for stimuli presented to the RVF when the memory load exceeded one item. No difference was observed for single letter memory loads. The importance of memory was also stressed by Hardyck, Tzeng and Wang (1977; 1978). These authors failed to obtain any evidence for cerebral lateralization under standard presentation of either verbal or spatial stimuli. Evidence for lateralization of linguistic material emerged only when a free recall condition was introduced. The authors concluded that lateralization was not a function of immediate cognitive processing in specialized cortical areas but reflected instead hemispheric differences in memory storage. The authors argued that most studies reporting a significant lateral difference use a limited number of relatively simple stimuli and an experimental procedure allowing the subject to become totally familiar with them. Experiments using a small number of stimuli relative to the number of trials result in miniscule or non-existent hemispheric differences. (Dimond, Gibson & Gazzaniga, 1972; Geffen et al., 1971).

The general model proposed by Moscovitch (1979) is not without challenges. There are several reports of significant VF differences using stimuli with low-level features (Anzola, Bertoloni, Buchtel & Rizzolatti, 1977; Davidoff, 1977; Filbey & Gazzaniga, 1969; Jeeves, 1969; Jeeves & Dixon, 1970; Kimura, 1961, 1966, 1969). Also, it is not always easy to determine in which category of low or high-level features some stimuli, such as lines in different orientation, should fall.

In a particularly interesting study, Cohen (1976) obtained differences in susceptibility to backward masking favoring the RVF and proposed that stimulus encoding as well as iconic persistence is differentially lateralized. She presented an array of six letters for 100 milliseconds (ms) in either VF and subjects had to report verbally all the letters (full report) or only those letters cued by color or location (partial report). Cuing could occur one second before the stimulus onset or 10 or 50 ms after it. A significant RVF advantage was obtained when a visual masking paradigm was introduced 20 ms after stimulus offset. By comparing masked and unmasked conditions, estimates of iconic persistence were computed. Persistence was significantly longer in the LVF than in the RVF (a mean of 57 ms against a mean of 34 ms). The author hypothesized a faster read-out process in the left than the right hemisphere.

Similar findings for letter pairs were reported by Hines, Satz and Clementino (1973). These data imply that encoding is faster in the RVF but that the LVF enjoys longer iconic persistence. The discrepancy between Moscovitch and Cohen's results might depend on the stimulus material used, as the former experimenter presented facial stimuli whereas the latter used letter stimuli. In favor of this hypothesis, it should be pointed out that those studies supporting the view that the right hemisphere carries out initial processing most efficiently used visual stimuli (Berlucchi et al, 1979; Rizzolatti & Buchtel, 1977) or spatial processing of verbal material (Bryden & Allard, 1976). In partial opposition to both of these interpretations, Jeeves and Dixon (1970) reported that unstructured visual stimuli were responded to faster when presented in the LVF than when presented in the RVF. This was true for right and left hand responses alike, whether the stimuli reached the temporal or the nasal part of the retina. The authors interpreted their results to mean that the sensory receiving area in the right hemisphere processed visual information faster than the corresponding area in the left hemisphere and also that the motor responding area in the left hemisphere was faster at initiating a response than the corresponding area in the right hemisphere. Taken together, all these findings point toward the existence of some differential information and memory processing between the two cerebral hemispheres. This does not however negate the possibility that there is a relative superiority of each hemisphere for different types of stimulus material or different types of processing.

Attentional Factors and Strategies

Kinsbourne (1970) has proposed a "Perceptual Orientation" model for cerebral functional asymmetries which is based on the hypothesis that functional superiority depends on the balance of arousal or expectancy of the cerebral hemispheres. When the focus of visual attention is "straight ahead," the bilateral hemispheric gaze mechanisms are presumed to be in a state of mutually inhibitory balance. Expectancy "activates" specialized areas in the brain which enhance performance in response to stimuli presented in the VF contralateral to the more activated hemisphere. In support of his hypothesis, Kinsbourne (1970) showed that while errors for detection of gaps in square stimuli did not significantly vary between the two VF under a standard condition, introduction of covert verbal activity enhanced performance following stimulus presentation in the RVF but not in the LVF.

This model has attracted a great deal of interest but has been supported by very few studies. In fact, Gardner and Branski (1976) were unable to replicate Kinsbourne's findings. Cohen (1975) confirmed that verbal cueing selectively enhanced the left hemisphere performance and biased attention toward the RVF. However, Hellige and Cox (1976) provided only partial support for the arousal theory. They found that a concurrent 'easy' verbal memory load (2 and 4 nouns) improved accuracy of recognition in the RVF for both a verbal and a complex visuo-spatial task (12 and 16 points polygons). There was no influence of verbal memory on visual form recognition in the LVF. Interestingly, the RVF superiority disappeared with a more difficult memory load (6 nouns), with accuracy falling below that of the no-memory condition. The authors concluded that their results could not be accounted for solely by the perceptual orientation model. Clearly several factors, such as stimulus codability, selective perceptual orientation and memory load contributed to visual lateral effects and Hellige and Cox argued that memory load would affect laterality by causing shifts in coding strategy. Furthermore, contrary to Kinsbourne's predictions, there is evidence that manipulation of a concurrent verbal activity interferes more with left than with right hemisphere motor processes (Lomas & Kimura,1976; Botkin, Schmaltz & Lamb, 1977). Finally, several experimenters have reported that manipulation of expectancy does not affect asymmetry in perceptual performance (Berlucchi, Brizzolara, Marzi, Rizzolatti & Umilta, 1974; Dee & Hannay, 1973; Geffen et al., 1972).

Despite its attractiveness, the arousal theory has several shortcomings. First, the model is implicitly based on the concept of a preexisting verbal-spatial duality of hemispheric functioning and, as such, is tautological. Secondly, Kinsbourne's theory is not inclusive enough to explain the broad range of laterality effects which have been reported. It also fails to have predictive value. Still, the model has the virtue that it leads to further exploration of the idea that cerebral asymmetries are not necessarily constant, but may vary as a function of state.

The possibility that laterality effects are due to the expression of differential hemispheric strategies has been suggested (Cohen, 1969; Hellige & Cox, 1976; Klein, Moscovitch & Vigna, 1976; Sperry, 1974; Umilta et al., 1974), but few experiments have explicitly tested this idea. Part of the difficulty resides in the fact that previous studies have used traditional psychophysical procedures and these do not differentiate sensory from decisional processes.

The theory of signal detection offers a way to distinguish between sensory and decisional processes by providing a relatively pure measure of sensitivity (d') and a measure of attitudinal bias (β) (Clark, 1966; Green & Swets, 1966; Pastore & Scheirer, 1974; Swets, 1964, 1973; Swets, Tanner & Birdsall, 1961). Unfortunately, signal detection has not often been used in the context of laterality research, though this omission is slowly being remedied. The relatively meager literature on the differential role of sensitivity and criterion in lateralized processing shows mixed evidence. Not all the results can be accounted for by true sensitivity differences between hemispheres, yet evidence for differences in decisional biases is also not convincing. It is likely that both sensitivity and strategy play a role in lateralized performance, depending on the type of task to be processed and the experimental setting.

For instance, Bryden's (1976) failure to replicate Kimura's findings of LVF superiority for dot detection led him to suspect the possibility of biasing factors. By using a signal detection paradigm, he demonstrated that most subjects show a response bias favoring the report of items presented in the LVF. Thus previous reports of right hemispheric superiority for dot detection may well have arisen from hemispheric differences in criterion rather than, or in addition to, actual sensitivity differences.

Gardner and Branski (1976) used a signal detection analysis to test the validity of Kinsbourne's arousal model. Detection of gaps in squares presented in the LVF or the RVF was studied under a standard condition and also under a condition where verbal or musical stimuli were presented prior to stimulus onset. Discriminability was decreased by both added conditions. There was thus no evidence of improvement of perception with an intervening task as the model would have predicted. Actually, subjects were more lax in their criterion for gap detection in the RVF with the verbal condition and in the LVF with the standard or music condition. Again, this experiment suggests that response bias should be considered in the interpretation of laterality experiments.

Some studies using signal detection have found little or no evidence for hemispheric differences in criteria. Robertshaw and Sheldon (1976) tested the validity of current views on hemispheric specialization with a signal detection paradigm, using a rating scale method. The task consisted of letter recognition or position discrimination. Subjects expressed their confidence that a letter was presented or that a specific cell was filled on a four point rating scale. No feedback was provided about their performance. In this experiment, asymmetries in performance in the two visual fields arose, at least in part, from differences in sensitivity between the hemispheres. Recognition of letters was more accurate when the stimuli were presented in the RVF, while judgments about position were more accurate in the LVF. Some differences were noted in decisional biases. This could be interpreted to mean that differences in strategies may have played a role in the response process. However, the authors were quite reticent about accepting this possibility as the criteria for judging stimuli in the two VF were actually set at the same distance from the mean of the noise distribution.

Finlay and French (1978) used signal detection analysis to determine whether reported hemispheric asymmetries for facial recognition were due to a particular characteristic of the two hemifaces or were a function of VF presentation. Superior detectability for faces was found in the LVF, while the criteria used remained relatively invariant.

Finally, some studies on patients with unilateral brain lesions seem to indicate that the impoverished visuo-spatial performance in the LVF observed in the patients with right posterior brain damage is related to a deficit in sensitivity and not to a change in criterion (Bisiach, Capitani, Nichelli & Spinnler, 1976; Bisiach et al., 1976).

A disconcerting possibility, which might be related to decisional processes, has emerged from the work of Simon and Rudell (1967) and Wallace (1971). In studies using choice RT unrelated to the question of laterality, these authors found that responses were always faster when the stimulus was ipsilateral than contralateral to the responding limb. This was true whether the responses were made with the hands in the usual position or with the hands crossed over each other. These results suggest that the relationship between VF and responding limb is not primarily based on the directness of neural connections but rather on some spatial compatibility between stimulus and response. This finding, upsetting the assumption that fixed structural connections are responsible for laterality effects, has been confirmed by Anzola et al. (1977) and Berlucchi, Crea, Di Stefano and Tassinari (1977). Both these groups replicated Wallace's findings of S-R compatibility in a choice RT but found this factor inoperative for simple RT. The authors recognized the importance of the S-R compatibility phenomenon but argued that it might fall into a different category than laterality effects. Broadbent (1974) made wide use of the findings of Simon and Rudell (1967) and Wallace (1971) to challenge the idea that lateral differences were based on anatomical routes. According to Broadbent, Wallace's results suggest that there is considerable interaction of function between hemispheres despite the evidence of asymmetry. Thus the assumption that, for a given function, there is a fixed superiority of one hemisphere over the other might be unjustified. The issue of laterality thus may be complicated by the possibility of shifts in relative hemispheric competence and changing strategies.

Visual Discrimination of Line Orientation

Discrimination of line orientation is strictly visuo-spatial in nature and should, according to the structural model of lateralization, be processed preferentially in the LVF. The research literature, however, is far from being unanimous on this topic and suggests rather that discrimination of line orientation can be performed by either hemisphere.

In accord with the hypothesis of right hemispheric superiority for visuo-spatial processing, Fontenot and Benton (1972) described more accurate identification of the direction of lines seen in the LVF than in the RVF. They presented slanted lines at ten possible orientations with an angular separation of 18 degrees, together with verbal stimuli consisting of three letter nonsense words of relatively low association value. After each stimulus presentation the subject was required to select the stimulus just seen from an array of ten different directions. Although the subjects showed the expected RVF superiority for verbal stimuli, accuracy for recognition of line orientation was significantly greater in the LVF than in the RVF. A right hemisphere superiority for orientation was also reported by Atkinson and Egeth (1973) using a same-different paradigm. RT to both stimulus matching and memory matching were significantly faster in the LVF for dissimilar but not similar responses.

Yet discrimination of line orientation does not always produce clear VF differences. Durnford (cited by Kimura & Durnford, 1974), using lines with eleven possible orientations, varying in 15 degree steps, failed to find VF differences. It was only after modifying the procedure (by using shorter lines and replacing the manual RT with a multiple choice recognition paradigm) that a small but consistent superiority for slope identification in the LVF was noted. Furthermore, White (1971), using verbal responses, reported a RVF superiority for recognition of vertical, horizontal and 45 degrees oblique lines. Only forty seven percent of stimulus orientations were correctly recognized when presented in the LVF, whereas as many as 84 % of the stimuli were correctly recognized in the RVF. White concluded that there was a "selective contour-tuning apparatus" in the left hemisphere and hypothesized that the left hemisphere superiority emerged because these orientations were easily analyzed and categorized in verbal terms. These conclusions were met with criticism. Geffen et al. (1972) suggested that the use of vocal responses had created a bias toward the left hemisphere which had masked a possible right hemisphere superiority, while Kimura (1974) challenged White's findings on three grounds. First, she contended that the use of a within subject design might have introduced a "stimulus context" confounding. Second, the presentation of only three types of lines might have facilitated verbal mediation, which caused the RVF superiority. Finally, Kimura criticized White's findings as being at variance with some the findings of clinical reports, in which impairment of the perception of horizontal and vertical was noted after right hemisphere lesions.

Nonetheless, Umilta et al. (1973, 1974), using manual RT rather than a verbal response, have obtained results comparable to those of

White. Their experiment will be reviewed in detail since it bears special interest for the present study.

Umilta et al. (1974) asked right-handed males to make discriminative RT (go, no-go) to two out of four possible line orientations flashed in the left or right visual field. Subjects were divided into three groups, each given four different stimulus orientations. Group one was presented with orientations similar to those used by White, vertical, horizontal, right oblique (45 degrees) and left oblique (45 degrees). Group two was presented with four different orientations (30 degrees and 45 degrees to the left or right of vertical). Group three was presented with stimuli 15, 30, 45 and 60 degrees from the vertical. For this group, the rotations were clockwise for stimuli presented to the left of the fixation point and counterclockwise for stimuli presented to the right of the fixation point. Stimuli were backprojected and presented monocularly on a luminous screen at 5 degrees of lateral visual angle for 100 ms each. Within each group half of the subjects used the right eye and half of the subjects used the left eye. Likewise, the right hand was used for responding on half of the trials and the left hand was used on the other half. Stimulus presentation was pseudorandomized. For data analysis, median RT were averaged over the eye condition, but analyzed separately for hand, visual field and stimulus orientation. RT for each of the three groups were then submitted to two way ANOVA (repeated measure design). In agreement with White (1971), Umilta et al. found that the left hemisphere was superior for discriminating what the authors termed a simple task, rectangles oriented in the vertical and horizontal planes. No VF differences were obtained for tasks of "intermediate" difficulty (30 or 45 degrees). However, a shift toward right hemispheric superiority was observed when the subjects had to discriminate among the orientations referred to as "difficult" (15, 30, 45 or 60 degrees). The authors concluded that the vertical and horizontal rectangles were responded to faster by the left hemisphere precisely because these orientations could be analyzed and categorized easily in verbal terms. The shift toward right hemisphere superiority for the difficult oblique lines was attributed to the adoption of a visual matching strategy necessitated by the lack of available verbal codes to represent these oblique lines.

A confounding remained though, in Umilta's experiment, between verbal codability and perceptual difficulty, since stimuli which are easy to perceive usually allow for readily available verbal mediation. If codability is a compelling factor, even complex visuospatial stimuli should evidence a left hemisphere superiority, provided that a verbal code is easily obtainable. Alternately if perceptual difficulty is critical in determining right hemispheric superiority, all easy visuospatial tasks should be analyzed more efficiently in the left hemisphere, regardless of codability.

In summary, the literature suggests that the discrimination of line orientation is compatible with the cognitive modes of both cerebral hemispheres. It is possible that contradictory findings do arise from some factor yet to be defined. It may also be that the cognitive modes used by the hemispheres are not fixed and constant but are influenced by experimental conditions.

Rationale

The present experiment addresses some of the issues pertaining to the functional specialization of the cerebral hemispheres, particularly the extent to which structural and decisional factors interplay in the lateralization of spatial processing. For this purpose, the lateralization of discrimination of line orientation was studied in normal adults in terms of reaction time and accuracy. In addition, the pattern of responses was studied to determine whether the performance expressed true differences in sensitivity between the cerebral hemispheres or rather differential operating strategies. A paradigm similar to the one devised by Umilta et al. (1974) was adopted. Several modifications were introduced to clarify and extend some of the implications of the earlier study. The rationale behind the subject selection, the choice of the independent variables, the dependent variables, and the procedure used in the present study are detailed below.

Subject Selection

Male subjects were used as they reportedly show overall superior spatial skills (see Harris' review, 1978), and greater and more consistent left visual field effects than females (Kimura, 1969; 1973; McGlone & Davidson, 1973).

It was decided to use only subjects displaying right sighting preference and to compare performance between the left and right eye instead of combining the results from the eyes with the usual counterbalancing procedure. This was based on the premise that, although eye preference may be related in some ways to laterality, its ties with hemispheric specialization are controversial. White (1969) argued that little evidence was offered that sighting dominance, one of the possible measures of eye dominance, has any explanatory value for cerebral lateral differences. In contradistinction, Kershner and Jeng (1972) reported an interplay between ocular and cerebral dominance. To add to the complexity, some authors argue that results seemingly pointing toward a relationship between cerebral dominance and eye dominance reflect instead the relative processing dominance of the crossed over the uncrossed visual pathway (Maddess, 1975; Osaka, 1978).

An additional criterion for inclusion in the study was a strong right hand preference. There is a wealth of data indicating that right handers display greater and more consistent asymmetry in performance than left handers (see, for example, Bryden, 1965, 1973; Hines & Satz, 1971, 1974; White, 1969; Zurif & Bryden, 1969).

Independent Variables

Visual field, eye and hand were rather obvious independent variables to be studied in the context of hemispheric asymmetries.

Discrimination of line orientation, was chosen for the following reasons. (a) Stimuli were easily definable, (b) information content could be manipulated by altering only one feature: orientation, and (c) the literature on discrimination of line orientation suggests that this task can be performed by either hemisphere. Two experimental conditions were contrasted. Under one experimental condition, discriminative responses to a vertical and an oblique line were investigated. Discriminative responses to two obliques were investigated under the other experimental condition. Since Umilta et al.'s results could equally well be interpreted in terms of verbal coding or perceptual difficulty, explicit labels were provided in an effort to equate the two tasks along the verbal dimension, and to vary only the perceptual difficulty of the tasks.

Dependent Variables

Two dependent variables (DV), RT for correct responses and percentage of correct responses, plus two signal detection measures, d' and β, were used. The use of two DV stemmed from the fact that in prior studies neither of these DV alone yielded unequivocal results. The choice of a go, no-go paradigm as compared to a forced choice procedure was based on the premise that following Umilta et al.'s paradigm as closely as possible would allow for valid comparison between the two experiments.

The measure of accuracy chosen in the present study was the percentage of the number of correct recognitions. This measure was favored over other laterality indices such as percentage of error (Krashen & Harshman, 1972; cited by Bryden, 1978), laterality coefficient (Hawles, 1969 ; cited by Marshall, Caplan, & Holmes, 1975) and Phi coefficient (Kuhn, 1973), all of which have limitations at high or low levels of accuracy or do not have the same limits at all levels of performance.

Manual RT was preferred to vocal RT to avoid linguistic contamination leading to potential left hemispheric bias. Since distal motor connections are maximally lateralized (Lawrence & Kuyper, 1968), responses were performed with the forefinger of either hand.

The data were examined within the framework of signal detection because it was reasoned that some of the inconsistencies encountered in the literature stemmed from differences in the decision-making processes of the two hemispheres. A rating scale procedure was chosen as it offered an economical way to gain information despite use of a relatively small number of stimulus presentations.

Tachistoscopic Presentation

Visual tachistoscopic presentation of stimuli was used. This procedure is based on the understanding that each VF projects directly to the contralateral hemisphere. Superior performance favoring one VF over the other is thus taken to be indicative of a greater participation of the contralateral than the ipsilateral hemisphere. Clearly, information will cross the cerebral commissures and reach the other hemisphere but it is assumed that this crossover will result in measurable time delay and loss of information content (Berlucchi, 1974).

The tachistoscopic technique is not, however, without problems. In order to be valid, visual presentation of stimuli must be submitted to several constraints. Stimuli must be presented at an eccentricity sufficient to avoid the foveal area, since the fovea enjoys bilateral cerebral representation. As a corollary, stimulus presentation should be briefer than the time necessary for the eyes to reflexively orient towards the stimulus in order to recenter it. Stimulus presentation should therefore be less than 150-200 ms, the latency of saccadic eye movements (Pirozzolo & Rayner, 1980; Saslow, 1967; Van Allen, 1970).

A further problem with visual tachistoscopic presentation is the monitoring of central fixation, which is necessary to insure that stimuli are projected only to the contralateral hemisphere. Really accurate devices, such as a pupil direction feedback system, are quite expensive. Direct observation of the pupil by the experimenter (Dimond, 1970) is not always possible. Techniques of fixation control, involving presentation of a central stimulus simultaneously with the lateralized stimulus (e.g. McKeever & Gill, 1972) probably insure fixation but have the drawback of providing competing memory traces and therefore possibly changing the overall task requirement. We therefore decided, as most experimenters do, to rely on the subject to follow the instructions to fixate steadily a central fixation mark. This procedure could not lead to artefactual positive results, since inadvertent foveal vision would stimulate both hemispheres equally. Pitblado (Note 1) has therefore argued that gaze orientation toward the stimulus, if it occurs, would result chiefly in nullifying laterality effects.

Data Analysis

Separate ANOVA were performed on the percentage and RT of correct responses to determine the effect of the four independent variables (IV) (stimulus condition, visual field, eye and hand). In view of positive interactions obtained between the eyes and other IV, RT results were further analyzed for each eye separately. This was not deemed necessary for the accuracy index since the ANOVA clearly showed a difference in accuracy between the eyes as a main effect.

Differences between this and Umilta et al.(1974)'s Paradigm

In essence, the design was based on that of Umilta. Certain differences should however be noted.

In the present experiment, all subjects were selected to be right eye dominant. While the stimuli used by Umilta et al. varied from each other by 45 or 15 degrees, according to the stimulus condition, the angular separation between stimuli in the present study was kept constant. The positive stimulus remained the same across the two conditions, rather than using counterbalanced 'go' stimuli across subjects. The duration of stimulus presentation was approximately 10 ms instead of the 100 ms used by Umilta. Standardized instructions emphasized explicit verbal coding, gaze maintenance, speed of response and accuracy. A within subject design, as opposed to Umilta's between subject design, was adopted in order to reduce subject variance. The present study incorporated the use of a signal detection analysis to evaluate the respective functions of the cerebral hemispheres in terms of both sensitivity and strategy and the use of an accuracy index. Finally, data analysis involved the use of geometric means of RT data, rather than median RT, in order to reduce the variance of RT distribution and avoid putting undue weight on extreme RT values. This latter situation could occur when few condition and thus few RT were obtained.

Predictions

Specific predictions were as follows:

1. Stimulus condition V-0 would result in greater accuracy than stimulus condition 0-0.

2. Greater accuracy would be observed with orientations projected in the LVF than the RVF.

3. The right hand would evidence faster RT than the left hand.

4. Accuracy for line orientation would be greater under the condition of right eye stimulation than left eye stimulation.

CHAPTER 2

METHOD

Subjects

Six male subjects, 18 to 27 years old, were used in the experiment. They were undergraduate and graduate students in psychology, and were selected to meet criteria (see below) of being right-handed, without familial history of left-handedness, and right-eye dominant, with visual acuity of no less than 20/30 in each eye and without significant astigmatism. Subjects were not aware of the exact nature of the experiment, although general information was provided in compliance with the "Protection of Human Subjects" guidelines. Financial remuneration was given on an hourly basis.

Handedness and familial history were determined by a questionnaire adapted from Annett (1970)(see Appendix A). The criterion for elimination of weak right-hand preference was set at 90%. A total of 99% of the activities listed in the questionnaire were performed with the right hand by all subjects, indicating a strong right-hand preference in our sample, complemented by the fact that there was no incidence of left-handedness in the immediate family of any subject.

Visual acuity was checked for each eye separately with a standard Snellen Chart. Two subjects demonstrated 20/25 visual acuity, two showed 20/20 visual acuity and the last two were corrected to

20/20 visual acuity. Three of the six subjects had had recent ophthalmological examinations and were apparently free of astigmatism. One subject wore hard contact lenses, effectively eliminating astigmatic aberrations (Sloane, 1963). In the absence of information regarding the possibility of astigmatism, the last two subjects were checked with a astigmatism chart (American Optical Association, No 1942) and found free of astigmatic distortion.

Two tests were used to determine eye dominance: the hole test and the point test (Porac & Coren, 1976). For the hole test, subjects held a square cardboard, 30 cm on edge, with both hands, at arm's length and looked at the experimenter through a center hole 1.25 cm in diameter. The eye used for viewing was assumed to be the dominant eye. In the point test, the subject held a pencil at arm's length and was asked to align it with the experimenter's nose, keeping both eyes open.The subject was then asked whether the pencil subjectively jumped when the left or the right eye was closed. The eye which, when closed, resulted in a subjective jump of the pencil was defined as dominant. Based on Porac and Coren's methodology, these procedures were repeated twice for each test. Both tests yielded similar results and all six subjects demonstrated perfectly reliable right-eye dominance on both tests. Of the prospective subjects one was rejected who did not fulfill the condition of eye dominance.

Paradigm

Two stimulus conditions were compared. In the V-0 task, on each trial, subjects were presented with either a vertical line (90 degrees from horizontal) or an oblique line (95 degrees from horizontal). In the 0-0 task, subjects were presented with one of two obliques : 95 or 100 degrees from horizontal. In both conditions the subject had to press a (go) telegraph key when the 95 degree stimulus was flashed. No response was required (no-go) when either of the two other stimuli were shown. After each trial, the subject verbally rated the certainty of his response on a four point scale.

The variables "eye" and "hand" were counterbalanced within and across sessions. The variable "stimulus condition" was counterbalanced across sessions whereas the variable "visual field" was fully randomized within and across sessions. There was balancing across all subjects regarding which condition was given first and which eye-hand combination was first presented. An ABBA order dictated the order of presentation of the stimulus conditions.

Within each condition there was pseudo-randomization of stimulus presentation, following the Gellerman series of random numbers, with the restriction that no more than three stimuli with similar orientation appeared in succession, and no stimulus appeared more than three times in succession in one visual field.

As a control for any possible undetected inaccuracies in the stimulus cards, the cards were alternated in direction, up versus down, after each sequence of forty stimulus presentations. Thus, each particular stimulus was presented an equal number of times in each visual field.

There were 80 stimuli, 40 'go' and 40 'no-go', presented for each of the four IV. Each subject therefore performed a total of 80 x 2 x 2 x 2 x 2 = 1280 trials. In addition there were 160 practice trials during the first session plus 10 practice trials at the beginning of each subsequent session.

Sessions were divided in four to six blocks of 40 stimuli each. Each block corresponded to one of the four possible eye-hand combinations (right eye-right hand; right eye-left hand; left eye- right hand; or left eye-left hand), and included 20 'go' and 20 'no-go' stimuli.

Stimuli

The line stimuli were actually black rectangles (19mm x 3mm), individually printed on white index cards (18cm x 13cm), 2 cm from the one side and equidistant from top and bottom. The stimuli could occupy one of three possible orientations, 90 degrees, 95 degrees or 100 degrees from the horizontal, and were pivoted around their center point (see Figure 1). The distance from the center of the card to the nearest edge of the stimulus was 2.5 degrees at a viewing distance of 127.5 cm, with the stimulus itself subtending a visual angle of 8 min of arc.

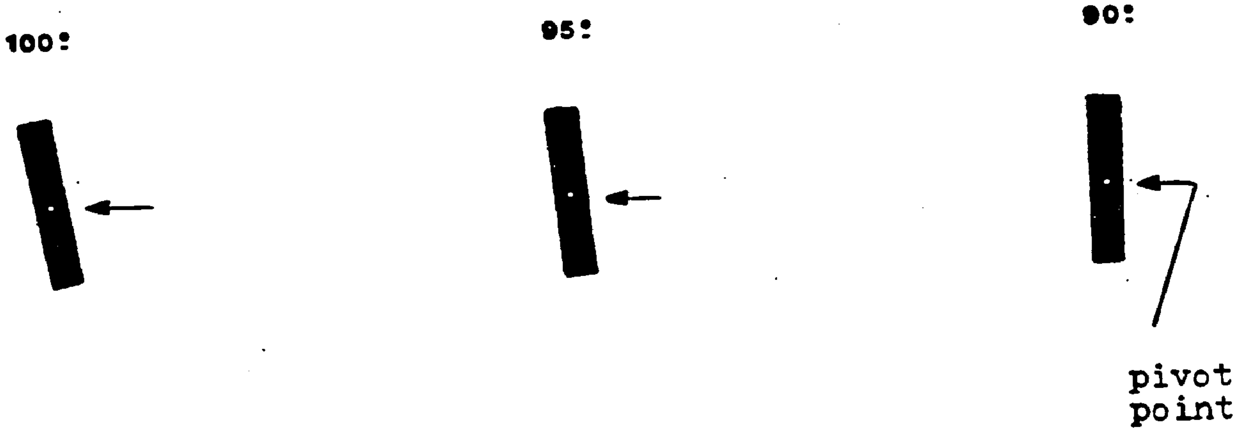


Figure 1. Stimulus orientations.

Apparatus

Stimuli were presented through one channel of a three-channel tachistoscope (Scientific Prototype Mfg. Corp., Model GA). The second channel was used to present the fixation point (fixation field). The third channel of the tachistoscope was not used.

An adjustable chin and head rest was used to help stabilize the subject's head. A wooden block with a circular aperture (2.5 cm in diameter) was fitted in the rubber viewing hood to restrict the subject to monocular viewing. In addition, a black eye patch was worn over the unused eye.

Several modifications introduced by D'Amico (Note 2) and Nelson (Note 3) were adopted to make sure that relative luminances ion the left and right sides of the screen remained within a 3% limit. The relative luminance of the various parts of the screen were monitored at regular intervals with a photometer (Photovolt Corp., model 520). The luminance of the fixation field and the stimulus field were respectively 1.34 and .66 foot lamberts.

A foot activated switch triggered the onset of a trial. The stimulus appeared after a 1200 ms delay and was coincident with the start of an electronic millisecond timer (Hewlett Packard 37B4A). Activation of a microswitch by pressure on a telegraph key served to stop the timer and to indicate a response. The experiment took place in a darkened room.

Experimental Procedure

Seven sessions (including an introductory one) were needed to complete the experiment. In order to build up the subject's endurance for the monotony of the task, the sessions were progressively lengthened. The first two sessions consisted of no more than 160 trials and lasted approximately 45 minutes. Thereafter the number of stimuli given during a session was 240, lasting no more than one hour, including a five minute rest period at mid-session.

The first session included checking eye and hand dominance, familial history of handedness, visual acuity and astigmatism.

The task was explained to each subject via standardized instructions (see Appendix B). The duration of tachistoscopic presentation needed to reach 60 - 80 % correct responses was then determined with a descending method of limits. The appropriate duration of stimulus presentation averaged 8 ms for all subjects, with a range of 6-14 ms.

After the subject was familiarized with the procedure, the concept of a rating scale was explained. The subject was asked to rate verbally how certain he felt about his response, on a scale from four to one. A rating of four meant that the subject was positive about the accuracy of his response; three meant that he was reasonably certain that his response was correct; two indicated that he was unsure of his response and a rating of one was used when the response was close to a guess. The subject was encouraged to use all four points on the rating scale and was advised against later changes. A rating was required whether or not the subject pressed the telegraph key.

During the first session, the subject was given 20 practice trials for each eye-hand combination under both conditions V-O and O-O. For these initial 160 trials, feedback was provided after each trial. The subject was informed, however, that during the actual experiment feedback would be given only after each block of 40 trials.

Each session began with a 15 min dark adaptation period, following which the subject was fitted with the eye patch and seated in front of the tachistoscope screen with his head in the head rest. He was instructed to keep the eye under the eye patch open, to limit muscular tension. The head restrainer was positioned by the experimenter before the session to allow for either the right or the left eye to be directly centered on the fixation dot, with the subject allowed to make minor adjustments. The height and angle of the head restrainer were adjusted so that the line of vision would be as close as possible to the horizontal plane.

During dark adaptation, the subject was informed of the eye-hand combination to use and was reminded of the importance of central fixation. He was verbally instructed as to which forefinger to use for the response but was encouraged to use whichever foot he felt most comfortable with to press the foot pedal. The two stimuli comprising the stimulus condition for that session were then presented twice in each visual field. The appropriate duration of the stimulus was determined for each individual at the beginning of each session. This procedure was based on the results of a pilot study which had shown that for some subjects the level of performance did not remain constant oversession; the stimulus duration determined during the introductory session did not always result in the 60-80% correct responses required for signal detection analysis. The first block of 40 trials was used as an index of the subject's performance on that day. If performance on this first block of trials fell below the 60% correct, the stimulus duration was increased by 30%; the duration was decreased by the same amount if performance rose above 85% correct. In all cases, results from the first block of trials were included in the analysis. In practice, these adjustments were seldom needed. Stimulus duration was not manipulated during sessions because it was reasoned that practice effects could not be teased from the effects of fatigue. The two stimuli of the stimulus condition used for that session were presented at the start of every block of 80 trials to refresh the subject's memory.

Following the experimenter's "Ready?" prompt, the subject initiated a trial when he felt prepared to do so, by depressing the foot pedal which triggered the onset of the stimulus. In response to the stimulus, the subject either pressed the telegraph key or refrained from doing so. In either case he rated the certainty of his response. The latency of the 'go' response, measured on the electronic timer, and its rating were manually recorded by the experimenter. Intertrial interval was approximately 15-20 seconds. Since subjects were instructed to respond as fast as possible, the speed of response might appear overemphasized at the expense of accuracy. To eliminate this possibility, accuracy of the response was closely monitored during the course of the experiment. At the end of each block of 40 trials, the subject received feedback regarding the number of hits and false alarms. If false alarms exceeded hits by more than 15%, the subject was advised to adopt a more cautious strategy. On the other hand, when the number of false alarms decreased close to zero, the subject was encouraged to be more liberal with his guesses. By this procedure, attention to accuracy of response was manipulated throughout the experiment with, hopefully, speed and accuracy equally emphasized. From time to time the subject was reminded that if he kept his gaze on the fixation mark this would optimize the correctness of his response, since stimuli were randomly presented to the left and right of fixation. After each block of 40 trials, which corresponded to one of the four eye-hand combinations, the subject was allowed a short rest period during which feedback was given in terms of the number of hits and false alarms obtained. After 120 trials the subject was allowed to take a longer rest. After each rest period the subject was asked to maintain his head in the headrest for at least 30 seconds before starting a trial.

Reaction times were read to the nearest millisecond. All reaction times over one second were discarded from data analysis. These occurred in about two percent of the responses.

Three subjects (Subjects 1, 4 and 5) began the experiment with condition V-O, and three subjects (Subjects 2, 3 and 6) started with condition O-O.

Data Analysis

Accuracy and RT.

Scores were averaged separately for the four IV and data were analyzed in terms of both RT and percentage of correct responses. Since each of the four IV had two levels, each subject contributed 16 mean scores to each dependent variable. The pattern of correct and incorrect responses was also studied, although only errors of commission (false alarms) were analyzed. Errors of omission (misses) could easily be obtained as they constituted the mirror image of the percentage of correct responses. Correct responses were expressed as:

$$\frac{\text{correct 'go' responses + correct 'no-go' responses}}{\text{stimuli presented}} \times 100$$

To determine the influence of crossed and uncrossed visual pathways on RT, the data were retabulated in the following manner: RT to stimuli impinging on the temporal retinae of the left and right eye were combined under the heading "uncrossed visual pathways"; data from the nasal retinae of the left and right eye were grouped under the heading "crossed visual pathway".

A completely crossed, repeated measure design (as described by Edwards, 1972; Myers, 1972; and Winer, 1962) was used throughout. This design requires fewer subjects than most types of ANOVA. It has the further advantage that variability due to individual differences does not inflate the error variance. All ANOVA were performed using

Biomedical Computer Program BMD08V (Dixon, 1976). Differences were considered to be significant if the probability of chance occurence was 5% or better.

A total of seven ANOVA were performed as follows:

For RT data, on the

1) results combining the data from the two eyes;
2) results obtained for the left eye,
3) results obtained for the right eye,
4) RT errors
5) data retabulated in terms of visual pathways.

For accuracy data, on the

1) percentage of correct responses,
2) errors of commission.

RT data were normalized by use of geometric means. This transformation avoids undue weight by extreme scores (Lindquist, 1953; Mueller, 1949). Accuracy scores expressed in percentages were subjected to an arc sin transformation ($X' = 2 \arcsin \sqrt{X}$), where X' is expressed as a proportion in radians. Such an angular transformation is recommended for normalization of data in the case of an underlying binomial distribution, which is the distribution associated with binary responses, such as those employed here (Edwards, 1972; Kirk, 1968). To verify the assumption of homogeneity of variance, Bartlett χ^2 tests were run prior to the ANOVA.

Signal Detection Analysis

With the rating scale procedure a signal trial was defined as one in which the 'go' stimulus (the stimulus with the 95 degree orientation) was presented, and a noise trial was defined as one in which a stimulus different from the 'go' stimulus was presented. Four point ratings given after each response led to the construction of individual Receiver Operating Characteristic (ROC) curves, following the standard cumulative procedure detailed by McNicol (1972, pp.105-108).

In general the ratings were well used, although the case of a missing cell for the extreme ratings (the "least certain" and the "most certain" categories) did occasionally occur. These were treated by the collapsing procedure described by McNicol.

Since the ANOVA showed no systematic hand effects, the scores from both hands were combined, thereby obtaining enough information to obtain smooth ROC curves. The p values of the scores for the signal trials [P(Sc/s)] and of the scores for the non-signal trials [P(sc/ns)] were then converted to Z scores to obtain the double probability plot of the ROC curves. A straight line was fitted through the points, using the method of mutual regression described by Grice (1966). This method was preferred over commonly used fitting methods like the method of least squares since, with ROC curves obtained with rating scales, both x and y are dependent variables. In the method of least squares, the line fitted through the points is the one that minimizes the vertical distances of the points from the line but only in one direction. In comparison, in the mutual regression method, it is the distance from the perpendicular drawn from each point to the line and not the vertical distances to the line that is minimized.

Since the slopes of the ROC curves deviated from unity, the index d'e was chosen as the measure of discrimination sensitivity. This is defined as "twice the value of Z(S/s) or Z(S/n), ignoring signs, at the point where the ROC curve intersects the negative diagonal" (McNicol, 1972. p.89). The theoretical basis for the choice of this measure is elaborated in McNicol (pp. 89-90). The interdependence of the points defining the ROC curve introduced some limitation in the choice of a significance test. Therefore the G measure developed by Gourevitch and Galanter (1967) and extended by Marascuilo (1970) was computed. Individual differences in sensitivity between left and right visual fields were computed separately for each eye in each condition. Four such G tests were performed on each subject (two visual fields x two stimulus conditions). A graphic representation of the group data was obtained by averaging the Z(Sc/s) and the Z(Sc/ns) of the six observers for each category and constructing an average ROC curve (see McNicol, pp. 111-113, for a discussion of this procedure).

Since signal detection was used primarily to determine whether there were overall differences in response bias between conditions or between hemispheres, it was considered satisfactory to calculate only a global criterion estimate. Because the two distributions of signal and signal + noise displayed unequal variances, the criterion β was judged inappropriate since it would not have been independent of sensitivity measures. A similar argument apparently stands for the non-parametric measure of response bias, B. McNicol (1972) conceded that B, defined as the rating scale category at which P(S/s) + P(S/n) = 1, would not coincide with the rating category at which β=1 when signal and noise distribution have unequal variance. On this basis, "β middle point" was chosen as a measure of criterion (Kietzman, Note 4). In the case of an ROC curve defined by an odd number of points, β middle point was immediately obtainable from the data. When the ROC curve was defined by an even number of points, the value of β middle point was interpolated from the two central points. If the central point was not on the fitted line a perpendicular was dropped onto it to determine the exact location of the criterion index. β middle point was further subjected to a logarithmic transform in order to normalize its distribution (see McNicol, pp.62-63). This transformation, expressed in terms of negative logarithms (Lewis, 1966), allowed the use of the Student t-Statistic for related measures to determine whether there was any significant difference in criteria between the cerebral hemispheres.

CHAPTER 3

RESULTS

Percentage of Correct Responses

Table 1 presents a summary of the four-way ANOVA (two stimulus conditions x two V F x two eyes x two hands) performed on the percentage of stimuli correctly recognized for each of the four IV, following arc sin transformation. This transformation was satisfactory for the acceptance of the assumption of variance homogeneity assessed by Bartlett's test, $\chi^2(15) = 7.13$, $p > .95$. A tabulation of the arc sin transformations of correct responses for the four IV in individual subjects is shown in Appendix C.

Significance of at least $\underline{p} \leqslant .05$ was reached for the three main effects. A greater percentage of correct responses was given for stimulus condition V-O than for stimulus condition O-O ($\bar{X}$ arc sin transformation: 2.12.versus 2.00). More correct responses were given when stimuli were projected in the LVF than in the RVF ($\bar{X}$ arc sin transformation: 2.12 versus 2.00). Lastly, a greater percentage of correct responses was given when the stimuli were projected to the right eye than when the stimuli were projected to the left eye ($\bar{X}$ arc sin transformation: 2.09 versus 2.04). In addition to these significant main effects, there was a strong interaction between VF and hand. As can be seen in Figure 2, the most accurate performance was achieved for the combination right hand-LVF while the worst performance was observed for the combination right hand-RVF.

Table 1: ANOVA on arc sin transformed percentage of correct responses.

Source	df	Sum of Squares	Mean Squares	F	P
Total					
C	1	.2784	.2784	10.50	.025
F	1	.2438	.2438	9.24	.05
E	1	.1092	.1092	8.32	.05
H	1	.0184	.0184	2.21	
C x F	1	.0624	.0624	2.77	
C x E	1	.0493	.0493	1.98	
C x H	1	.0004	.0004	1.17	
F x E	1	.0467	.0467	1.20	
F x H	1	.0809	.0809	24.25	.005
E x H	1	.0002	.0002	1.07	
C x F x E	1	.0000	.0000	.00	
C x F x H	1	.0122	.0122	.59	
C x E x H	1	.0005	.0005	.32	
F x E x H	1	.0116	.0116	1.48	
C x F x E x H	1	.0002	.0002	.51	

Key to the Table

C	:	Stimulus Condition
F	:	Visual Field
E	:	Eye
H	:	Hand

For the sake of clarity error terms are not shown.

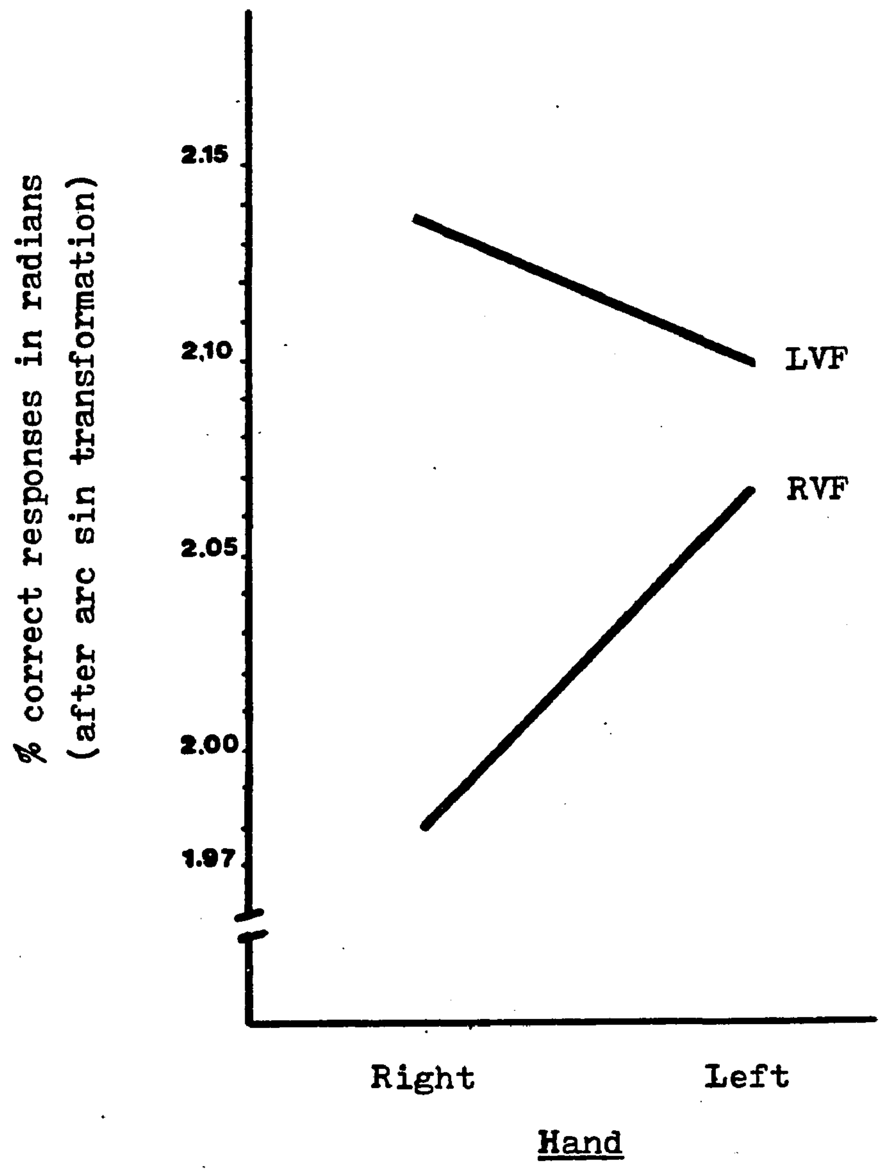


Figure 2. Interaction between VF and hand.

Reaction Time of Correct Responses

Four-Way ANOVA

Table 2 displays the summary of a four-way ANOVA (two stimulus conditions x two V F x two eyes x two hands) conducted on the geometric means of the RT to correct responses for the six subjects. The assumption of variance homogeneity was accepted, assessed by Bartlett's test, $\chi^2(15) = 9.97$, $p > .75$. None of the main effects reached significance. The latency of the responses were not different for the two VF, the two conditions, the two eyes or the two hands. A strong interaction was observed, however, between stimulus condition and VF, and a less powerful interaction between stimulus condition and eye.

Examination of the stimulus condition x VF interaction, (see Figure 3), indicates that, in the LVF, stimulus condition V-O was responded to with a mean RT 41 ms shorter than stimulus condition O-O. Differences between stimulus conditions were not apparent for the RVF.

The interaction between stimulus condition and eye tested also reached significance. As can be seen in Figure 4, responses were given on an average 20 ms faster under stimulus condition O-O when the right eye was used than when the left eye was used. There appeared to be no relationship between eye and stimulus condition V-O and no other interaction reached significance.

Table 2: ANOVA of geometric means of RT for correct responses

Source	df	Sum of Squares	Means Squares	F	P
Total		450,497.83			
C	1	10,292.04	10,292.04	2.5	
F	1	160.17	160.17	.10	
E	1	1,650.04	1,650.04	5.5	
H	1	32.67	32.67	.04	
C x F	1	1,626.04	1,626.04	157.03	.001
C x E	1	3,037.50	3,037.50	7.59	.05
C x H	1	442.04	442.04	.91	
F x E	1	513.38	513.38	1.98	
F x H	1	322.67	322.67	.43	
E x H	1	176.04	176.04	.11	
C x F x E	1	640.67	640.67	1.07	
C x F x H	1	135.38	135.38	.20	
C x E x H	1	42.67	42.67	.08	
F x E x H	1	51.04	51.04	.13	
C x F x E x H	1	337.50	337.50	2.06	

Key to the Table

C : Stimulus Condition
F : Visual Field
E : Eye
H : Hand

For the sake of clarity error terms are not shown.

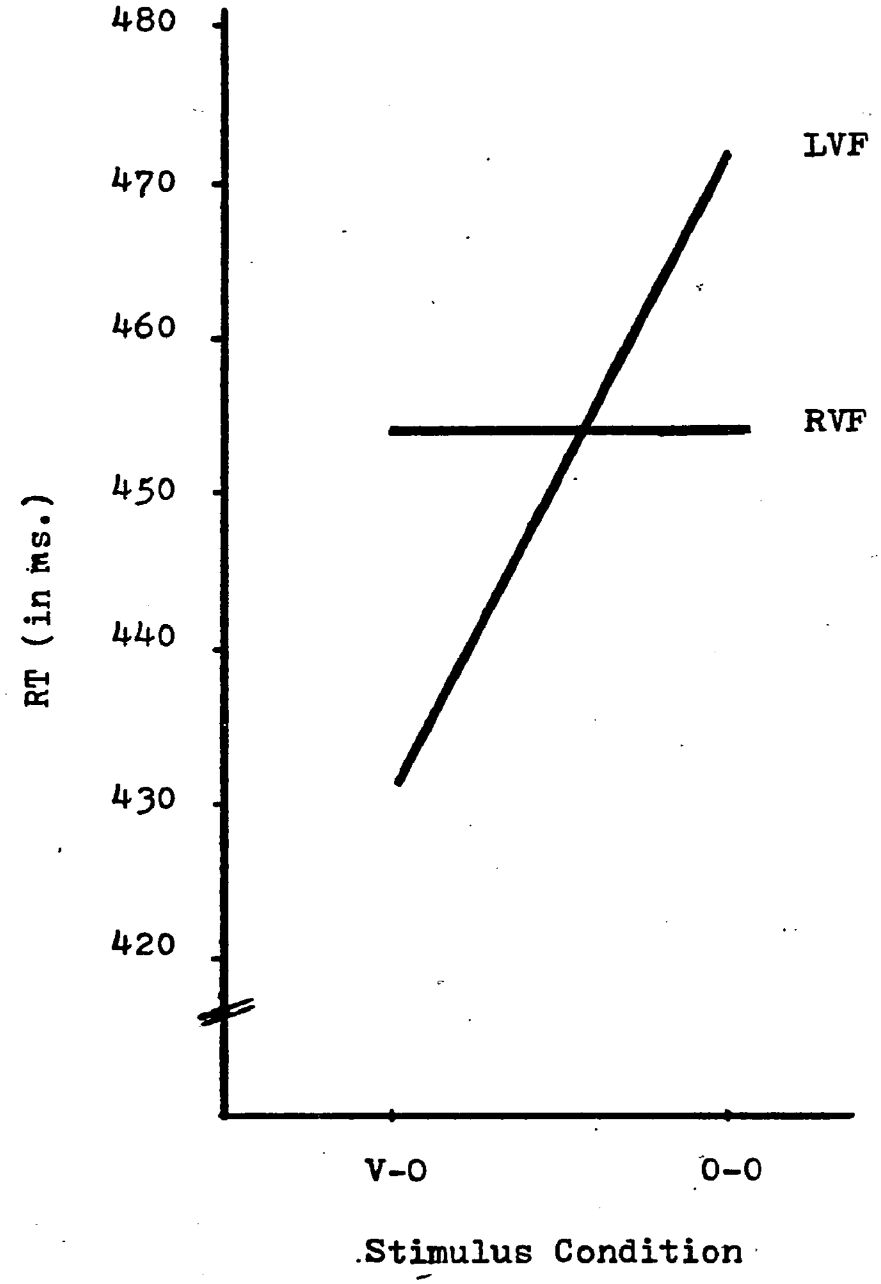


Figure 3. Interaction between stimulus condition and VF.

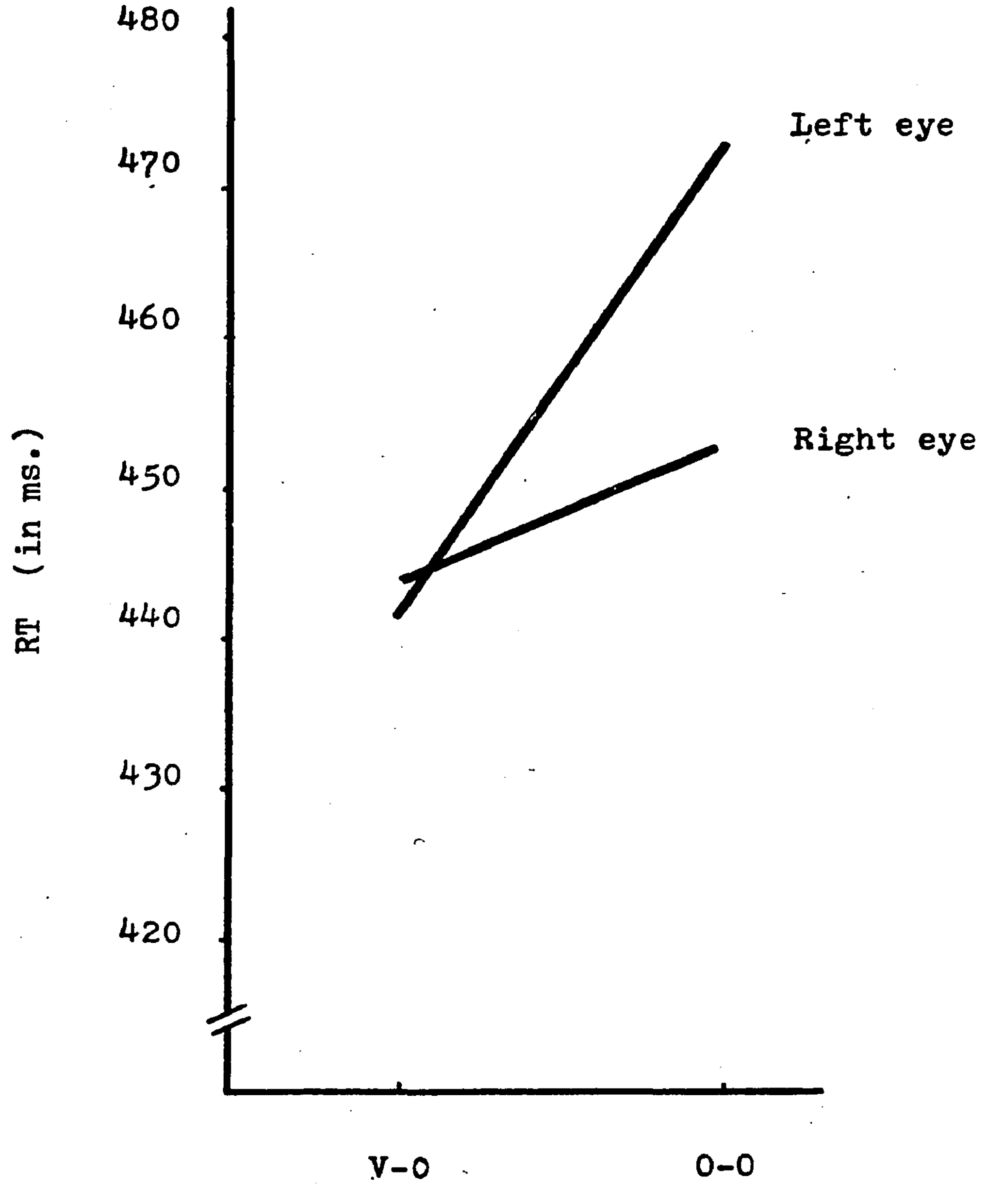


Figure 4. Interaction between stimulus condition and eye.

A tabulation of the geometric means of correct RT for the four IV in individual subjects is shown in Appendix D.

Three-Way ANOVA (right and left eyes separately)

Tables 3 and 4 present summaries of two three-way ANOVA (two stimulus conditions x two VF x two hands) performed on the geometric means of correct RT for the right and left eye separately.

The interaction between stimulus condition and VF for the right and left eye analyzed separately is displayed in Figure 5. The only significant effect was in in processing time in the RVF between the two conditions. When stimulating the right eye, stimulus condition O-O was processed, on the average, 17 ms faster in the RVF than in the LVF. The same relationship for the left eye fell short of significance ($p < .10$).

RT of Correct Responses as Function of the Visual Pathways

The RT data retabulated in terms of crossed and uncrossed visual pathways were submitted to a four-way ANOVA (two visual pathways x two stimulus conditions x two eyes x two hands) which is shown in Table 5. There was no significant main effect but the interaction between eyes and conditions, previously noted in the RT analysis, remained significant.

Table 3: ANOVA of geometric means of RT for correct responses

Right eye

Source	df	Sum of squares	Mean squares	F	P
Total		190,343.81			
C	1	1,073.52	1,073.52	.76	
F	1	50.02	50.02	.09	
H	1	180.19	180.19	.54	
C x F	1	8,242.52	8,242.52	21.51	.01
C x H	1	379.69	379.69	1.74	
F x H	1	315.19	315.19	2.81	
F x C x H	1	450.19	450.19	1.45	

Key to the Table

F : Visual Field
C : Stimulus Condition
H : Hand

For the sake of clarity error terms are not shown.

Table 4: ANOVA of geometric means of RT for correct responses

Left eye

Source	df	Sum of squares	Mean squares	F	P
Total		258,503.98			
C	1	12,256.03	12,256.03	4,02	
F	1	623.52	623.52	.49	
H	1	28.52	28.52	.01	
C x F	1	3,024.19	3,024.19	10.76	
C x H	1	105.02	105.02	.13	
F x H	1	58.52	58.52	.06	
C x F x H	1	22.68	22.68	.04	

Key to the Table

F : Visual Field
C : Stimulus Condition
H : Hand

For the sake of clarity error terms are not shown.

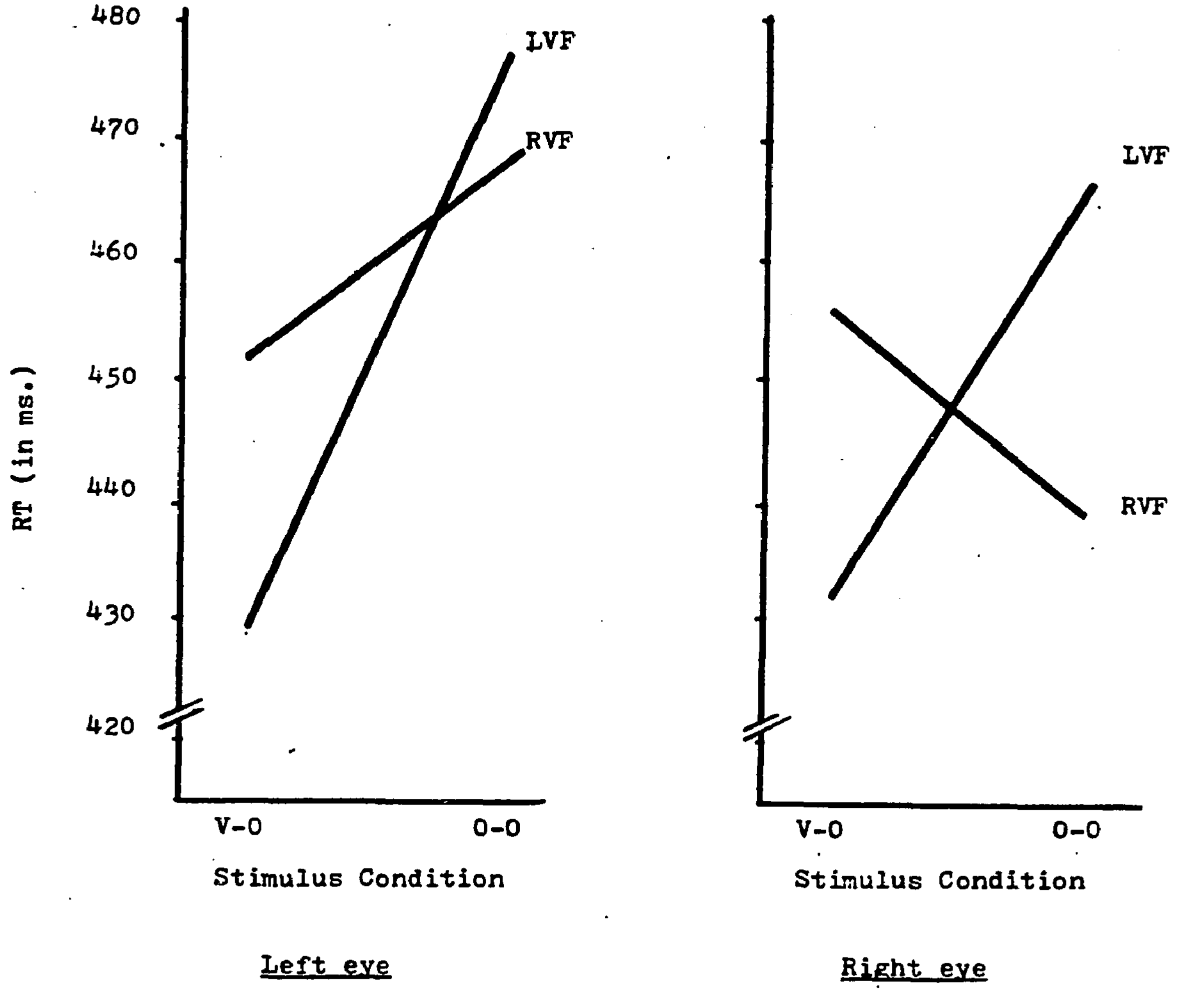


Figure 5. Interaction between stimulus condition and VF, for stimuli presented to the left and right eye.

Table 5: ANOVA of geometric means of RT for correct responses (as function of the visual pathways)

Source	df	Sum of Squares	Mean Squares	F	P
Total		450,497.83			
P	1	513.37	513.37	1.98	
E	1	1,650.04	1,650.04	5.46	
C	1	10,292.04	10,292.04	2.54	
H	1	32.66	32.66	.04	
P x C	1	640.67	640.67	1.07	
P x E	1	160.17	160.17	.10	
P x H	1	51.05	51.05	.13	
C x E	1	3,037.50	3,037.50	7.59	.05
C x H	1	442.05	442.05	.91	
E x H	1	176.05	176.05	.11	
P x C x E	1	626.04	626.04	157.03	.001
P x C x H	1	337.50	337.50	2.06	
P x E x H	1	322.66	322.66	.43	
C x E x H	1	42.66	42.66	.08	
P x C x E x H	1	135.38	135.38	.20	

Key to the table

P : Visual Pathways
C : Stimulus condition
E : Eye
H : Hand

For the sake of clarity error terms are not shown.

There was also a significant three-way interaction among the variables eyes, conditions and visual pathways. This three-way interaction is graphically presented in Figure 6. RT tended to be slower for stimulus condition V-O than for stimulus condition O-O for stimuli projected to the crossed visual pathway (nasal retina) of the right eye. The reverse relationship was observed for stimuli presented to the crossed visual pathway (nasal retina) of the left eye. The uncrossed pathways (temporal retinal fields) showed less clear-cut differences between eyes. Stimulus condition V-O led to slower responses in the uncrossed pathway (temporal field) of the left eye than of the uncrossed pathway of the right eye. No difference was observed between the uncrossed visual pathways (temporal fields) under stimulus condition O-O.

Errors of Commission

Arc sin transforms of geometric means of the speed of erroneous responses and percentage of errors of commission, were examined with two five-way ANOVA (Tables 6 and 7). The raw data relating to these analyses is presented in Appendices E and F respectively.

Table 6 indicates that the distribution of the latency of erroneous responses was at chance level across the IV. Analysis of the percentage of errors (Table 7) indicates that more erroneous responses were given to stimuli presented in the RVF than in the LVF ($\bar{X}$ arc sin transformation: 1.10 versus .96), and that there were significantly more mistakes made for stimulus condition O-O than for stimulus condition V-O ($\bar{X}$ arc sin transformation:1.13 versus .92).

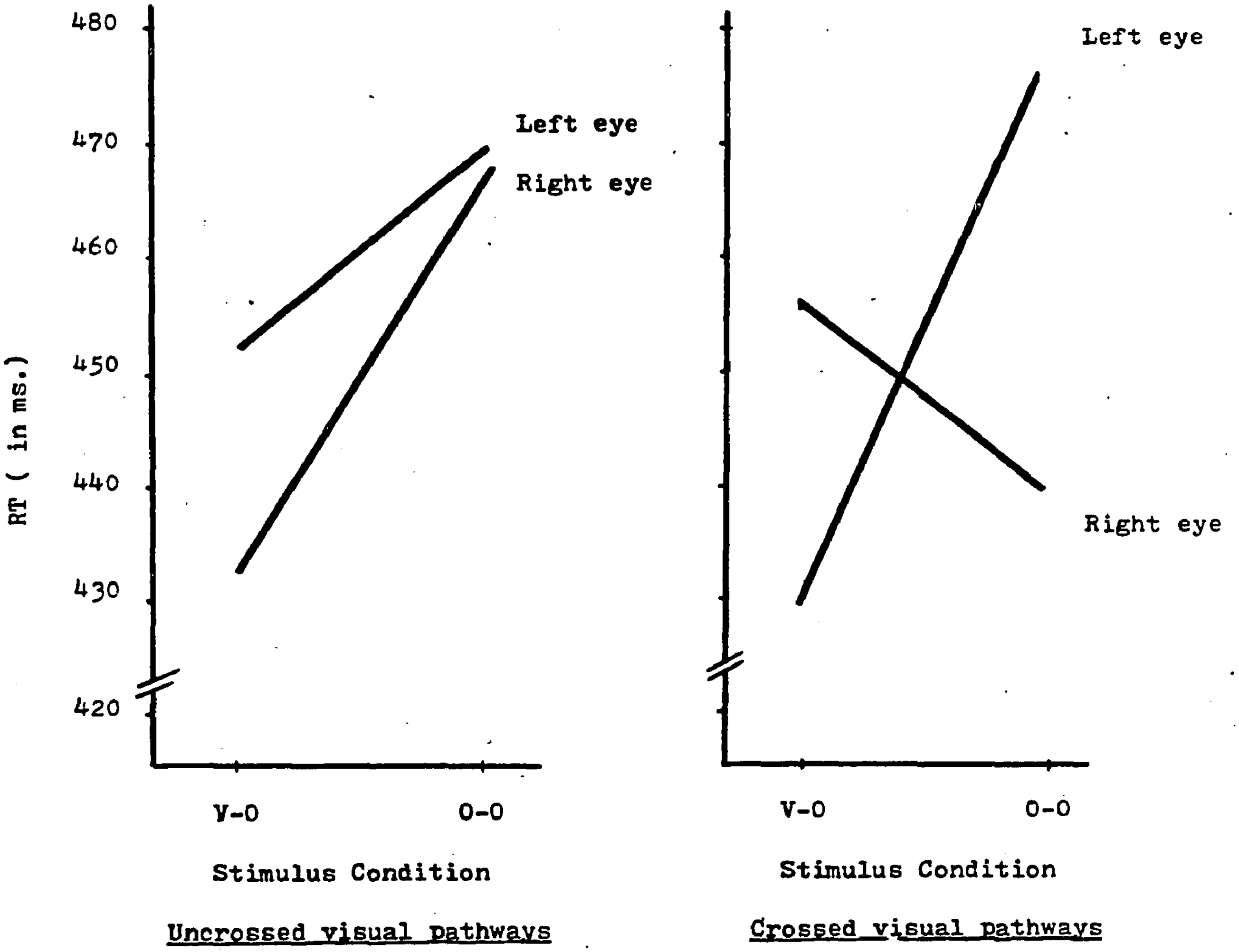


Figure 6. Three way interaction between visual pathway, eye, and stimulus condition.

Table 6: ANOVA of geometric means of RT of errors of commission

Source	df	Sum of Squares	Mean Squares	F	P
C	1	4,760.17	4,760.17	.47	
F	1	1,855.04	1,855.04	.31	
E	1	11,528.17	11,528.17	2.11	
H	1	3,927.04	3,927.04	.57	
C x F	1	864.00	864.00	.19	
C x E	1	345.04	345.04	.09	
C x H	1	6,337.5	6,337.5	.73	
F x E	1	160.17	160.17	.07	
F x H	1	2,420.04	2,420.04	.88	
E x H	1	3,901.5	3,901.5	.67	
C x F x E	1	1,426.04	1,426.04	2.45	
C x F x H	1	6,208.17	6,208.17	1.26	
C x E x H	1	1,890.38	1,890.38	.37	
F x E x H	1	8,512.67	8,512.67	4.3	
C x F x E x H	1	11,660.04	11,660.04	4.19	

Key to the table

C : Stimulus Condition
F : Visual Field
E : Eye
H : Hand

For the sake of clarity error terms are not shown.

Table 7: ANOVA on arc sin transformed percentage of errors of commission

Source	df	Sum of Squares	Mean Squares	F	P
C	1	1.0308	1.0308	9.51	.05
F	1	.4455	.4455	8.58	.05
E	1	.0215	.0215	1.77	
H	1	.0001	.0001	.05	
C x F	1	.2179	.2179	1.39	
C x E	1	.1015	.1015	2.82	
C x H	1	.0005	.0005	.22	
F x E	1	.3199	.3199	3.82	
F x H	1	.0467	.0467	4.15	
E x H	1	.0653	.0653	2.51	
C x F x E	1	.0209	.0209	.24	
C x F x H	1	.0248	.0248	.54	
C x E x H	1	.0112	.0112	.40	
F x E x H	1	.0009	.0009	.47	
C x F x E x H	1	.0480	.0480	5.49	

Key to the table

C : Stimulus Condition
F : Visual Field
E : Eye
H : Hand

For the sake of clarity error terms are not shown.

Summary of Results on Accuracy and RT

In summary of the results so far, accuracy of performance was significantly greater for stimuli presented in the LVF than in the RVF. Also, stimulus condition V-O was discriminated significantly more accurately than stimulus condition O-O and stimuli presented to the right eye were perceived with greater accuracy than when projected to the left eye. In addition, there was a strong interaction between the hand used to respond and the VF, with the more accurate performance obtained for the combination right hand-LVF.

As far as RT for correct responses is concerned, none of the main effects reached significance, though there was a strong interaction between VF and stimulus condition. A positive relationship was also observed between stimulus condition and eye stimulated, with stimulus condition O-O being processed faster via the right eye than via the left eye.

No main effect or interaction reached significance when the left eye was considered alone. But, when the right eye was considered, a strong interaction between stimulus condition and VF was observed. This last interaction was similar in trend to the one observed for the two eyes combined. It is apparent that for the right eye alone stimulus condition O-O was handled much faster in the RVF than the LVF.

The RT data retabulated according to the visual pathways (uncrossed and crossed) showed again significant interaction between stimulus condition and eye stimulated and, in addition, a highly significant three way interaction indicated the existence of a positive relationship between visual pathway, stimulus condition and eye stimulated. This three way interaction showed that, for crossed visual pathways, stimulus condition O-O was responded to faster when projected to the right eye than to the left eye.

The distribution of errors of commission was not significant across the four IV, as far as speed of the response was concerned. However, as far as accuracy of the response, more errors were made for stimulus condition O-O than for stimulus condition V-O, and also when stimuli were projected to the RVF than to the LVF.

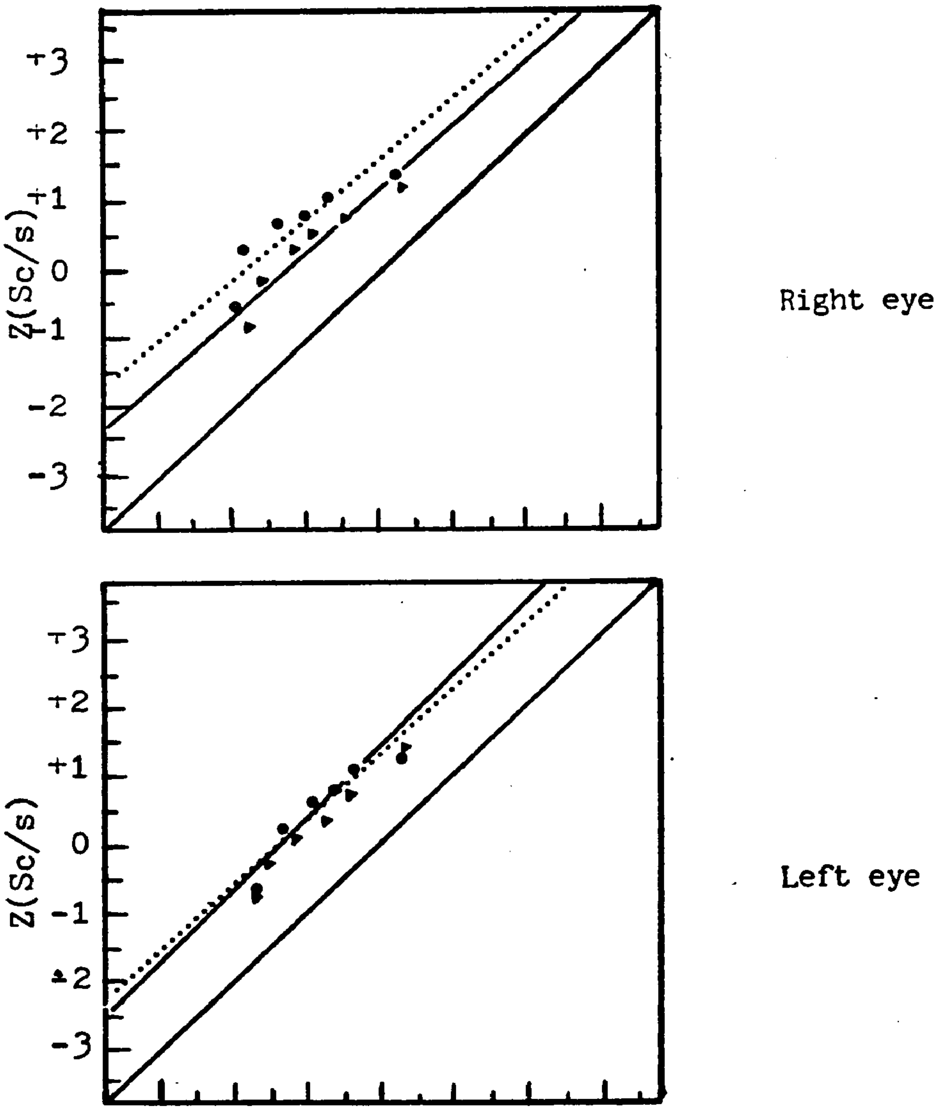
Signal Detection

Sensitivity

Averaged ROC curves. The averaged ROC curves, obtained by averaging the Z values of the scores for the signal trials [Z(Sc/s)] and the Z values of the scores for the non-signal trials [Z(Sc/ns)] over the six subjects, are displayed in Figures 7 and 8. A LVF superiority was present for stimulus condition V-O, for the right eye alone. No difference between VF was noted for the left eye. Considerable overlap between the ROC curves was evidenced for stimulus condition O-O.

Figure Caption

Figure 7. Averaged normalized ROC curves for the six subjects for stimulus condition V-0, in terms of Z scores. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.



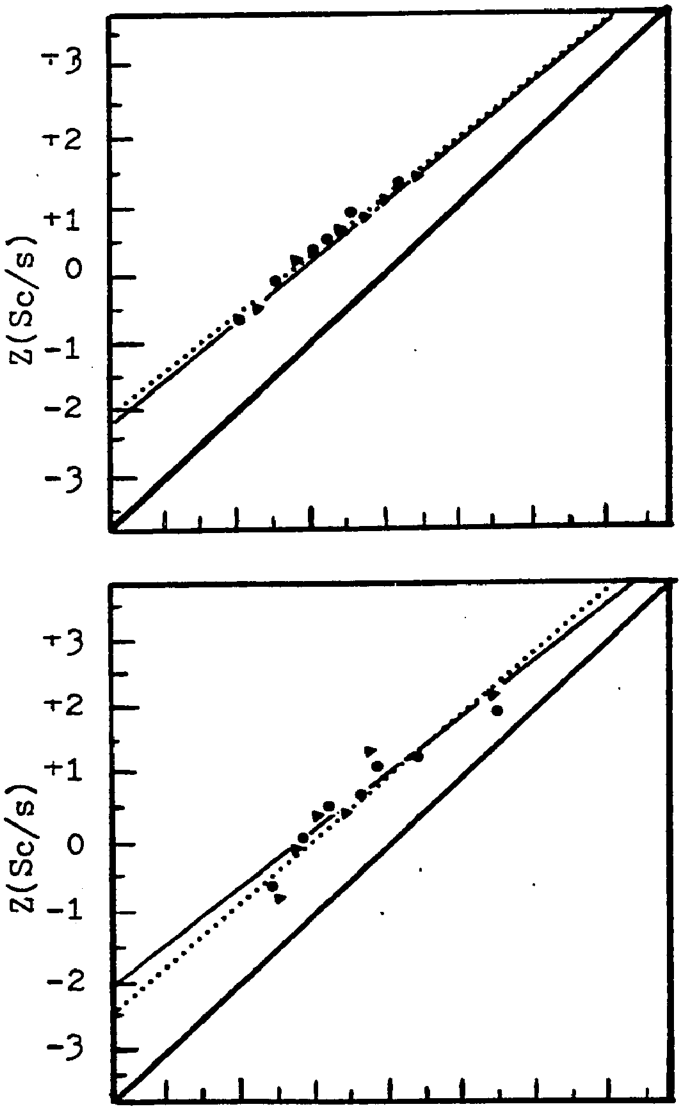
Right eye

Left eye

Figure 7. Averaged ROC curves - Stimulus condition V-O.

Figure Caption

Figure 8. Averaged normalized ROC curves for the six subjects for stimulus condition O-O, in terms of Z scores. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.



Right eye

Left eye

Figure 8. Averaged ROC curves - Stimulus condition 0-0.

Individual ROC curves. To provide additional confidence in the above findings, the VF discrimination sensitivities for the right and left eye were compared for each of the six subjects, under each stimulus condition (Figures 9, 10, 11 and 12).

As was the case with the averaged data, a straight line was fitted easily through the cumulative probability points of the ROC curves, thereby justifying the assumption of normality. The prediction of equal variance between the two overlapping distributions of noise and signal + noise was not fulfilled, however. This is expressed graphically by the lack of parallelism between the ROC curves and the positive diagonal (Figures 9-12) and numerically by the deviations from unity of the ROC slopes seen (Table 8).

The discrimination index _d'e_, calculated directly from the graphs, is shown in Table 9 for each eye and visual field under both experimental conditions. Inspection of this table, in conjunction with Figures 9-12, confirms that at least for stimulus condition V-O some discrimination difference was present between the two VF. More specifically, three of the six subjects (Subjects 1, 2 and 5) showed a greater sensitivity in the LVF than the RVF when using their right eyes. Although this general trend could also be seen for the left eye, differences between the visual fields were not as clear. There was considerable overlap between the distributions of the two visual fields for stimulus condition O-O.

Figure Caption

Figure 9. Individual normalized ROC curves in terms of Z scores, when stimulus-condition V-O was presented to the right eye. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.

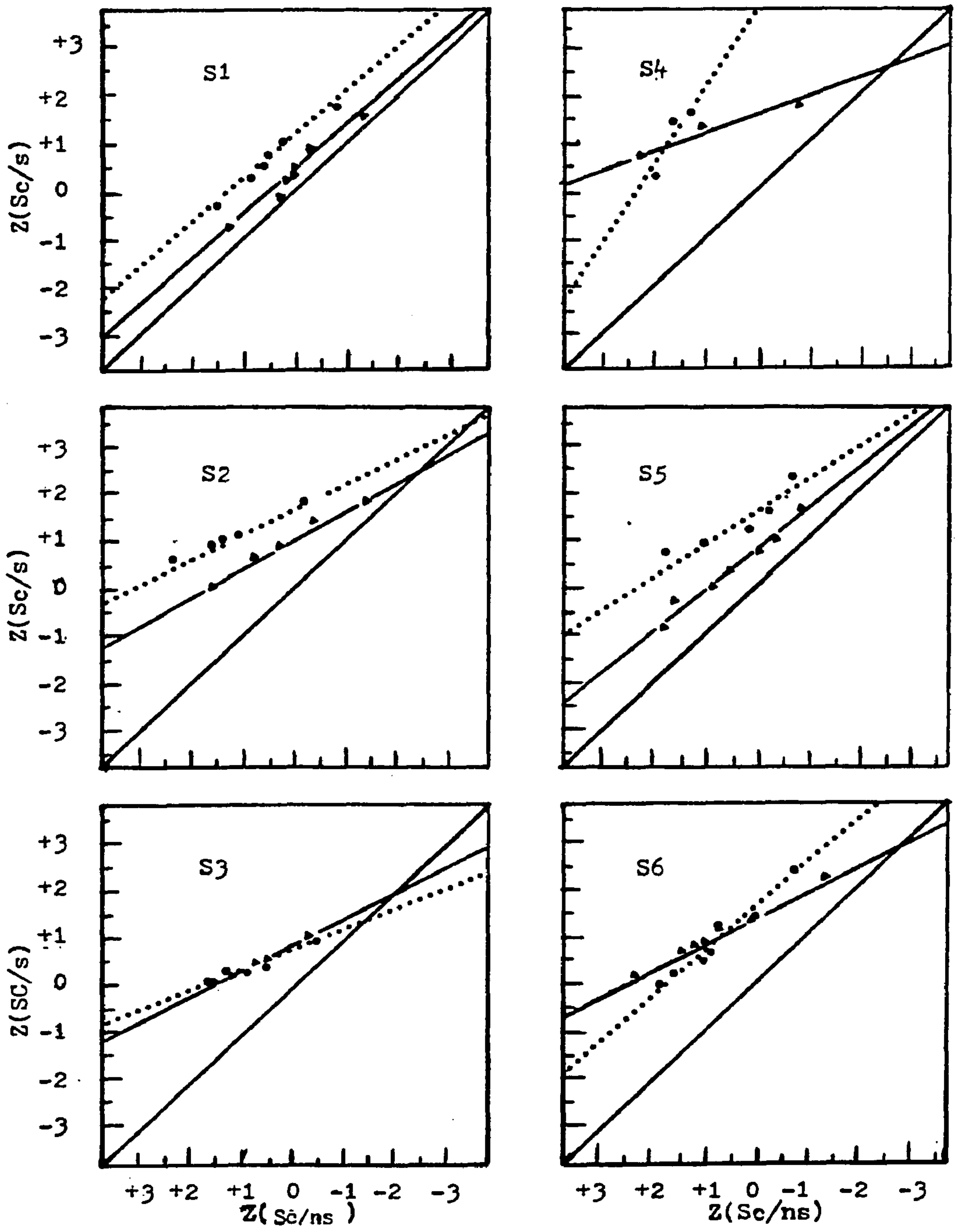


Figure 9. Stimulus condition V-O (right eye).

Figure Caption

Figure 10. Individual normalized ROC curves in terms of Z scores, when stimulus-condition V-O was presented to the left eye. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.

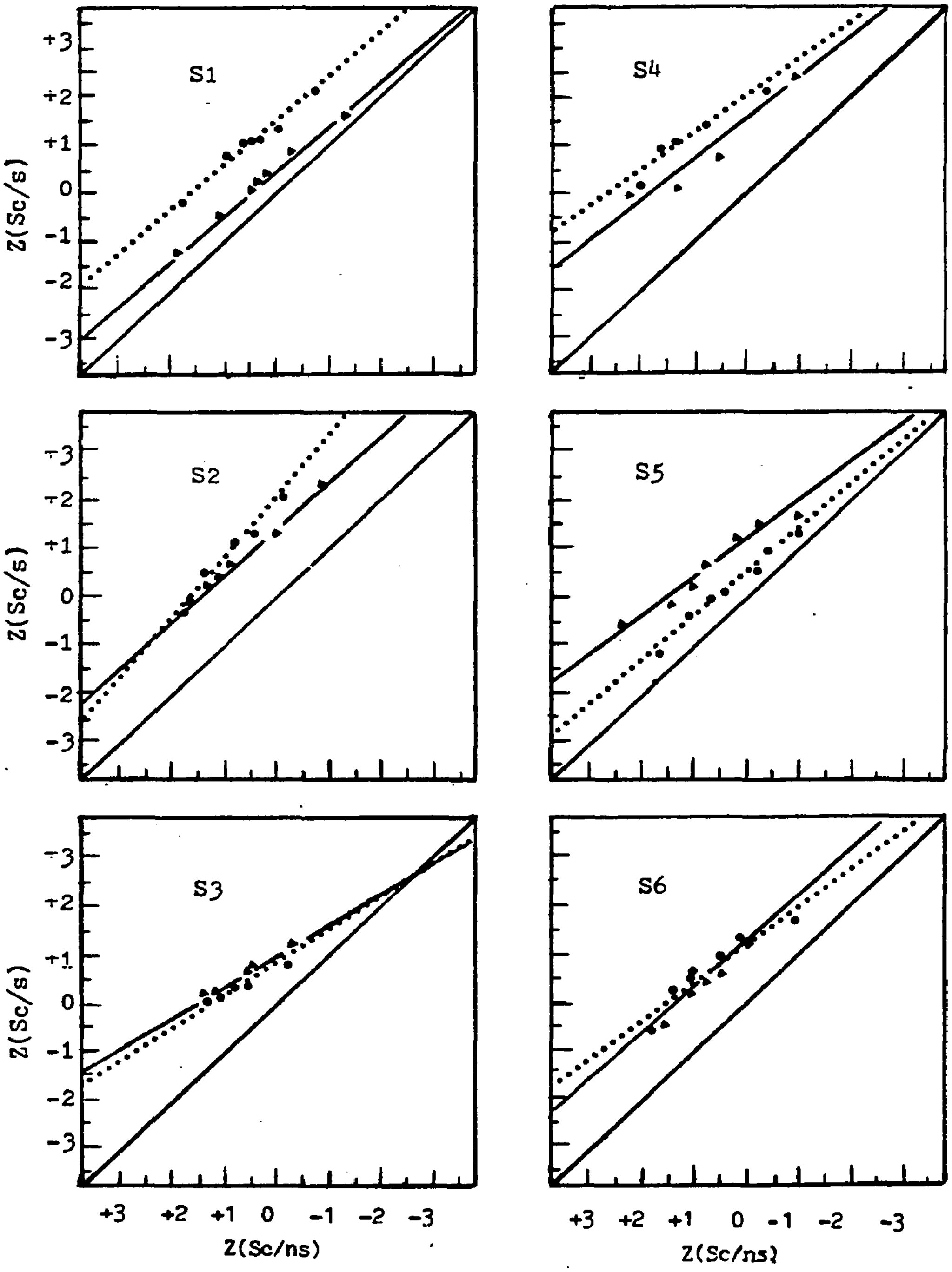


Figure 10. Stimulus condition V-0 (left eye).

Figure Caption

Figure 11. Individual normalized ROC curves in terms of Z scores, when stimulus-condition O-O was presented to the right eye. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.

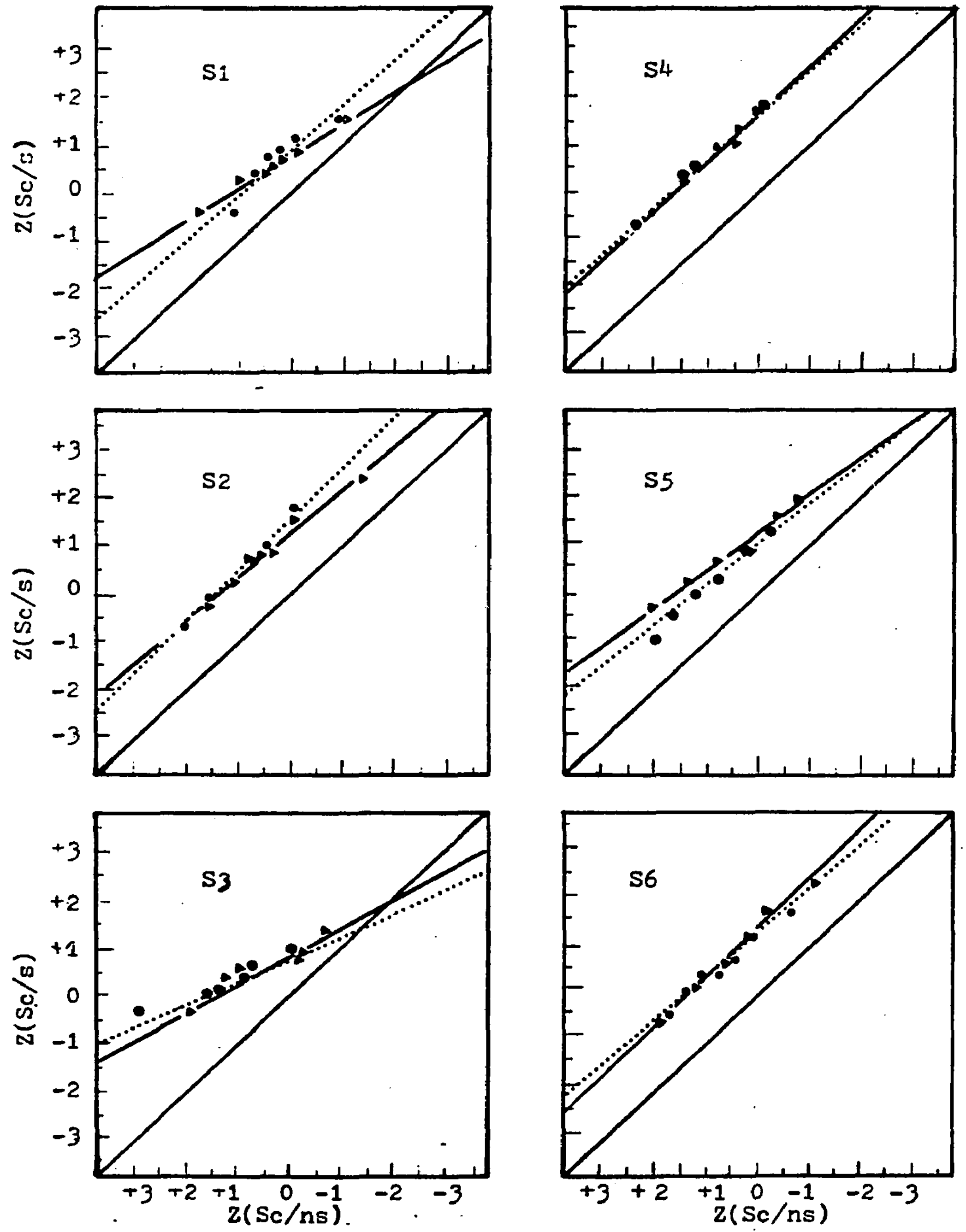


Figure 11. Stimulus condition 0-0 (right eye).

Figure Caption

Figure 12. Individual normalized ROC curves in terms of Z scores, when stimulus-condition 0-0 was presented to the left eye. The probability of a response to a signal [Z(Sc/s)] is plotted as a function of the probability of a response to a non-signal [Z(Sc/ns)]. Circles (●) and dotted lines represent LVF; triangles (▲) and continuous lines represent RVF.

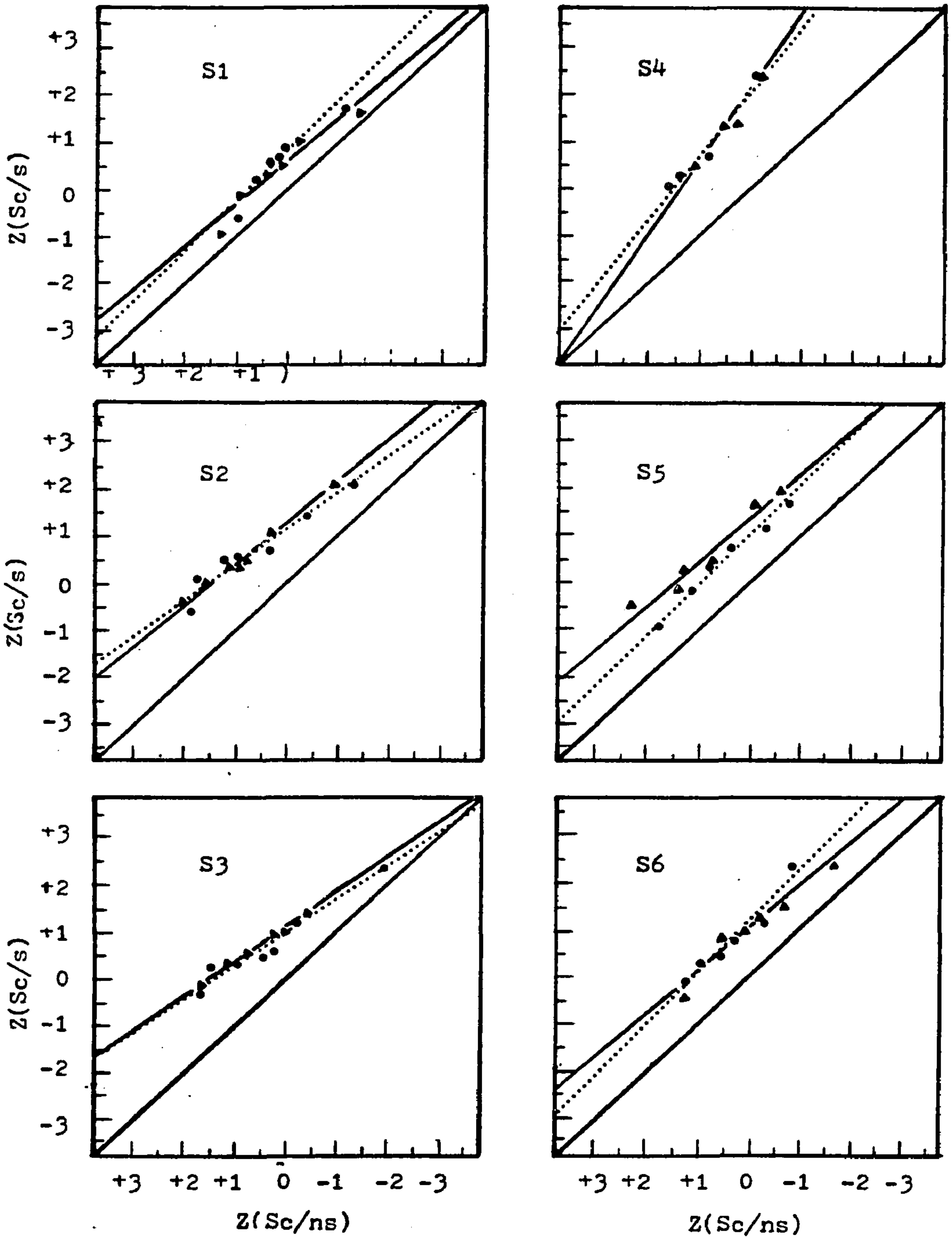


Figure 12. Stimulus condition 0-0 (left eye).

Table 8: ROC curve slopes.

Stimulus Condition V-0

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	.91	.94	.87	.87
2	.48	.60	1.20	.93
3	.30	.43	.68	.65
4	1.71	.35	.76	.82
5	.66	.86	.93	.77
6	.95	.54	.81	.97
$\bar{X}$	.84	.62	.88	.84
SD	.50	.23	.18	.12

Stimulus Condition 0-0

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	.94	.66	1.10	.91
2	1.06	.89	.76	.86
3	.45	.56	.71	.76
4	.97	.99	1.38	1.55
5	1.18	.79	1.02	.92
6	.92	1.03	1.11	.91
$\bar{X}$	.92	.82	1.01	.99
SD	.25	.19	.25	.28

Table 9: Values of d'e.

Stimulus Condition V-O

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	1.2	.8	1.6	.3
2	2.1	1.3	1.9	1.4
3	1.3	1.2	1.0	1.2
4	2.8	2.2	2.2	1.7
5	1.8	.8	.4	1.4
6	1.7	1.9	1.3	1.3
$\bar{X}$	1.82	1.37	1.39	1.21
SD	.58	.58	.64	.50

Stimulus Condition O-O

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	.9	.9	.8	.5
2	1.6	1.4	1.3	1.4
3	1.1	1.1	1.2	1.3
4	1.7	1.6	1.8	1.6
5	1.1	1.4	.8	1.5
6	1.4	1.3	1.2	1.0
$\bar{X}$	1.30	1.28	1.18	1.22
SD	.32	.25	.37	.41

In only one instance was a difference noted. This was for subject 5 who displayed a slight RVF superiority in both eyes.

These apparent differences between VF were further examined statistically using the G test (Gourevitch & Galanter, 1967; Marascuilo, 1970). The results of this analysis, expressed in terms of Z left - Z right, are presented in Table 10.

There was generally good agreement between the information obtained from the G statistic and the ROC curves. Under stimulus condition V-O, the .05 significance level was reached by subjects 1, 2 and 5 when they used their right eyes. For the left eye, subjects 1, 4 and 5 showed significant results. For subject 5, there was an RVF superiority in contrast to the LVF supremacies displayed by the other subjects. Thus, the G statistic showed no significant difference between VF for stimulus condition O-O. This constituted the only discrepancy with the graphic representation, in which subject 5 displayed some slight RVF superiority for both eyes.

Decision Bias

Estimates of the criterion index "log β middle point" are presented in Table 11 for all the independent variables studied. A completely opposite result to the sensitivity measure was obtained for the response criterion.

Table 10: G Statistic

Stimulus Condition V-0

	Right Eye		Left Eye	
Subject	Z LVF - Z RVF	P	Z LVF - Z RVF	P
1	2.91	.05	3.07	.05
2	2.92	.05	.95	.05
3	-.03		-.17	
4	-.75		2.58	.05
5	3.33	.05	-2.95	.05
6	-.64		-.47	

Stimulus Condition O-O

	Right Eye		Left Eye	
Subject	Z LVF - Z RVF	P	Z LVF - Z RVF	P
1	.80		.49	
2	.29		.64	
3	1.03		-.74	
4	.42		-.15	
5	-.19		-.53	
6	.47		-.37	

Table 11: Log β middle point.

Stimulus Condition V-0

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	-.092	-.051	-.276	-.046
2	-.143	-.357	-.004	.127
3	-.319	-.215	-.027	-.187
4	.498	-.602	.021	.053
5	-.495	-.041	.009	-.086
6	.045	-.167	.037	.029
$\bar{X}$	-.084	-.239	-.040	-.018
SD	.340	.210	.118	.112

Stimulus Condition 0-0

	Right Eye		Left Eye	
Subject	L V F	R V F	L V F	R V F
1	-.131	-.200	-.032	-.022
2	.017	-.114	.017	.111
3	-.149	-.310	-.161	-.194
4	.301	-.222	.322	-.174
5	.281	-.194	-.071	.021
6	.057	-.060	-.009	-.252
$\bar{X}$	.063	-.183	.011	-.085
SD	.194	.087	.165	.143

Note: For computation convenience, ordinary logarithms have been transformed into negative logarithms.

A clear difference between criteria for stimuli presented in the left and right VF was observed for stimulus condition O-O while no evidence of response criterion difference was observed for stimulus condition V-O (right eye: *t* (5) = .96, N.S.; left eye: *t* (5) = .37, N.S.). For stimulus condition O-O a more lax criterion was noted in the RVF than in the LVF, when the right eye was used, *t* (5) = 3.03, *p* < .025. No indication of bias was noted for the left eye, *t* (5) = .98, N.S.

Summary of the Signal Detection Results

Under stimulus condition V-O, the data for the group indicated significant VF asymmetry for each eye. Analysis of the individual performances indicated that three subjects out of six showed evidence of different discrimination sensitivities for stimuli presented in the two VF, when stimulus condition V-O was used. Only one subject displayed a consistent LVF superiority in both eyes. Another subject showed the opposite superiority in the two VF for both eyes and the last two subjects displayed some VF superiority in one eye only. There was no evidence of lateralized discrimination when stimulus condition O-O was presented, although as far as judgmental bias is concerned, subjects were more liberal about identifying a stimulus in the RVF, but only when they used their right eye. No evidence of judgmental bias was observed for stimulus condition V-O.

CHAPTER 4

DISCUSSION

The results obtained in this study supported most of our predictions regarding accuracy. Greater accuracy for detection of line orientation was observed when stimuli were presented in the LVF than the RVF; stimulus condition V-O was easier than stimulus O-O; and a greater percentage of correct responses were given when the right eye was stimulated than when the left eye was stimulated. The only prediction which was not upheld concerned the hands. Accuracy of performance with the right hand did not differ significantly from that with the left hand, though a positive interaction between VF and hand was noted. Different findings emerged from the RT analysis. The main effects (VF, stimulus condition, eye and hand) varied only at chance level, while two interactions were significant. An interaction between stimulus condition and VF indicated that stimulus condition V-O was responded to 41 ms faster than stimulus condition O-O when projected to the LVF. An interaction between stimulus condition and eye showed that responses were faster under stimulus condition O-O when the right eye was used than when the left eye was used. Results from signal detection analysis were quite similar to those obtained with RT, inasmuch as greater sensitivity was noted for stimulus condition V-O when it was projected in the LVF than in the RVF, while no such differential sensitivity was noted for task O-O. As with the RT data, this was true for the right eye only. In addition, different strategies were used by the two hemispheres. A more lax criterion was adopted for the more difficult condition when presented to the left than to the right hemisphere. Again, this was true only for the right eye.

Stimulus Condition

There is good evidence that the task V-O was easier than task O-O, based on the significantly greater accuracy displayed for the latter task. The superiority of recognition for vertical over oblique lines is well documented (Appelle, 1972; Campbell, Kulikowsky, & Levinson, 1966; Ogilvie & Taylor, 1958). The nature of the mechanisms underlying this superiority has been linked to both environmental and physiological factors, with the strong possibility that these two cannot be totally dissociated.

Those who favor an environmental interpretation believe that some orientational selectivity mechanism is likely to favor vertical and horizontal anchors, because of the predominance of these orientations in the western rectilinear world (Blakemore, 1974). Proponents of a physiological explanation, extrapolating from animal research, argue that visual acuity is greater for vertical and horizontal than for oblique orientations, due to such structural aspects of the visual system as contrast and spatial frequency (Campbell et al., 1966; Campbell & Maffei, 1970; Maffei & Campbell, 1970) and of specific feature-extracting neurons recorded from the visual cortex of most species (Barlow & Hill, 1963; Hubel & Wiesel, 1959; 1970; Lettvin, Maturana, McCullough & Pitts, 1959)

Yet, the importance of higher mental processes in the recognition of orientations should not be overlooked. It has been found that recognition of the left oblique takes longer than recognition of the right oblique (Olson & Hildyard, 1977), even though there are no notable acuity differences between these two orientations (Appelle, 1972). This implies that, in addition to perceptual mechanisms, semantic systems of representations might be needed to differentiate between obliques. In further support of the role of higher mental functions in the discrimination of line orientation, Weitzman and Smith (1973), using a signal detection paradigm, found that differences in acuity between vertical and horizontal lines were related to differences in judgmental standards and not to differences in sensitivity.

Thus decision making functions may interact with the stimulus properties. Umilta et al. (1974) make the point that task difficulty can be defined conceptually, in addition to perceptually, by the presence or absence of verbal codes. Since, in the present experiment, explicit verbal codes were provided for all stimuli and since a difference in sensitivity favoring stimulus condition V-O was observed, it is likely that the task difficulty here was mainly of perceptual origin.

Visual Field

The present findings support the often demonstrated superiority of the right hemisphere for visuospatial tasks (see for example, Dimond & Beaumont, 1974; Milner, 1971; Sperry, 1974). The asymmetrical performance favoring the right hemisphere in this study may have been due to a combination of factors, such as the use of male subjects and difficult tasks, and the role played by mnemonic variables.

Compared to females, males are known to show greater and more consistent superiority for stimuli presented in the LVF than RVF (Harris, 1978; Kimura, 1969; 1973; McGlone & Davidson, 1973). Various models have been proposed to explain such gender differences. Rudel, Denckla and Spalten (1974) and Witelson (1975) believe that these are due to earlier right hemisphere lateralization in males than in females. Others have proposed that the superiority for spatial skills in males results rather from early bilateral spatial representation, contrasting with earlier maturation of the left hemisphere and unilateral representation of spatial skills in females (Buffery & Gray, 1972). As an alternative explanation, Kimura (1969, 1973) hypothesized that there is, in general, greater lateralization of functions in males than in females.

The degree of task difficulty seems also to be a critical factor in the expression of right hemisphere function. A review of the literature indicates that the greater involvement of the right than the left hemisphere for the discrimination of line orientation is observed in normal subjects only when the discrimination is relatively difficult (Atkinson & Egeth, 1973; Durnford & Kimura, 1971; Fontenot & Benton, 1972; Kimura & Durnford, 1974; Umilta et al., 1974) or entails higher order processing (Moscovitch, 1979). An interpretation of right hemisphere superiority in terms of perceptual difficulty certainly fits the present findings. Our tasks were by operational definition quite hard, since the percentage of hits was manipulated to revolve around 60-70%. The finding that both stimulus conditions were processed more accurately in the LVF than the RVF, contrary to both White's and Umilta's results, most likely results from the perceptual difficulty of our tasks.

The issue of perceptual difficulty is complicated by a critical variable: the availability of verbal codes. It is argued that right hemisphere superiority arises not from the perceptual difficulty of the task but rather when there is an absence of or an unavailability of verbal codes. If so, visuospatial tasks amenable to verbal mediation ought to elicit left hemisphere rather than right hemisphere superiority. Codable visuo-spatial tasks have been reported to lead to left hemisphere superiority, but the tasks used were usually easy (Bryden & Rainey, 1963; Umilta et al., 1973, 1974; White, 1971; Wycke and Ettlinger, 1961). The distinction between the factors of perceptual difficulty and verbal codability in eliciting hemispheric asymmetries is, however, a rather fluid one since, as was pointed out in the introduction, easy tasks usually lend themselves to readily available verbal codes (Umilta et al. 1974).

Several experiments have attempted to delineate the relative importance of these factors, with mixed results. Evidence is mixed. In favor of the preeminence of perceptual difficulty, Berlucchi et al. (1979) showed that difficult tasks, with or without verbal codes, are processed more efficiently in the right hemisphere. In contrast, Ornstein, Johnstone, Herron, & Swencionis (1980) found that right hemisphere superiority subsides when tasks requiring great analytic power are used. This indicates that the notion of visual difficulty needs further refinement as to whether it is taken to mean perceptual or analytic difficulty.

Memory is another variable that may critically affect hemispheric asymmetry. Hardyck et al. (1978) have proposed that hemispheric superiority arises not from perceptual processes but rather from memory factors. This hypothesis however is based on experimental findings utilizing verbal material and may be limited to the left hemisphere. Evidence regarding the effect of memory on right hemisphere performance is contradictory depending whether short- or long-term memory processes are involved. There is converging evidence that right hemisphere superiority is enhanced for short-term memory by lengthening the interval between stimulus and response (Bevilacqua et al., 1979; Dee & Fontenot, 1973; Moscovitch et al., 1976). Under this circumstance, the greater efficiency of the right than the left hemisphere for later stages of processing has been ascribed both to differential encoding speed between the hemispheres and to greater iconic persistence in the LVF than the RVF (Cohen, 1976; Hellige and Webster, 1979; Moscovitch , 1979). In comparison, the effect of long term memory on right hemisphere performance is refuted by Marzi et al. (1974) and Umilta et al. (1978) who showed that increasing familiarity with unknown faces causes a shift toward left hemisphere superiority, instead of increasing right hemisphere dominance. Our data, although not geared to test the effect of memory, are more in agreement with Hardyck et al.'s proposal since the great number of trials used in the present experiment did not apparently serve as a deterrent to the expression of right hemispheric superiority. Rather, one could speculate that the number of trials necessitated by signal detection may have served to enhance the asymmetry in lateralized performance.

Another aspect of the VF results that warrants discussion is the direction of the interaction VF x stimulus condition. The easier task (discrimination between a vertical and a 95 degree oblique line) was processed faster when presented in the LVF than in the RVF. However, there was a shift toward a RVF superiority for the more difficult task (discrimination between two obliques differing by five degrees). This goes against Umilta's et al.(1974) findings of a RVF superiority for an "easy" task (discrimination between a vertical and a 45 degree oblique) with a shift toward a LVF superiority for a more difficult task (discrimination between two obliques differing by 15 degrees).

The discrepancy between Umilta's and the present findings can be explained three ways: by differences in perceptual difficulty between the two studies, and both by the availability of verbal coding and the demonstration of different response bias between the hemispheres in the present study. These three interpretations are not mutually exclusive, but are in fact complementary.

The absence of evidence for a left hemisphere superiority for our "easy" task may have stemmed from the relatively high perceptual difficulty of this stimulus condition. Our "easy" task was certainly more difficult than that used by Umilta et al. In their paradigm, in addition to a readily available verbal code, the stimuli were separated by 45 degrees of angle and thus extremely easy to differentiate from each other. Furthermore, a stimulus duration of 100 milliseconds made the stimuli quite easy to perceive. Since task difficulty has been shown to play a critical role in inducing right hemispheric superiority (Berlucchi et al., 1979; Fontenot, 1973; Hellige and Webster, 1979; Umilta et al., 1974; 1978), it was not surprising to note that in Umilta's experiment a right hemisphere superiority, expressed in terms of RT, was present only when task difficulty was increased.

Some researchers have proposed that the right hemisphere superiority subsides as the task becomes more complex, requiring more of an analytic type of processing (De Renzi, 1978; Hellige and Cox, 1976; Ornstein et al., 1980). This hypothesis, however, is not supported by the results of the present study. Here, stimuli presented to the RVF were not discriminated more accurately than those presented in the LVF.

A complementary interpretation of these results suggests that laterality effects were due to differential hemispheric strategies. Examination of the criteria β middle point for the two VF suggests that, at least for stimulus condition 0-0, two different strategies were used. Signal detection analysis makes it clear that the left hemisphere was not more proficient in handling the more difficult task, as was also shown by the absence of significance in the accuracy analysis.

It is with some confidence that the assertion of differential cognitive strategies can be made. The odds were stacked against the uncovering of any strategy difference, since randomization of stimulus presentation in the two VF favored the use of a unified strategy. Nevertheless, the subjects kept track simultaneously of two decisional biases, one in each VF. This is a rather difficult task. The use of a within-subject design further strengthens the finding of a differential strategy for the two tasks. Also, the contrasting pattern of results obtained for the two stimulus conditions suggests that the possible confounding presented by the "stimulus context" in within subjects designs (Kimura, 1974) was minor enough as not to override laterality differences. Since the underlying density function can be assumed to be Gaussian, it is probable that no large error factor was correlated with the subjects' criterion (Pastore & Scheirer, 1974). Furthermore, the large number of trials used in this experiment increases confidence that no large error masked an actual deviation from normality. Thus signal detection analysis, which isolates the effects of sensitivity from decision bias, agreed with our more general analysis of the distribution of RT. Signal detection analysis, which gives a measure of discrimination presumably uncontaminated by processes like expectation suggested that the right hemisphere displayed a truly greater sensitivity than the left hemisphere in the handling of task V-O. The apparent superiority noticed for the right hemisphere for the more difficult task O-O, was actually related to more liberal judgmental standards.

In conclusion, the discrepancy between our results and those of Umilta can best be explained by a combination of our use of stimuli with greater perceptual difficulty, leading to a right hemisphere competence for both tasks, and the use of clear verbal instructions, allowing for greater processing speed in the left hemisphere. This left hemisphere superiority was the expression, at least in the present experiment, of more liberal judgmental standards and not of differential competence between the hemispheres. Furthermore, the striking similarities between signal detection data and RT findings suggested that, even though signal detection was based on the percentage of hits and false alarms differences between the two hemispheres, speed of processing may be the expression of differential cognitive strategies rather than the expression of superiority of one hemisphere over the other.

The present finding that left hemisphere function expressed itself by increased speed and more liberal judgments, rather than greater accuracy, are at variance with Kinsbourne's attentional model (1970). According to this model, instructions serve to prime the left hemisphere, thereby facilitating its performance. As Kinsbourne recognizes, the attention model relates to accuracy of performance rather than speed of performance (Kinsbourne, 1973). It should be noted, also, that Kinsbourne's attentional model offers no provision as to why there should be differential arousal depending on the discrimination difficulty of the task.

Rather than exerting an undifferentiated bias in arousal, verbal coding may have influenced the type of cognitive strategies used by the subjects. Some suggestion to this effect has recently been advanced by Niederbuhl and Springer (1979). Subjects were presented with sets of letters and were told to respond to them either on the basis of their names or on the basis of their shape. When instructions stressed naming, the response in the left hemisphere was 14 ms faster than in the right hemisphere. When task instructions stressed attention to shape, there was a trend toward a right hemisphere superiority. These results strongly point toward the importance of different cognitive strategies in hemispheric asymmetry.

The analysis of errors did not bring any new insight regarding the differential treatment of the two stimulus conditions. The finding that more errors were made with stimuli presented in the RVF than in the LVF and that more mistakes were made for stimulus condition O-O than for stimulus condition V-O concurred with the already discussed analysis of correct responses. As the latency of response for errors was entirely at chance level it appeared that subjects were not aware that they were in error. RT for correct responses was therefore not different in this case from the distribution of RT for errors.

Eye

The superiority of the right eye over the left eye was variously noted throughout the results, in terms of accuracy, RT, as well as sensitivity. There was a significant interaction between stimulus condition and eye stimulated for RT. Also the interaction between VF and stimulus condition observed for the two eyes combined was significant when the data obtained from the right eye was analyzed and was not significant when the data obtained from the left eye was analyzed, suggesting that the interaction was mainly supported by the right eye effect. Finally there was a significant three-way interaction among visual pathways, stimulus condition and eye stimulated.

As the subjects were selected on the basis of right eye dominance, the most immediate interpretation of this right eye efficiency would be, of course, in terms of sighting dominance. The functional significance of eye dominance, particularly in terms of cerebral asymmetry, is still largely unknown. One of the reasons may reside in the number of definitions attached to eye dominance, expressed variously in terms of sensory, acuity or sighting dominance. Sensory dominance, a condition in which there is a sustained discrepancy in the inputs to the two eyes, is rarely encountered under normal circumstances (Porac & Coren, 1976). Acuity dominance, which refers to the greater acuity of one eye, is the definition most often used in clinical populations. However, a normal observer without massive acuity imbalance is not dependent on this form of ocular dominance (Porac & Coren, 1976). Under normal viewing conditions, therefore, neither sensory or acuity dominance contribute greatly to visual information.

In contrast, sighting dominance may have functional significance and, as such, be related to the integration of lateralized perception. Walls (1951) has proposed a theory according to which the dominant sighting eye is mainly responsible for the stability of the visual field during eye movement and for the control of ocular movement. Sighting dominance has been correlated also with greater perceptual accuracy (Money, 1972; Sampson, 1969) and faster detection time, especially for right eye dominant subjects (Hilborn & Conklin, 1964). The present data are in agreement with these findings. It should be noted however that a peripheral interpretation in terms of eye dominance cannot account for the difference in speed between the two eyes observed for the two stimulus conditions. Such an effect implies in addition the role of more central mechanisms of perceptual integration.

Some investigators have argued that the superior performance observed when stimuli are presented to the right eye does not arise from eye dominance _per se_ but from other factors such as a difference in speed of conduction between the crossed and uncrossed pathways or hemispheric differences in perception.

Kimura (1966) has offered some evidence against the eye dominance hypothesis. She found that form enumeration was usually best performed in the LVF by both right eyed and left eyed subjects. This was taken to support an interpretation of cerebral rather than eye dominance. In all likelihood, however, these three factors of eye dominance, visual pathways and cerebral asymmetry are interconnected. For example, Hayashi and Bryden (1967) showed that, under binocular presentation, right eyed subjects showed a greater recognition for letters in the RVF than in the LVF, while left eye dominant subjects showed no differential effect. Although the authors did not pursue this argument, one could argue that left eye dominant subjects showed no effect because the crossed path from the dominant eye goes to the right hemisphere while the crossed visual path from the dominant eye of right eyed subjects goes to the left hemisphere. It should be noted that eye dominance was defined in Hayashi and Bryden's experiment in terms of acuity dominance and not sighting dominance.

Bryden (1973) has pursued the study of the relationship among task, eye dominance and laterality. He found that stimuli composed of letters were affected by both types of eye dominance while performance on dot localization was unrelated to either kind of dominance. In further support of the notion of an interplay between eye dominance and cerebral specialization, Kershner and Jeng (1972) reported that eye dominance was associated with better recall of certain materials. In a bilingual population, right eyed-subjects were better at processing Chinese and English words while left-eyed subjects were superior at recalling geometric forms. In addition the results indicated that geometric forms were better recalled when presented in the LVF than in the RVF, while verbal material was recalled better in the RVF. Thus, besides being compatible with a cerebral specialization interpretation, these results are in concordance with the idea that contralateral afferent projections from the retina may be stronger than ipsilateral afferent projections. The preeminence of the crossed visual pathways over the uncrossed pathways is well documented (Andreassi et al., 1975; Hubel and Wiesel, 1959, 1970; Maddess, 1975; Osaka, 1978). There would thus be an advantage in terms of speed to the LVF of the left eye and to the RVF of the right eye. This interpretation is supported in our data. The significant three way interaction, stimulus conditions x visual pathway x eye observed, confirmed that the crossed visual pathways carried information faster than the uncrossed pathways and that speed of response was related to the eye stimulated and to the type of stimulus material being processed.

Contrary to our findings of right eye superiority, some reports have indicated that the RVF superiority usually noted for verbal material is mostly due to an effect in the left eye (Luria, 1974; Markovitz and Weitzman, 1969). Interpretation of these experiments is difficult, however, since there was no mention of the subjects' eye dominance. Luria (1974) reported the findings without offering an explanation, while Markowitz and Weitzman (1969) suggested that the interaction between RVF and left eye reflected a slightly better acuity of the temporal retina.

To conclude, either interpretation, that of eye dominance or that of hemispheric specialization, is not sufficient to explain the speed difference found between tasks. It seems necessary to postulate an interplay between eye dominance and cerebral specialization. Since it is as yet unknown how and at which level information from the two eyes is integrated, it seems prudent to document performance separately from the two eyes instead of assuming that the two channels are equivalent.

Hands

Although the findings of Maddess (1975) and Rizzolatti et al. (1971) had led us to expect otherwise, the dominant right hand did not provide faster or more accurate performance than the left hand. On the contrary, the interaction of VF with hand indicated that the most accurate performance was obtained for the contralateral combination of LVF-right hand while the worst performance was given when the ipsilateral combination of RVF-right hand was used. Furthermore, the data did not provide support for the view that responses ipsilateral to the stimulus are faster than contralateral responses. This weakens both the importance given to faster anatomical connections between ipsilateral VF and responding hand (Berlucchi et al., 1977; Davis & Schmit, 1971, 1973; Maddess, 1975; Poffenberger, 1912; Rizzolatti et al., 1971) and to the notion of S-R compatibility (Anzola et al., 1977; Berlucchi et al., 1977; Wallace, 1971) as explanations of lateral differences. Our results are more consonant with Berlucchi et al. (1977)'s interpretation that hemispheric processing overrides the locus of response initiation.

On a more general level, the absence of overlap between the results obtained with the two DV suggests that accuracy and RT are not necessarily equivalent expressions of lateral differences. This finding was quite unexpected. A search of the literature confirmed the possibility of a qualitative difference between the two indices. Of the few experiments in which simultaneous use of RT and accuracy measures are reported, all but one showed different patterns of lateralization for the two indices. For example, Pennal (1977) combined measures of accuracy and RT to determine lateralization of colour perception and found different patterns of lateral differences. He did not, however, discuss the lack of overlap between the two indices. Guiard and Requin (1977), in a study of interhemispheric sharing of information, suggested that the two measures were not identical. They defined errors in their paradigm of simple RT as anticipatory responses and this, of course, prevents a comparison between their study and ours. In the context of musical decision, both Gates and Bradshaw (1977) and Shannon (1980) obtained lateralization effects for error rates but not for RT. This point was mentioned as an aside by Shannon, but without discussion. This separation between the two indices is also found in a study of spatial orientation relative to gravity, in which both speed and accuracy of vertical perception were tested, with and without visible frame of reference (Pitblado, 1979). When no visual preference axes were used, vertical lines were perceived faster in the RVF than the LVF. On the other hand accuracy of the response was always greater in the LVF. These results, it is interesting to note, are in agreement with our findings. Pitblado concluded that there was a left hemisphere superiority for spatial judgment of vertical lines when no frame of reference was given but, oddly enough, dismissed his findings on accuracy as being unrelated to cerebral lateralization.

One study only, to the best of our knowledge, used both accuracy and RT measures in a difficult visuospatial task. This showed no difference in accuracy between the VF, but differences in RT (Berlucchi et al., 1979). The reason for findings which differ from ours may reside in the procedure used, namely the dismissal of a fourth of the subjects who showed too many errors. This procedure may have biased the results towards speed differences and similarity of accuracy between VF.

It becomes necessary to discuss which of these measures best reflect lateral differences. Generally, RT is considered to be a more sensitive lateralization index than accuracy (Gazzaniga, 1970; Geffen et al., 1971; Gross, 1972). However, there is disagrement on this issue. Swanson, Ledlow and Kinsbourne (1978) argue that RT studies are likely to be biased because RT studies are commonly based on near perfect scores. Error rates never exceed 10 % and usually revolve around 1-5 % (e.g. Berlucchi et al., 1974; Gates and Bradshaw, 1977; Longden et al., 1976). Since it has been reported that task difficulty enhances lateralization effects (Atkinson & Egeth, 1973; Berlucchi et al., 1979; Fontenot, 1973; Hellige & Webster, 1979; Umilta et al., 1974; 1978), it is debatable whether speed of processing of a near errorless performance can truly reflect hemispheric superiority. The value of this practice is questionable. It should be emphasized, however, that this widely used practice does not reflect on the actual value of choice RT as a sensitive psychological tool.

CHAPTER 5

CONCLUSIONS

The present findings support the conclusion of functional asymmetry between the cerebral hemispheres. The results are in agreement with the model of structural differences between the hemispheres, as there is evidence of a greater competence of the right hemisphere than the left hemisphere for visuospatial material. However the data do not support the view that verbally and visually coded information are processed exclusively in the left and right hemisphere, respectively. It was further shown that slower RT cannot be accounted for entirely by the interhemispheric transmission time but rather may reflect the degree of task difficulty. The data are in partial agreement with Kinsbourne's model of arousal, inasmuch as there were suggestions of lateralized shifts in performance as a function of cognitive strategies. However, since there was clearly an interaction between task and VF, the notion of undifferentiated hemisphere priming does not fit the present data. Rather, differential cognitive modes of processing appear to play a role in the elicitation of lateral differences. It is becoming increasingly evident that both hemishpheres are able to deal with most tasks, each with their specialized cognitive modes. These lateralized cognitive modes are not fixed and constant but are apparently influenced by a host of variables which are expressed in dynamic strategies.

Our results support Umilta's findings that task difficulty produces a shift toward a LVF superiority but do not show evidence of a RVF superiority for easy tasks. The discrepancy between Umilta's and the present findings probably stems from procedural differences, such as the greater perceptual difficulty of the tasks used in this experiment and the availability of verbal codes.

By the simultaneous use of two dependent variables, the present experiment made it clear that the left hemisphere was not more proficient than the right hemisphere in handling a more difficult visuo-spatial task. Right hemisphere function was expressed in terms of accuracy of performance, with an increase in processing time when the task increased in difficulty. Left hemisphere function, most likely influenced by the verbal codes provided with the instructions, was expressed in more liberal judgmental standards and faster responses. Thus, in a global sense, the present findings corroborate Umilta et al.'s interpretation attributing the left hemisphere superiority to the use of verbal mediators and the right hemisphere superiority to the use of a non-verbal strategy. The present findings demonstrate, however, that the terms "hemispheric superiority" and "strategy" need clarification, as to whether they are taken to mean speed or accuracy of the performance.

Ubiquitous preeminence of the right eye in our data suggests that eye dominance is a variable to consider in laterality effects. The interplay between eye, visual pathway and cerebral dominance deserves further clarification.

Finally, a contribution of this research has been to show that accuracy and RT are not necessarily equivalent expressions of lateral differences. The combined use of both indices offered new insight for the conceptualization of hemispheric differences. Clearly greater accuracy was displayed when stimuli were projected to the LVF-right hemisphere. But it appeared also that speed of reaction time, which has come to be viewed as a more sensitive indicator of hemispheric specialization than accuracy, may be biased by specific experimental procedures. The striking similarities between the signal detection data and the RT findings, suggest that speed of processing might be related to differential judgment standards rather than simply being an expression of the superiority of one hemisphere over the other. This interesting possibility needs to be explored further.

Appendix A: Classification of hand preference

Name -------------------- Date ------------

Sex M F Age ------------

Score ------------

This inventory is designed to discover which hand you use in the following manual activities.

Circle L if you perform the task with your left hand.

Circle R if you perform the task with your right hand.

Circle B if you perform the task equally well with both hands.

Assume that your hands are empty (except as indicated) before considering each task.

If you have no experience with a given task, do not mark preference.

A. Are you right handed or left handed ?	R	L	B

B. With which hand(s) do you:

1. write ?	R	L	B
2. draw ?	R	L	B
3. use a tennis raquet ?	R	L	B
4. use a screwdriver ?	R	L	B
5. throw a ball ?	R	L	B
6. use a hammer ?	R	L	B
7. light a match ?	R	L	B

8. use a toothbrush ?	R	L	B
9. hold a knife when carving meat ?	R	L	B
10.use a bottle opener ?	R	L	B
11.use scissors ?	R	L	B
12.use a bottle opener ?	R	L	B
13.stir a liquid ?	R	L	B
14.carry your books or book bags ?	R	L	B
15.pick up the salt or pepper shaker ?	R	L	B
16.hold a filled cup when drinking ?	R	L	B
17.with which foot do you kick a ball ?	R	L	B

C. Are there any one-handed actions for which you use the other hand ?

Please record them here: ----------------------------------

D. How many people in your family show a hand preference

different from yours ? -------------------------------------

who ? ---

Appendix B: Instructions read to subjects

A black line will be presented in one of two orientations to your left or to your right. The task consists in responding as fast as possible to one of these two orientations. Let me show you the two possible orientations, to the left or to the right: one is vertical. You will respond to the other which is oblique. (or: both are oblique. This is the more oblique. You will respond to the other, the less oblique one.)

[stimuli presented at 100 milliseconds (ms.) duration]
[90 degree (RVF), 90 degree (LVF)]
[95 degree (LVF), 95 degree (RVF)] .*

Here is what you will have to do: you fixate the dot in the center of the screen and when you feel ready (i.e. comfortable, attentive, not on the point of blinking, etc) keep your eye on the dot and press the foot pedal. This will trigger the onset of the stimulus. If the orientation you have to respond to appears, press the telegraph key with your forefinger as fast as possible. When the other orientation appears you don't do anything.

Let me show again the orientations you have to respond to. Remember that because the stimulus can appear in the left or the right of the screen, it is best to keep your gaze on the dot in order to maximize the number of correct responses.

[presented at 80 ms. duration]

[95 degree (RVF), 95 degree (LVF)] *

You do not respond to this:

[presented at 80 ms. duration]

[90 degree (RVF), 90 degree (LVF).] *

Let's do some practice trials and see if you have to respond to the following stimuli. When you feel ready, press the foot pedal. Remember to keep your eye on the dot all the time during the trial.

[presented at 80 ms. duration] 95 degree (LVF),90 degree (LVF)
at 60 ms. : 95 degree (RVF),90 degree (RVF) *
at 40 ms. : 95 degree (LVF),90 degree (LVF) *
at 30 ms. : 95 degree (RVF),95 degree (LVF)
at 20 ms. : 90 degree (RVF),90 degree (LVF) *
at 14 ms. : 95 degree (RVF),90 degree (RVF) *
at 12 ms. : 90 degree (LVF),95 degree (RVF)
95 degree (LVF),90 degree (RVF) *

Very good. Let's do some practice (feedback given after each stimulus presentation). Do you have any question ? Now that you understand that task well, I would like you to tell me for each stimulus how certain you were of your response, on a scale from 1 to 4.

4 means that you were positive,
3 means that you were fairly certain of your answer,
2 means that you were half certain
and 1 means that it was almost a guess. Let me show you again the

stimulus you have to respond to :

[presented at 12 ms 95 degrees (LVF),95 degrees (RVF)

Remember to keep your eye on the dot and to respond as fast as possible.

Now I won't tell you how you did after each trial,
but I will tell you your results after each block of 40 trials.

Note:

* : for stimulus condition 0-0 (95 degree versus 100 degree) the stimulus "90 degree" is replaced by the stimulus 100 degree.

Appendix C : Arc sin transformation of percentage of correct responses.

Stimulus Condition V-O

V.F.	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
S								
1	1.9823	2.0715	2.1652	2.1177	1.6911	1.7315	1.7515	1.8546
2	2.4655	2.3746	2.3462	2.0944	1.9823	2.2143	2.1177	2.1177
3	2.2143	2.0488	2.0715	1.8965	1.9823	2.1177	1.9606	2.0488
4	2.6467	2.5322	2.3462	2.4655	2.4655	2.3462	2.0042	2.0264
5	2.4655	2.2395	1.6911	1.8755	1.8338	2.0042	2.0715	2.1895
6	2.2143	2.1177	2.2143	2.1177	2.1895	2.4655	2.0042	2.0715

Stimulus Condition O-O

V.F.	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
S								
1	1.9823	2.0488	1.9391	1.8546	1.8546	1.9823	1.7518	1.9391
2	2.0488	2.2143	2.0264	2.2395	2.0944	2.0715	2.0944	2.0042
3	2.1652	1.9823	1.9391	1.9606	1.7518	1.7722	2.0715	1.8965
4	2.1895	2.1652	2.2143	2.0488	2.0042	2.2395	2.1177	2.1652
5	1.9606	2.0488	2.0042	1.9606	1.8755	2.1652	2.0042	2.0944
6	2.0715	2.0488	1.9606	1.9823	1.9823	2.0042	1.8755	2.0488

Appendix D: Geometric means for correct RT (in ms).

Stimulus-Condition V-O

Visual Field	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
Subject								
1	470	499	453	490	518	508	507	552
2	451	446	425	428	463	438	500	445
3	341	344	358	341	350	362	363	353
4	461	478	461	508	504	495	490	462
5	410	434	441	417	413	464	458	380
6	432	415	423	407	456	500	403	516

Stimulus-Condition O-O

Visual Field	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
Subject								
1	535	537	574	587	554	533	578	609
2	492	485	497	514	491	459	484	476
3	344	368	302	348	301	299	311	327
4	551	531	557	512	482	509	548	488
5	432	449	488	435	394	379	437	399
6	460	463	456	456	452	417	469	496

Appendix E: Geometric means of RT for errors of commission (in ms).

Stimulus Condition V-O

V.Field	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
Subject								
1	540	547	537	672	568	555	524	673
2	419	425	414	433	452	469	474	432
3	394	336	468	314	314	333	397	325
4	421	439	486	462	466	447	545	515
5	477	477	459	463	439	409	434	407
6	418	392	494	453	422	506	453	448

Stimulus Condition O-O

	V.Field							
Eye	Right				Left			
Hand	Right	Left	Right	Left	Right	Left	Right	Left
Subject								
1	614	587	613	543	652	610	696	664
2	631	520	479	490	497	483	399	546
3	348	344	309	335	330	307	320	311
4	391	683	571	527	513	527	574	528
5	379	462	432	392	409	350	432	391
6	440	517	425	498	435	461	470	584

Appendix F: Arc sin transformation of percentage of errors of commission.

Stimulus Condition V-O

V.F.	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
S								
1	1.2025	1.0004	1.2661	1.1152	1.4505	1.6308	1.3284	1.2661
2	.5735	.6435	.9273	1.3694	1.2239	.7954	.7377	.7954
3	1.0004	1.0004	.7377	1.1152	.7954	.9273	1.1593	1.1152
4	.5735	.3482	.5735	.7377	.3482	.3482	.5735	.5735
5	.5735	.8763	1.2661	1.1593	1.2661	1.0472	1.0004	1.0004
6	1.0928	.8763	.7377	.9273	1.0004	.4510	1.0472	.7954

Stimulus Condition O-O

V.F.	Left				Right			
Eye	Right		Left		Right		Left	
Hand	Right	Left	Right	Left	Right	Left	Right	Left
S								
1	1.2239	1.2661	1.4303	1.3694	1.2661	1.2661	1.3694	1.1132
2	1.0239	1.0701	1.0239	.6435	1.1593	1.1152	.8763	.8230
3	.7377	1.0472	.9273	1.3694	1.7722	1.6308	1.2451	1.4706
4	.5735	.7377	.6435	.5735	1.3284	1.2239	1.3284	1.3284
5	1.0004	.9273	1.3284	1.2661	1.5308	1.2239	.9273	1.0472
6	1.0472	.8763	1.1152	1.1593	1.2661	1.2661	.9273	1.4303

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